INTELLECTUAL PROPERTY INDIA
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सत्यमेव जयते

क्रम सं/SL No :044200389

पेटेंट कार्यालय,भारत सरकार | The Patent Office, Government Of India

पेटेंट प्रमाण पत्र | Patent Certificate

(पेटेंट नियमावली का नियम 74) | (Rule 74 of The Patents Rules)

पेटेंट सं. / Patent No. : 571028

आवेदन सं. / Application No. : 202441067213

फाइल करने की तारीख / Date of Filing : 05/09/2024

पेटेंटी / Patentee : Indian Institute of Science

प्रमाणित किया जाता है कि पेटेंटी को, उपरोक्त आवेदन में यथाप्रकटित *METHOD FOR FABRICATION OF FLEXIBLE HYDROGEN DETECTION SENSOR* नामक आविष्कार के लिए, पेटेंट अधिनियम, 1970 के उपबंधों के अनुसार आज तारीख सितम्बर 2024 के पांचवें दिन से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled *METHOD FOR FABRICATION OF FLEXIBLE HYDROGEN DETECTION SENSOR* as disclosed in the above mentioned application for the term of 20 years from the 5th day of September 2024 in accordance with the provisions of the Patents Act,1970.

अनुदान की तारीख : 23/09/2025
Date of Grant :

उन्नत पी. पंडित
पेटेंट नियंत्रक
Controller of Patents

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, सितम्बर 2026 के पांचवें दिन को और उसके पश्चात प्रत्येक वर्ष मे उसी दिन देय होगी।

Note. - The fees for renewal of this patent, if it is to be maintained, will fall / has fallen due on 5th day of September 2026 and on the same day in every year thereafter.

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जी.एस.टी.रोड, गिंडी/ G.S.T.Road, Guindy,
चेन्नई/ Chennai- 600032
दूरभाष/ Tel. No. : (091)(044)22502081-84
फैक्स/ Fax: 044 22502066

Email/ई मेल : Chennai-patent@nic.in
वेबसाइट /Website: http://ipindia.nic.in

सं. \ No. 202441067213

दिनांक \ Dated the 23/09/2025

सेवा मे, \ To :

Address of Service:- C block Sector 2, C-44 First Floor, Noida, Uttar Pradesh 201301, India
Email Id:- paralegal@arcticinvent.com

विषय :- पेटेंट आवेदन संख्या 202441067213 के संबंध मे अधिनियम की धारा 43 के तहत पेटेंट अनुदान तथा पेटेंट रजिस्टर मे प्रविष्टि की सूचना
Sub :- Intimation of the grant and recordal of patent under section 43 of the Act in respect of patent application no. 202441067213

महोदय/महोदया,
Sir/Madam,

आपको सूचित किया जाता है कि पेटेंट अधिनिय, 1970 की धारा 12 व 13 तथा उस आधार पर बने नियम के तहत उपर्युक्त पेटेंट आवेदन के परीक्षण [व 25/08/2025 को हुई सुनवाई] के उपरांत एतद्द्वारा पेटेंट अनुदान किया जाता है। तथा पेटेंट अनुदान की प्रविष्टि 23/09/2025 को पेटेंट रजिस्टर मे कर दी गयी है।

This is to Inform you that following the examination of above mentioned patent application under section 12 and 13 of The Patents Act, 1970 and Rules made thereunder [and hearing held on 25/08/2025] a patent is hereby granted and recorded in the Register of Patents on the 23/09/2025. The Patent Certificate is enclosed herewith.

पेटेंट संख्या \ Patent No : 571028

आवेदक का नाम \ Name Of Applicant : Indian Institute of Science

पेटेंट दिनांक \ Date of Patent : 05/09/2024

पूर्विक्ता तिथि \ Priority Date : 05/09/2024

परीक्षण हेतु अनुरोध दाखिल करने की तिथि \ Filling date of Request for examination : 05/09/2024

शीर्षक \ Title : METHOD FOR FABRICATION OF FLEXIBLE HYDROGEN DETECTION SENSOR

दावों की संख्या \ Number of claims : 1-8

Controller' Name : Manoj Kumar

Controller' Email : mkumar91.ipo@gov.in

Controller' Location : Delhi

उपर्युक्त पेटेंट के अनुदान का प्रकाशन अधिनियम की धारा 43 के तहत पेटेंट कार्यालय के आधिकारिक जर्नल मे किया जाएगा।
The grant of above mentioned patent will be published in the Official Journal of the patent Office under section 43 of the Act.

पेटेंट अधिनियम 1970 यथा संशोधित पेटेंट (संशोधन) नियम, 2005/ पेटेंट नियम, 2003 यथा संशोधित पेटेंट (संशोधन) नियम, 2016 की धारा 142 की उप-धारा (4) के प्रावधानों के तहत उपरोक्त प्रविष्टि की तिथि से 3 माह के भीतर इस कार्यालय मे नवीकरण शुल्क जमा किया जाना चाहिए।
The payment of renewal fee is required to be made at this office within three(3) months from the aforesaid date of recording according to the proviso in sub-section(4) of Section 142 of The Patents Act,1970, as amended by The Patents (Amendment) Act, 2005 / The Patents Rules, 2003 as amended by The Patents (Amendment) Rules, 2016.

Manoj Kumar
(नियंत्रक पेटेंट)
Controller of Patents

टिप्पणी / Note :

1. संशोधित नवीकरण शुल्क हेतु कृपया महानियंत्रक पेटेंट, अभिकल्प एवं व्यापार चिह्न की आधिकारिक वैबसाइट www.ipindia.gov.in पर उपलब्ध पेटेंट (संशोधन) नियम 2016 की प्रथम अनुसूची (शुल्क) देखें।
   For revised renewal fees kindly refer to the First Schedule (fees) of The Patents (Amendment) Rules 2016 available on the official website of Controller General of Patents, Designs and Trade Marks www.ipindia.gov.in
2. कार्यालय द्वारा पेटेंट प्रमाणपत्र की कोई भी कागजी प्रति अलग से जारी नहीं की जाएगी।
   No hard copy of Patent Certificate shall be issued separately by the office.

FORM 2

THE PATENTS ACT, 1970
(**39** of **1970**)
&
THE PATENTS RULES, 2003

COMPLETE SPECIFICATION

1. TITLE OF THE INVENTION

METHOD FOR FABRICATION OF FLEXIBLE HYDROGEN DETECTION SENSOR

2. APPLICANT(S)

a) Name **:Indian Institute of Science**
b) Nationality **:India**
c) Address **:Sir C V Raman Road, Bangalore, 560012, Karnataka, India**

3. PREAMBLE TO DESCRIPTION

COMPLETE SPECIFICATION

The following specification particularly describes the invention and the manner in which it is to be performed.

TECHNICAL FIELD

The present disclosure relates to the field of hydrogen detection and leak monitoring. Moreover, the present disclosure relates to a method for the fabrication of a flexible hydrogen detection sensor.

BACKGROUND

Hydrogen is a widely used raw material in various industries and serves as a fuel for fuel-cell vehicles and space exploration. However, hydrogen's highly flammable nature and extensive flammability range (4% v/v to 75% v/v in air) pose significant safety risks. As a colourless and odourless gas, hydrogen is difficult to detect visually or by smell, and its lightness allows it to leak through the smallest openings, potentially forming explosive mixtures with air. The necessity for fast-responding hydrogen sensors is evident in environments where hydrogen is utilized. Effective hydrogen leak detection systems are crucial in preventing accidents.

Existing hydrogen sensors often utilize palladium-based sensing elements due to their excellent selectivity and sensitivity to hydrogen at room temperature. The existing hydrogen sensors generally operate on the principle of chemoresistance, where the electrical resistance of the palladium changes upon exposure to hydrogen. Despite their effectiveness, conventional hydrogen sensors often face limitations in terms of mechanical rigidity, which restricts their ability to conform to irregular or flexible surfaces such as pipe fittings where leaks are likely to occur. This has led to an increasing interest in the development of flexible sensors that can better accommodate these challenging environments. While several methods for fabricating flexible hydrogen sensors have been explored, including sputtering, lithographically patterned nano-electrodeposition, and hydrothermal synthesis, these techniques often require complex equipment, operate under extreme conditions, or are time-consuming. Additionally, current flexible sensors, like those based on colour-changing tape, are limited by the need for manual inspection and single-use functionality.

Therefore, in light of the foregoing discussion, there exists a need to overcome the aforementioned drawbacks.

SUMMARY

The present disclosure provides a method for fabrication of a flexible hydrogen detection sensor. The present disclosure provides a solution to the technical problem of how to create a hydrogen detection sensor that combines high sensitivity, fast response time, and mechanical flexibility, allowing the hydrogen detection sensor to be easily integrated into various industrial settings, particularly in areas with irregular or non-rigid surfaces like pipelines and joints. An aim of the present disclosure is to provide a solution that overcomes at least partially the problems encountered in the prior art and provide an improved method that not only synthesizes flexible hydrogen detection sensor that is cost-effective but the method that may be easily adopted. Thus, the method of the present disclosure manifests a technical advancement as well as economic benefits.

One or more objectives of the present disclosure is achieved by the solutions provided in the enclosed independent claims. Advantageous implementations of the present disclosure are further defined in the dependent claims.

In one aspect, the present disclosure provides a method for fabrication of a flexible hydrogen detection sensor. The method includes preparing a polyimide-substrate assembly and pre-treating the polyimide-substrate assembly with an alkaline solution. Further, the method includes creating an aluminium-polyimide assembly by affixing an aluminium tape to the pre-treated polyimide-substrate assembly. The method further includes preparing a precursor solution comprising palladium and platinum compounds and applying the precursor solution to the aluminium-polyimide assembly, allowing the precursor solution to contact the aluminium tape. Further, the method includes allowing a reaction between the precursor solution and the aluminium tape to proceed for a first predetermined time period and removing the precursor solution and separating the aluminium tape from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly. Furthermore, the method includes performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period. The electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration.

The method of the present disclosure for the fabrication of the flexible hydrogen detection sensor has several significant technical effects.

The use of a polyimide-substrate assembly and aluminium tape enables the flexible hydrogen detection sensor to be flexible and conform to a variety of shapes and surfaces. The flexibility is particularly beneficial for applications on curved or irregular surfaces, such as pipe flanges and joints, where traditional rigid sensors cannot be effectively used. The electrically conductive metal nanoparticle deposit, formed from palladium and platinum compounds, offers high sensitivity to hydrogen. The combination of palladium and platinum compounds allows the flexible hydrogen detection sensor to detect low concentrations of the hydrogen gas quickly, significantly reducing the risk of undetected leaks and potential explosions. The method involves simple steps, such as pre-treating the substrate with the alkaline solution and applying the precursor solution. The steps do not require expensive or complex equipment, making the fabrication process cost-effective and potentially scalable for mass production. The use of palladium and platinum in the precursor solution enhances the selectivity for hydrogen while maintaining stability under various environmental conditions. This ensures reliable and accurate detection over extended periods. The simplicity of the method allows for adjustments in the precursor solution or substrate materials to customize the flexible hydrogen detection sensor for different applications or specific performance requirements, enhancing its versatility. The post-treatment reinforces the electrically conductive metal nanoparticle network, ensuring that the flexible hydrogen detection sensor maintains its performance over multiple detection cycles. The reliable performance reduces the need for frequent replacements and maintenance. By providing fast and accurate detection of hydrogen leaks, the flexible hydrogen detection sensor significantly enhances safety in environments where the hydrogen gas is used, protecting both personnel and equipment from potential hazards. The fabrication process operates at ambient conditions, reducing energy consumption and environmental impact compared to methods requiring elevated temperatures or pressures. The straightforward and reproducible nature of the fabrication process ensures ease of manufacturing and deployment in various industrial settings, enabling widespread adoption and integration into existing safety systems.

It is to be appreciated that all the aforementioned implementation forms can be combined. All steps which are performed by the various entities described in the present application as well as the functionalities described to be performed by the various entities are intended to mean that the respective entity is adapted to or configured to perform the respective steps and functionalities. It will be appreciated that features of the present disclosure are susceptible to being combined in various combinations without departing from the scope of the present disclosure as defined by the appended claims.

Additional aspects, advantages, features, and objects of the present disclosure would be made apparent from the drawings and the detailed description of the illustrative implementations construed in conjunction with the appended claims that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

The summary above, as well as the following detailed description of illustrative embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the present disclosure, exemplary constructions of the disclosure are shown in the drawings. However, the present disclosure is not limited to specific methods and instrumentalities disclosed herein. Moreover, those skilled in the art will understand that the drawings are not to scale. Wherever possible, like elements have been indicated by identical numbers.

Embodiments of the present disclosure will now be described, by way of example only, with reference to the following diagrams wherein:

FIG. 1 is a flowchart depicting a method for fabrication of a flexible hydrogen detection sensor, in accordance with an embodiment of the present disclosure;

FIGs. 2A, 2B, 2C and 2D depict schematic views of various steps for setting an inverted assembly, in accordance with an embodiment of the present disclosure.;

FIG. 3 is an exemplary diagram illustrating a schematic of a side view of the inverted assembly, in accordance with an embodiment of the present disclosure;

FIGs. 4A, 4B and 4C depict schematic views of various steps for setting an upright assembly, in accordance with another embodiment of the present disclosure;

FIG. 5 is an exemplary diagram illustrating the schematic of a side view of the upright assembly, in accordance with an embodiment of the present disclosure.;

FIGs. 6A and 6B are the graphical representations illustrating the response of the flexible hydrogen detection sensor with respect to different gases, in accordance with an embodiment of the present disclosure;

FIGs. 7A and 7B are graphical representations illustrating the performance of the flexible hydrogen detection sensor, in accordance with an embodiment of the present disclosure;

FIGs. 8A and 8B are graphical representations illustrating the behaviour of the flexible hydrogen detection sensor with the molecular sieve coating on exposure to interference gases, in accordance with an embodiment of the disclosure;

FIGs. 8C and 8D are graphical representations illustrating the behaviour of the flexible hydrogen detection sensor without the molecular sieve coating on exposure to interference gases, in accordance with an embodiment of the disclosure;

FIGs. 9A and 9B are graphical representations illustrating the six-month stability of the flexible hydrogen detection sensor with the molecular sieve coating;

FIGs. 9C and 9D are graphical representations illustrating the six-month stability of the flexible hydrogen detection sensor without the molecular sieve coating, in accordance with an embodiment of the present disclosure;

FIGs 10A and 10B are graphical representations illustrating the response of the flexible hydrogen detection sensor with the molecular sieve coating under tension and compression, in accordance with an embodiment of the present disclosure;

FIGs 10C and 10D are graphical representations illustrating the response of the flexible hydrogen detection sensor without the molecular sieve coating under tension and compression, in accordance with an embodiment of the present disclosure;

FIGs. 11A and 11B are graphical representations illustrating the effect of platinum content on the flexible hydrogen detection sensor with molecular sieve coating, in accordance with an embodiment of the present disclosure;

FIGs. 12A and 12B are graphical representations illustrating the limit of detection of the hydrogen gas by flexible hydrogen detection sensor with molecular sieve coating, in accordance with an embodiment of the present disclosure; and

FIGs. 12C and 12D are graphical representations illustrating the limit of detection of the hydrogen gas by flexible hydrogen detection sensor without the molecular sieve coating, in accordance with an embodiment of the present disclosure.

In the accompanying drawings, an underlined number is employed to represent an item over which the underlined number is positioned or an item to which the underlined number is adjacent. A non-underlined number relates to an item identified by a line linking the non-underlined number to the item. When a number is non-underlined and accompanied by an associated arrow, the non-underlined number is used to identify a general item at which the arrow is pointing.

DETAILED DESCRIPTION OF EMBODIMENTS

The following detailed description illustrates embodiments of the present disclosure and ways in which they can be implemented. Although some modes of carrying out the present disclosure have been disclosed, those skilled in the art would recognize that other embodiments for carrying out or practicing the present disclosure are also possible.

FIG. 1 is a flowchart depicting a method for fabrication of a flexible hydrogen detection sensor, in accordance with an embodiment of the present disclosure. With reference to FIG. 1, there is shown a flowchart of a method **100**. In some implementations, the method **100** is executed by a skilled person. The method **100** may include steps **102** to **116**.

At step **102**, the method **100** includes preparing a polyimide-substrate assembly. The polyimide is a type of polymer characterized by imide monomers in its chemical structure and due to their excellent insulating properties and flexibility. In some examples, the polyimide is used in the manufacture of flexible electronic devices and sensors. Throughout the present disclosure, the term “polyimide-substrate assembly” refers to a composite structure where a polyimide tape is adhered to a supporting substrate, which is a flexible polymer. In an example, a plastic tray is filled with tap water and a suitable amount of a cleaning agent (for example, Labolene) is added to the tap water. The mixture of the tap water and the cleaning agent is stirred gently to create a uniform, soapy solution. The polyimide tape is cut and immersed into the uniform, soapy solution, ensuring the polyimide tape becomes completely wet. The immersion of the polyimide tape in the soapy solution temporarily weakens the adhesive, preventing the polyimide tape from sticking to itself. The wet polyimide tape is removed from the soapy solution.

In an implementation, preparing the polyimide-substrate assembly includes adhering a polyimide tape to a polyester. In some implementations, the wet polyimide tape is laid on a transparent polyester sheet (for example, PET), ensuring it is smooth and free of air bubbles or wrinkles. Further, the polyimide-substrate assembly is rinsed with running tap water to flush out any remaining soapy solution from between the polyimide tape and the polyester sheet. In some examples, a paperweight may be used to press out the trapped water between the polyimide tape and the polyester sheet. The paperweight is moved across the surface of the polyimide tape, applying even pressure to ensure all excess water is expelled. The polyimide-substrate assembly is cleaned with a tissue paper to absorb any remaining moisture. Later, the polyimide-substrate assembly is allowed to dry overnight to ensure that any residual water is fully absorbed and evaporated, leaving the polyimide firmly adhered to the polyester sheet. The temporary weakening of the adhesive effect by the cleaning agent enables smooth application and ensures the durability of the polyimide-substrate assembly.

At step **104**, the method **100** includes pre-treating the polyimide-substrate assembly with an alkaline solution. The polyimide-substrate assembly is cut into smaller pieces and immersed in a solution of cleaning agent and deionized water. Further, the pieces of the polyimide-substrate assembly are washed thoroughly with deionized water and treated with an alkaline solution. In some implementations, the alkaline solution is a potassium hydroxide solution. In an example, the potassium hydroxide solution is prepared by mixing 0.4-0.6 M of potassium hydroxide with 18 -20 ml of deionized water. The potassium hydroxide treatment implants K^+ ions into a polyimide surface of the polyimide-substrate assembly, which are replaced with metal ions, forming a metal interlayer that enhances the adhesion of electrically conductive metal nanoparticle deposits. After treating the pieces of the polyimide-substrate assembly with the alkaline solution, the pre-treated polyimide-substrate assembly is washed with the deionized water.

In some examples, the alkaline solution may include, but not limited to, a sodium hydroxide solution, a calcium hydroxide solution, a lithium hydroxide solution, a potassium carbonate solution, an ammonium hydroxide solution, a sodium phosphate solution, or a sodium aluminate solution. In some other examples, the alkaline solution may include an alkali solution, an alkali metal hydroxide, or any other solution with an abrasive nature.

At step **106**, the method **100** includes creating an aluminium-polyimide assembly by affixing an aluminium tape to the pre-treated polyimide-substrate assembly. The aluminium tape has an aluminium side and an adhesive side with a paper backing on an opposite side of the aluminium tape. The paper backing from the aluminium tape is removed and replaced with a cello tape, ensuring that the adhesive side of the aluminium tape sticks to the cello tape. The aluminium tape is cut to the predefined length. In some examples, the aluminium tape is wiped with an ethanol-soaked tissue to clear any dust. Further, a pen knife may be used to cut along the edge using multiple strokes gently. After that, the aluminium tape is placed on the pre-treated polyimide-substrate assembly, ensuring the aluminium side faces the polyimide side of the pre-treated polyimide-substrate assembly. The aluminium-polyimide assembly provides a stable and durable platform for various applications, including the fabrication of flexible sensors and other electronic devices.

At step **108**, the method **100** includes preparing a precursor solution including palladium and platinum compounds. In some implementations, one or more components, such as ethanol, deionized water, hydrochloric acid, and palladium chloride, are mixed together to form a palladium chloride solution. The palladium chloride solution is kept sit overnight to ensure complete dissolution. Further, potassium tetrachloroplatinate is dissolved in the deionized water to create a potassium tetrachloroplatinate solution. In addition, potassium bromide (KBr) is mixed with the deionized water to form a potassium bromide (KBr) solution. Finally, predefined volumes of the palladium chloride solution, the potassium tetrachloroplatinate solution, the potassium bromide (KBr) solution, acidic ethanol (ethanol mixed with an acid), and the deionized water are mixed together to form the precursor solution.

In an implementation, the precursor solution includes 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate. In some implementations, the precursor solution may include 28 to 38 %v/v of palladium chloride and 1.5 to 2.5 %v/v of potassium tetrachloroplatinate. Specifically, in some other implementations, the precursor solution includes 35.4 %v/v of palladium chloride solution, 2.1 %v/v of potassium tetrachloroplatinate solution, 12.5 %v/v of potassium bromide solution, 25 %v/v of the acidic ethanol, and 25 %v/v of the deionized water. The high concentration of palladium chloride provides a sufficient amount of palladium, a metal known for its excellent hydrogen absorption properties. The absorption enhances the sensitivity of the flexible to hydrogen gas by enabling a more significant change in electrical resistance upon hydrogen exposure. The inclusion of potassium tetrachloroplatinate in a lower concentration contributes to improved deposition efficiency and faster response time eventually.

At step **110**, the method **100** includes applying the precursor solution to the aluminium-polyimide assembly, allowing the precursor solution to contact the aluminium tape. The precursor solution is applied uniformly over the aluminium-polyimide assembly. The application can be done using various techniques, such as drop-casting, spin-coating, or dipping, depending on the predefined thickness and uniformity of the metal nanoparticle layer.

At step **112**, the method **100** includes allowing a reaction between the precursor solution and the aluminium tape to proceed for a first predetermined time period. The assembly is left undisturbed to allow the precursor solution to come into contact with the aluminium tape. During this period, the metal ions in the solution are reduced by the aluminium, leading to the formation of metal nanoparticles. As the precursor solution contacts the aluminium tape, a redox reaction occurs. The aluminium reacts with the precursor solution and indirectly reduces the metal ions to their metallic state. This results in the deposition of metal nanoparticles on the polyimide surface. In some implementations, the first predetermined time period is between 60 to **1200** seconds. In some other implementations, the first predetermined time period may be between **240** to **300** seconds. The controlled time period ensures that the metal nanoparticles are uniformly distributed across the polyimide surface of the polyimide-substrate assembly. The duration helps in achieving the predefined thickness of the electrically conductive metal nanoparticle deposit metal nanoparticle layer, which is essential for the sensitivity and response time of the flexible hydrogen detection sensor. A well-regulated deposition time promotes the formation of continuous and conductive nanoparticle networks. This enhances the electrical conductivity of the flexible hydrogen detection sensor, which is vital for detecting hydrogen gas through resistance changes.

At step **114**, the method **100** includes removing the precursor solution and separating the aluminium tape from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on the surface of the polyimide-substrate assembly. Once the precursor solution has sufficiently reacted with the aluminium tape, resulting in the deposition of metal nanoparticles on the polyimide surface, the next step is to remove the remaining precursor solution.

In an implementation, the method further includes washing the electrically conductive metal nanoparticle deposit with deionized water after removing the precursor solution and before performing the post-treatment step. The aluminium polyimide assembly is rinsed with the deionized water to remove any excess precursor solution. Rinsing ensures that no unreacted metal salts or other contaminants remain on the polyimide surface. After rinsing, the aluminium polyimide assembly is dried. In an example, drying may be performed using air drying, a gentle stream of nitrogen gas, or a low-temperature oven. Proper drying is essential to ensure that the metal nanoparticles remain firmly adhered to the polyimide surface. Once the precursor solution is removed and the assembly is dried, the aluminium tape needs to be carefully separated from the polyimide substrate. Separation must be done cautiously to avoid damaging the newly formed metal nanoparticle layer. The aluminium tape is gently peeled off from the polyimide substrate. The polyimide tape, now with an electrically conductive layer of metal nanoparticles deposited on its surface, is revealed. The polyimide-substrate assembly is inspected to ensure a uniform and intact layer of electrically conductive metal nanoparticles. The electrically conductive metal nanoparticles, which have been deposited through the reduction process, form an electrically conductive layer on the polyimide surface. The electrically conductive layer is crucial for the functionality of the hydrogen sensor, as it allows the detection of hydrogen gas through changes in electrical resistance.

At step **116**, the method **100** includes performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period. A fresh batch of the precursor solution further refined the nanoparticle deposit. The fresh batch of the precursor solution uniformly over the already deposited electrically conductive metal nanoparticles on the polyimide substrate. This can be achieved through techniques such as drop-casting, spin-coating, or dipping. Allow the precursor solution to remain in contact with the electrically conductive nanoparticle deposit for the second predetermined time period, which is optimized for the predefined enhancement effects. The second predetermined time period typically varies based on the specific requirements of the performance of the flexible hydrogen detection sensor. During the second predetermined time period, the fresh precursor solution inhibits the atmospheric oxidation of the metal nanoparticle deposits to a certain degree. After the second predetermined time period, the polyimide substrate is rinsed with a suitable solvent to remove any excess precursor solution. The polyimide substrate is thoroughly dried using air drying, a gentle stream of nitrogen gas, or a low-temperature oven. In an implementation, the second predetermined time period is 10 to **1000** seconds. In some other implementations, the second predetermined time period is 50 to 70 seconds.

In an implementation, the concentration of the precursor solution used in the post-treatment step is the same as the concentration used when initially applying the precursor solution to the aluminium-polyimide assembly. Maintaining the same concentration ensures uniform deposition of palladium and platinum nanoparticles throughout the fabrication process. The use of the potassium bromide in the post-treatment precursor solution for the post-treatment step enables the electrically conductive deposits for hydrogen sensing, such that the change in their electrical resistance can be correlated with the exposed the hydrogen gas concentration in the environment of air. The incorporation of the platinum and the palladium salts, along with the potassium bromide in the post-treatment solution, improves the hydrogen sensitivity further. Therefore, all the three component solutions, i.e. the potassium bromide, the palladium chloride, and the potassium tetra chloroplatinate are required to be present in the solution for the post-treatment step. To simplify, the fresh precursor solution itself was used for the post-treatment step.

The electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration. During the initial deposition process, metal nanoparticles (e.g., palladium and platinum) are deposited onto the polyimide substrate through a reduction reaction facilitated by the aluminium tape. The fresh batch of the precursor solution is applied in a post-treatment step, enhancing the density and uniformity of the electrically conductive metal nanoparticle layer. The electrically conductive metal nanoparticles form a continuous, interconnected network on the polyimide substrate. The interconnected network is essential for creating a path for electron flow, making the substrate electrically conductive. The controlled deposition and post-treatment steps ensure that the electrically conductive metal nanoparticle layer is uniform and dense, contributing to stable electrical properties. When the flexible hydrogen detection sensor is exposed to hydrogen gas, hydrogen molecules adsorb onto the surface of the metal nanoparticles. This interaction is particularly strong with metals like palladium, which can absorb hydrogen into their lattice structure. The adsorption of hydrogen onto the electrically conductive metal nanoparticles alters their electronic structure, leading to a change in electrical resistance. The change in electrical resistance occurs due to the formation of metal hydrides and changes in the charge carrier density within the conductive network. The change in resistance is measurable using standard electrical measurement techniques. This measurable change is a direct indicator of the presence and concentration of hydrogen gas.

The flexible hydrogen detection sensor can be calibrated to establish a relationship between the change in electrical resistance and the concentration of hydrogen. The calibration involves measuring the resistance change at known hydrogen concentrations to create a calibration curve. The sensitivity of the flexible hydrogen detection sensor is determined by the magnitude of the resistance change in response to a given concentration of hydrogen. A more sensitive sensor will show a more significant resistance change for a smaller amount of hydrogen.

In some implementations, attaching electrical contacts to the electrically conductive metal nanoparticle deposit to measure the change in electrical resistance. Attaching electrical contacts to the electrically conductive metal nanoparticle deposit enables the measurement of changes in electrical resistance, which occurs when the sensor is exposed to hydrogen. These contacts serve as interfaces between the sensor material and external measurement equipment, allowing for accurate detection and quantification of hydrogen concentration based on the resistance change. This setup is essential for converting the chemical interaction of hydrogen with the sensor into a measurable electrical signal.

The method **100** further includes applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection. A molecular sieve is a material with pores of uniform size that selectively adsorbs molecules based on their size and shape. Common materials used as molecular sieves include zeolites and metal-organic frameworks (MOFs). The deposit consists of metal nanoparticles (e.g., palladium and platinum) on a polyimide substrate, forming an electrically conductive network. The network changes its electrical resistance upon exposure to hydrogen gas. The molecular sieve coating is applied to increase the selectivity of the flexible hydrogen detection sensor towards the hydrogen gas over other gases. Hydrogen gas molecules are smaller and can pass through the pores of the molecular sieve, while larger molecules are excluded.

In practical applications, various gases might be present in the environment. The molecular sieve coating helps to filter out larger, non-target gas molecules that could otherwise interfere with the readings of the flexible hydrogen detection sensor, ensuring more accurate hydrogen detection. By selectively allowing only hydrogen molecules to reach the metal nanoparticles, the sensor provides more precise measurements. The sieve coating enhances the reliability of the flexible hydrogen detection sensor in diverse and potentially contaminated environments by minimizing false positives and negatives. The molecular sieve layer helps discriminate against interference gases.

In an example, in order to prepare a molecular sieve solution, a solution containing the molecular sieve material is prepared. This may involve dissolving or dispersing the material in a suitable solvent. The molecular sieve solution is uniformly applied to the surface of the electrically conductive metal nanoparticle deposit. This can be done using techniques such as dip-coating, spin-coating, or spray-coating to ensure even coverage. The thickness of the sieve coating is carefully controlled to maintain the balance between selectivity and accessibility. The coating must be thick enough to filter out larger molecules but thin enough to allow hydrogen molecules to reach the nanoparticles. After application, the sieve coating is dried to remove the solvent, leaving behind a uniform layer of the molecular sieve material. Curing processes such as heat treatment may be employed to enhance the stability and adherence of the molecular sieve coating to the nanoparticle layer. The pore size and distribution of the molecular sieve are verified to ensure they match the predefined specifications for selective hydrogen detection. The flexible hydrogen detection sensor is tested to confirm that the molecular sieve coating effectively enhances selectivity for hydrogen while maintaining the sensitivity and response time of the flexible hydrogen detection sensor.

The steps **102** to **116** are only illustrative, and other alternatives can also be provided where one or more steps are added, one or more steps are removed, or one or more steps are provided in a different sequence without departing from the scope of the claims herein.

FIG. 2A, 2B, 2C and 2D depict schematic views of various steps for setting an inverted assembly, in accordance with an embodiment of the present disclosure. FIGs. 2A to 2D are described in conjunction with elements from FIG. 1. With reference to FIG. 2A, there is shown a base assembly **200A** that includes a base **202A**, a first piece of double-sided tape **204A** and a second piece of double-sided tape **206A**. With reference to FIG. 2B, there is shown an aluminium-polyimide assembly **200B** including a polyimide substrate assembly including a polyimide tape **202B** and a polyester sheet **206B** on which the polyimide tape **202B** is adhered. The aluminium-polyimide assembly **200B** further includes an aluminium tape **204B** including an aluminium side and the adhesive side. With reference to FIG. 2C, there is shown a combined assembly **200C** including the aluminium-polyimide assembly **200B** attached to the base assembly **200A**. With reference to FIG. 2D, there is shown an inverted assembly **200D**, in which the aluminium-polyimide assembly **200B** is placed in an inverted orientation with the aluminium side of the aluminium tape **204B** facing upward, i.e., towards the polyimide tape **202B** and the polyimide tape is **202B** facing the base **202A** during the application of the precursor solution. The application of the precursor solution is shown by a shaded area **202D** in FIG. 2D. The inverted assembly **200D** allows the precursor solution to interact uniformly with the aluminium side of the aluminium tape **204B**, promoting even deposition of electrically conductive metal nanoparticles on the polyimide-substrate assembly. The aluminium acts as a temporary surface for the chemical reaction, which facilitates the transfer of metal ions from the precursor solution onto the polyimide-substrate assembly. The reaction between the aluminium and the precursor solution produces bubbles, assumed to be of the hydrogen gas. These bubbles are thought to play a significant role in creating the deposits on polyimide or any other substrate as well. The inverted assembly approach is designed in such a way that the bubbles are able to do their job much more efficiently. By placing the aluminium side of aluminium polyimide assembly **200B** upward, gravity helps to keep the bubbles in contact with the polyimide surface, ensuring consistent exposure and reaction time.

FIG. 3 is an exemplary diagram illustrating a schematic of a side view of the inverted assembly. FIG. 3 is described in conjunction with elements from FIGs. 1 to 2D. With reference to FIG. 3, there is shown an exemplary diagram **300** depicting the side view of the inverted assembly **200D**. The exemplary diagram **300** includes the polyester sheet **206B**, the polyimide tape **202B**, the base **202A**, the aluminium side of the aluminium tape **204B**, the cello-tape backing **302**, a clearance **304** between the aluminium tape and the base **202A**.

In an implementation, the applying the precursor solution to the aluminium-polyimide assembly **200B** includes securing the aluminium-polyimide assembly **200B** in an inverted orientation with the aluminium side of the aluminium tape **204B** facing upward, i.e., towards the polyimide tape **202B**, creating the clearance **304** between the aluminium side of the aluminium tape **204B** and the supporting surface (i.e., the base **202A**); applying the precursor solution to fill the clearance

304; and allowing the precursor solution to react with the aluminium side of the aluminium tape **204B** in the inverted orientation.

The aluminium-polyimide assembly **200B**, which includes the aluminium side of the aluminium tape **204B** and the polyimide-substrate assembly, is positioned in an inverted orientation, which means that the aluminium side of the aluminium tape **204B** faces upward. i.e., towards the polyimide tape **202B**. In contrast, the polyimide-substrate assembly is oriented downward. The clearance **304** is established between the aluminium side of the aluminium tape **204B** and the base **202A** below it. The clearance **304** acts as a controlled space for holding the precursor solution. The clearance **304** may be achieved by raising the aluminium-polyimide assembly **200B** slightly above the base **202A**, ensuring that the precursor solution can be contained within this space without spilling. The precursor solution, containing palladium and platinum compounds, is then carefully applied to fill the clearance **304**. The application is done in such a way that the entire aluminium surface is covered with the precursor solution. The application ensures uniform exposure of the aluminium side of the aluminium tape **204B** to the precursor solution, which is critical for consistent nanoparticle formation. Once the precursor solution is in place, it is allowed to react with the aluminium side of the aluminium tape **204B**. In the inverted orientation, gravity assists in maintaining the bubbles' contact with the aluminium surface. The reaction between the precursor solution and the aluminium side of the aluminium tape **204B** results in the deposition of electrically conductive metal nanoparticles onto the polyimide-substrate assembly, forming an electrically conductive layer. This reaction is typically controlled for a specific period to achieve the predefined properties of the nanoparticle layer.

In an implementation, the volume of precursor solution applied is proportional to the length of the aluminium tape **204B** used in the aluminium-polyimide assembly **200B**. By scaling the volume of the precursor solution with the length of the aluminium tape, an entire surface of the aluminium tape **204B** may be uniformly covered, ensuring consistent exposure across the entire area. The uniformity is vital for achieving an even deposition of nanoparticles. Proportionally adjusting the volume of the precursor solution helps in optimizing the use of materials. It ensures that sufficient precursor solution is available to react with the entire length of the aluminium tape **204B** without wastage. Maintaining a proportional relationship between the precursor solution volume and aluminium tape length allows for better control over the thickness and uniformity of the deposited electrically conductive metal nanoparticle layer. This control is essential for achieving predefined electrical properties, such as consistent conductivity and resistance, which directly impact the performance of the flexible hydrogen detection sensor.

FIGs 4A, 4B, and 4C depict an exemplary scenario for setting an upright assembly, in accordance with an embodiment of the present disclosure. FIG. 4A to 4C are described in conjunction with elements from FIG. 1 to FIG. 3. With reference to FIG. 4A, there is shown an aluminium polyimide assembly **200B**, including a polyimide tape **202B**, a polyester sheet **206B**, and the aluminium side of the aluminium tape **204B**. The polyimide tape **202B** refers to a specific type of tape that consists of a polyimide film coated with an adhesive layer, often with a protective backing that can be removed before application. The polyester sheet **206B** refers to a specific sheet made from polyester material, known for its durability, chemical resistance, and mechanical strength.

With reference to FIG. 4B, there is shown an exemplary diagram **400B** including a container frame **402B** that is stuck around the aluminium tape. With reference to FIG. 4C, there is shown an upright assembly **400C**, in which the aluminium-polyimide assembly **200B** is placed in an upright orientation with the aluminium side of the aluminium tape **204B** facing downward during the application of the precursor solution. The aluminium-polyimide assembly **200B** is positioned vertically, the aluminium side of the aluminium tape **204B** facing downward, i.e. towards the polyimide tape **202B**. The orientation ensures that the aluminium surface is directly exposed to the precursor solution. The precursor solution is then introduced into a space **402C**, created by the container - frame **402B**. This can be done by applying the solution so that it comes into contact with the downward-facing aluminium surface. The precursor solution comes into direct contact with the aluminium side of the aluminium tape **204B**, allowing the chemical reaction to occur. Gravity assists in keeping the solution in contact with the aluminium surface, helping to maintain a consistent and uniform reaction. The reaction leads to the deposition of electrically conductive metal nanoparticles on the polyimide-substrate assembly.

In an implementation, applying the precursor solution to the aluminium-polyimide assembly comprises creating the container frame **402B** around the aluminium tape **204B** on the polyimide-substrate assembly, filling the container-frame with the precursor solution, and allowing the precursor solution to react with the aluminium side of the aluminium tape **204B** in the upright orientation.

The process of applying the precursor solution to the aluminium-polyimide assembly **200B** involves several detailed steps to ensure controlled and uniform deposition of the electrically conductive metal nanoparticle layer. The container frame **402B** is constructed around the aluminium tape, which is adhered to the polyimide-substrate assembly. The container frame **402B** acts as a boundary or barrier to contain the precursor solution. The container frame **402B** is positioned in such a way that it surrounds the aluminium side of the aluminium tape **204B** and forms a shallow container above it. The container frame **402B** can be made of a chemically inert material that does not react with the precursor solution. Once the container frame **402B** is securely in place, the precursor solution is carefully poured into the frame, filling it to a level that submerges the aluminium tape. The container frame **402B** ensures that the precursor solution is evenly distributed across the surface of the aluminium side of the aluminium tape **204B**. The amount of precursor solution used should be sufficient to completely cover the aluminium side of the aluminium tape **204B**, ensuring uniform exposure. With the aluminium-polyimide assembly **200B** in an upright orientation (aluminium side facing downward), the precursor solution within the container frame **402B** is allowed to interact with the aluminium side of the aluminium tape **204B**.

During this reaction, the palladium and platinum compounds in the precursor solution react with the aluminium surface, leading to the formation and deposition of electrically conductive metal nanoparticles onto the polyimide-substrate assembly. This reaction typically takes place over a specific period, during which the solution remains in contact with the aluminium tape. It creates a controlled environment where the precursor solution is stayed connected with the aluminium tape, ensuring consistent exposure and reaction. The frame prevents the precursor solution from spilling or spreading beyond the intended area, leading to more efficient use of the solution. By containing the solution directly over the aluminium tape, the container-frame **402B** helps achieve uniform deposition of nanoparticles, which is critical for the electrical and functional properties of the flexible hydrogen detection sensor.

FIG. 5 is an exemplary diagram illustrating a schematic of a side view of the upright assembly. FIG. 5 is described in conjunction with elements from FIGs. 1 to 4B. With reference to FIG. 5, there is shown an exemplary diagram **500** depicting a side view of the upright assembly. The exemplary diagram **500** includes the polyester sheet **206B**, the polyimide tape **202B**, the aluminium side of the aluminium tape **204B**, and a cello-tape backing **302**. The upright orientation allows for precise control over the application of the precursor solution. The use of gravity ensures that the solution remains in contact with the aluminium surface, facilitating uniform distribution and reaction across the entire tape. By positioning the aluminium surface downward, the upward assembly allows for better contacting between the hydrogen gas bubbles and the polyimide tape **202B** in comparison to a situation if the aluminium were to face upwards. If the aluminium were to face upwards (instead of downwards) in the upright orientation method, there would be no “sandwiching” of the bubbles between the aluminium and the polyimide tape **202B**. The reason is that the bubbles would originate from the aluminium and directly float away without even touching the polyimide, thereby not creating any deposition whatsoever.

The downward-facing aluminium surface benefits from a consistent and stable reaction environment. The precursor solution is evenly distributed across the aluminium surface, aided by gravity, leading to a uniform reaction and consistent nanoparticle layer formation. This uniformity is vital for the electrical characteristics of the sensor, ensuring reliable detection of hydrogen gas. After the reaction, the excess precursor solution can be efficiently removed by draining it away from the aluminium surface. This prevents excess precursor solution from pooling or creating inconsistencies in the nanoparticle layer. Nanoparticle deposition is essential for the performance and reliability of flexible hydrogen sensors.

FIGs. 6A and 6B are the graphical representations illustrating the response of the flexible hydrogen detection sensor to different gases, in accordance with an embodiment of the present disclosure. FIGs. 6A and 6B are described in conjunction with elements from the FIGs. 1 to 5. With reference to FIG. 6A, there is shown a graphical representation **600A** when the flexible hydrogen detection sensor is exposed to nitrogen gas and hydrogen gas. The graphical representation **600A** includes three regions, namely a region **602A**, a region **604A** and a region **606A**. The region**s 602A** and the region **606A** correspond to the time duration when the flexible hydrogen detection sensor is exposed to only background nitrogen gas flowing at 8 litres per minute (LPM). The region **604A** corresponds to the time duration when the flexible hydrogen detection sensor is exposed to 3% hydrogen gas with nitrogen gas flowing in the background at 8 litres per minute (LPM).

When the hydrogen gas is introduced sharp increase in sensitivity is observed, and peak sensitivity reaches approximately 4.8%. Further, the sensitivity plateaus within about 50 seconds, i.e., the flexible hydrogen detection sensor achieves quick saturation., maintains high sensitivity during hydrogen gas exposure, rapid decrease in sensitivity upon removal of the hydrogen gas.

With reference to FIG. 6B, there is shown a graphical representation **600B** depicting the response of the flexible hydrogen detection sensor to the same conditions as illustrated by the graphical representation **600A** after four days. The graphical representation **600B** includes. The graphical representation **600B** includes three regions, namely a region **602B**, a region **604B** and a region **606B**. The regions **602B** and the region **606B** correspond to the time duration when the flexible hydrogen detection sensor is exposed to only background nitrogen gas flowing at 8 litres per minute (LPM). The region **604B** corresponds to the time duration when the flexible hydrogen detection sensor is exposed to 3% hydrogen gas with nitrogen gas flowing in the background at 8 litres per minute (LPM).

The graphical representation **600B** depicts consistent behaviour of the flexible hydrogen detection sensor similar to the shown by the graphical representation **600A**. There is a slight decrease in sensitivity observed (peak sensitivity reaches about 3.5%), a similar response profile is obtained and an effective recovery. The flexible hydrogen detection sensor maintains its overall response characteristics after four days, indicating good short-term stability. While there is a slight decrease in peak sensitivity (from ~4.8% to ~3.5%), the sensor remains highly responsive to the hydrogen gas. Both the graphical representations **600A** and **600B** show rapid response to hydrogen gas introduction and quick recovery upon removal of the hydrogen gas, demonstrating consistent kinetics.

Further, the graphical representations **600A** and **600B** exhibit low noise and clear distinction between without hydrogen gas exposure and hydrogen gas exposure phases. These results demonstrate that the presence of bimetallic palladium and platinum in the flexible hydrogen detection sensor effectively mitigates hydrogen embrittlement issues commonly associated with pure palladium sensors. The flexible hydrogen detection sensor maintains high sensitivity, rapid response, and quick recovery over multiple days of testing. The performance stability suggests that the palladium and the platinum nanoparticle structure are more resistant to structural changes induced by repeated hydrogen exposure, making it a promising candidate for long-term, reliable hydrogen sensing applications.

FIGs. 7A and 7B are graphical representations illustrating the performance of the flexible hydrogen detection sensor, in accordance with an embodiment of the disclosure. FIGs. 7A and 7B are described in conjunction with elements from FIGs. 1 to 6B. With reference to FIG. 7A, there is shown a graphical representation **700A** depicting the response of the flexible hydrogen detection sensor when exposed to 3.28% hydrogen in the air background. The time is measured in seconds (sec) in an abscissa axis (X-axis). The sensitivity is expressed in percentage in an ordinate axis (Y-axis).

The graphical representation **700A** includes a curve **702A**, a curve **704A** and a curve **706A**. The curve **702A** represents the initial sensitivity, which is close to 0%. The curve **704A** represents a sharp increase in sensitivity, which occurs at around **100** seconds. The sensitivity peaks at about 3.5% when exposed to 3.28% of hydrogen gas. Further, the curve **706** represents a rapid decrease in sensitivity.

With reference to FIG. 7B, there is shown a graphical representation **700B** depicting the response of the flexible hydrogen detection sensor when exposed to multiple cycles of different hydrogen gas concentrations. The time is measured in seconds (sec) in an abscissa axis (X-axis). The sensitivity is expressed in percentage in an ordinate axis (Y-axis).

The graphical representation **700B** includes a first region **702B**, a second region **708B**, a third region **714B** and a fourth region **720B**. The first region **702B**, corresponds time duration for which the flexible hydrogen detection sensor is exposed to 3.28% of hydrogen gas in the air background. The first region **702B**, includes a curve **704B** and a curve **706B**. The curve **704B** corresponds to a rise in sensitivity, and the curve **706B** corresponds to a fall in sensitivity. The second region **708B**, corresponds to the time duration for which the flexible hydrogen detection sensor is exposed to 1.27% of the hydrogen gas in the air background. The second region **708B**, includes a curve **710B** and a curve **712B**. The curve **710B** and the curve **712B** corresponds to rise in sensitivity and fall in sensitivity, respectively. The third region **714B**, corresponds to the time duration for which the flexible hydrogen detection sensor is exposed to 0.64% of the hydrogen gas in the air background. The third region **714B**, includes a curve **716B**, representing a rise in sensitivity, and a curve **718B**, representing a fall in sensitivity. The fourth region **720B**, corresponds to the time duration for which the flexible hydrogen detection sensor is exposed to 2.41% of the hydrogen gas in the air background. The fourth region **720B**, includes a curve **722B**, representing a rise in sensitivity and a curve **724B**, representing a fall in sensitivity. Each exposure results in a peak in sensitivity, with higher concentrations producing larger peaks. The sensor shows good recovery between exposures, returning close to the baseline.

The graphical representation **700A** shows a smaller response, due to initial oxide removal. The graphical representation **700B** shows consistent and repeatable responses. The flexible hydrogen detection sensor demonstrates a clear concentration-dependent response, with higher hydrogen gas concentrations producing larger sensitivity peaks. The flexible hydrogen detection sensor exhibits good recovery between exposures, indicating reversibility. The presence of potassium bromide in the precursor solution has enabled oxide-resistant nanoparticles, as evidenced by the consistent increase in electrical resistance (i.e., positive sensitivity) for all hydrogen gas exposures. The slightly lower initial resistance in the graphical representation **700A** is due to the oxide removal during the first exposure. The graphical representations **700A** and **700B** demonstrate that the flexible hydrogen detection sensor consisting of palladium and platinum with potassium bromide treatment shows good sensitivity, repeatability, and concentration-dependent response to hydrogen gas.

FIGs. 8A and 8B are graphical representations illustrating the behaviour of the flexible hydrogen detection sensor with the molecular sieve coating on exposure to interference gases, in accordance with an embodiment of the disclosure. FIGs. 8A and 8B are described in conjunction with elements from FIGs. 1 to 7B. With reference to FIG. 8A, there is shown a graphical representation **800A** illustrating the relative change in sensitivity of the flexible hydrogen detection sensor before and after exposure to interference gases. The flexible hydrogen detection sensor is subjected to 1 hour of interference gas flow at a rate of 5.5 LPM. The abscissa axis represents the square root of the hydrogen gas concentration expressed in percentage. The ordinate axis represents the ratio of change in the average sensitivity before and after the exposure relative to the initial average sensitivity at a given concentration of the hydrogen gas. Further, different interference gases, i.e., hydrogen sulphide (H_2S), sulphur dioxide (SO_2), Hexamethyldisilazane (HMDS), carbon monoxide (CO) and isooctane, methane (CH_4), and nitrogen dioxide (NO_2) are shown in the FIG. 8A with different patterns.

The graphical representation **800A i**ncludes a first region **802A**, a second region **804A**, a third region **806A** and a fourth region **810A**. The first region **802A**, corresponds behaviour of the flexible hydrogen detection sensor at 3.23 % of the hydrogen gas. The second region **804A**, corresponds behaviour of the flexible hydrogen detection sensor at 2.38 % of the hydrogen gas. The third region **806A**, corresponds behaviour of the flexible hydrogen detection sensor at 1.23% of the hydrogen gas. The fourth region **808A**, corresponds behaviour of the flexible hydrogen detection sensor at 0.63% of the hydrogen gas.

With reference to FIG. 8B, there is shown a graphical representation **800B** illustrating the change in sensitivity of the flexible hydrogen detection sensor (with the molecular sieve coating) before and after exposure to interference gases. The flexible hydrogen detection sensor is subjected to 5 minutes of interference gas flow rate of 4 LPM. The abscissa axis represents the square root (sqrt) of the hydrogen gas concentration expressed in percentage. The ordinate axis represents the ratio of change in the average sensitivity before and after the exposure relative to the initial average sensitivity at a given concentration of the hydrogen gas.

The graphical representation **800B** includes a first region **802B**, a second region **804B**, a third region **806B** and a fourth region **810B**. The first region **802B**, corresponds behaviour of the flexible hydrogen detection sensor at 3.23 % of the hydrogen gas. The second region **804B**, corresponds behaviour of the flexible hydrogen detection sensor at 2.38 vol% of the hydrogen gas. The third region **806B**, corresponds behaviour of the flexible hydrogen detection sensor at 1.23% of the hydrogen gas. The fourth region **808B**, corresponds behaviour of the flexible hydrogen detection sensor at 0.63% of the hydrogen gas. Further, different interference gases, i.e., hydrogen sulphide (H_2S), sulphur dioxide (SO_2), Hexamethyldisilazane (HMDS), carbon monoxide (CO) and isooctane, methane (CH_4), and nitrogen dioxide (NO_2) are shown in the FIG. 8A with different patterns.

The flexible hydrogen detection sensor (with the molecular sieve coating) is resistant to gases such as the hydrogen sulphide (H_2S), sulphur dioxide (SO_2), HMDS, CO, and isooctane for the 1-hour exposure. In the case of the methane (CH_4), a slight increase in sensitivity after exposure is observed, while in the case of nitrogen dioxide (NO_2) exposure, the sensitivity diminished by more than 20% for the 1-hour exposure.

FIGs. 8C and 8D are graphical representations illustrating the behaviour of the flexible hydrogen detection sensor without the molecular sieve coating on exposure to interference gases, in accordance with an embodiment of the disclosure. FIGs. 8C and 8D are described in conjunction with elements from FIGs. 1 to 8B. With reference to FIG. 8C, there is shown a graphical representation **800C** illustrating the change in sensitivity of the flexible hydrogen detection sensor before and after exposure to interference gases. The flexible hydrogen detection sensor is subjected to 1 hour of interference gas flow at a rate of 5.5 LPM. The abscissa axis represents the square root (sqrt) of the hydrogen gas concentration expressed in percentage. The ordinate axis represents the ratio of change in the average sensitivity before and after the exposure relative to the initial average sensitivity at a given concentration of the hydrogen gas. Further different interference gases, i.e., hydrogen sulphide (H2S), sulphur dioxide (SO2), Hexamethyldisilazane (HMDS), carbon monoxide (CO) and isooctane methane (CH_4), and nitrogen dioxide (NO_2) are represented by the different patterns as shown in the FIG. 8A.

With reference to FIG. 8D, there is shown a graphical representation **800D** illustrating the change in sensitivity of the flexible hydrogen detection sensor (without the molecular sieve coating) before and after exposure to interference gases. The flexible hydrogen detection sensor is subjected to 5 minutes of interference gas flow at a rate of 4 LPM. The abscissa axis represents the square root (sqrt) of the hydrogen gas concentration expressed in percentage. The ordinate axis represents the ratio of change in the average sensitivity before and after the exposure to the initial average sensitivity at a given concentration of the hydrogen gas. Further, different interference gases, i.e., hydrogen sulphide (H2S), sulphur dioxide (SO2), Hexamethyldisilazane (HMDS), carbon monoxide (CO) and isooctane, methane (CH_4), and nitrogen dioxide (NO_2) are represented by the different patterns as shown in the FIG. 8A.

The graphical representation **800D** includes a first region **802D**, a second region **804D**, a third region **806D** and a fourth region **810D**. The first region **802D**, corresponds behaviour of the flexible hydrogen detection sensor at 3.23% of the hydrogen gas. The second region **804D**, corresponds behaviour of the flexible hydrogen detection sensor at 2.38 vol% of the hydrogen gas. The third region **806D**, corresponds behaviour of the flexible hydrogen detection sensor at 1.23% of the hydrogen gas. The fourth region **808D**, corresponds behaviour of the flexible hydrogen detection sensor at 0.63% of the hydrogen gas. Further, different interference gases, i.e., hydrogen sulphide (H2S), sulphur dioxide (SO2), Hexamethyldisilazane (HMDS), carbon monoxide (CO) and isooctane, methane (CH_4), and nitrogen dioxide (NO_2) are shown in the FIG. 8A with different patterns. The flexible hydrogen detection sensor (without the molecular sieve coating) is also resistant to all the interference gases except the hydrogen sulphide, which resulted in a more than 20% drop in sensitivity after exposure.

FIGs. 9A and 9B are graphical representations illustrating the six-month stability of the flexible hydrogen detection sensor with the molecular sieve coating, in accordance with an embodiment of the present disclosure. FIGs. 9A and 9B are described in conjunction with elements from FIGs. 1 to 9B. With reference to FIG. 9A, there is shown a graphical representation **900A** illustrating the comparison between the average sensitivity of the flexible hydrogen detection sensor with the molecular sieve coating, as observed at the beginning versus at the end of the six-month period. The abscissa axis represents the square root of the hydrogen gas concentration expressed in percentage. The ordinate axis represents the average sensitivity expressed in percentage.

The graphical representation **900A** includes a first curve **902A**, and a second curve **904A**. The first curve **902A** represents the performance of the flexible hydrogen detection sensor at the beginning of the six-month period, i.e., May month. The second curve **904A** represents the performance of the flexible hydrogen detection sensor at the end of the six-month period, i.e., December month.

The first curve **902A** shows a steady increase in the sensitivity as hydrogen gas concentration increases. The sensitivity ranges from about 1.7% at the lowest hydrogen gas concentration to 4% at the highest hydrogen gas concentration. The second curve **904A** also shows an increasing trend in sensitivity with hydrogen gas concentration. The sensitivity ranges from about 1.8% at the lowest concentration to 4.7% at the highest hydrogen gas concentration. The first curve **902A**, and the second curve **904A** show similar trends, indicating consistent behaviour of the flexible hydrogen detection sensor over time. The second curve **904A** shows slightly higher sensitivity across all hydrogen gas concentrations, suggesting an improvement in the performance of the flexible hydrogen detection sensor over the six-month period. The difference in sensitivity becomes more pronounced at higher hydrogen gas concentrations.

With reference to FIG. 9B, there is shown a graphical representation **900B** illustrating the comparison between the average response time of the flexible hydrogen detection sensor with the molecular sieve coating, as observed at the beginning vs at the end of the six-month period. The abscissa axis represents the hydrogen gas concentration expressed in volume percentage. The ordinate axis represents the average response time expressed in seconds.

The graphical representation **900B** includes a first curve **902B** and a second curve **904B**. The first curve **902B**, represents the performance of the flexible hydrogen detection sensor at the beginning of the six-month period, i.e., May month. The second curve **904B**, represents the performance of the flexible hydrogen detection sensor at the end of the six-month period, i.e., December month. The first curve **902B**, shows a decreasing trend in response time as hydrogen gas concentration increases. The response time decreases from about 7.5 seconds at 0.63 % of the hydrogen gas to 3.5 seconds at 3.23 % of the hydrogen gas. The second curve **904B**, also shows a general decreasing trend in response time with increasing hydrogen gas concentration. The response time decreases from about 10.5 seconds at 0.63 % of the hydrogen gas concentration to 6 seconds at 3.23 % of the hydrogen gas concentration.

Both the curves, i.e., the first curve **902B** and the second curve **904B**, show faster response times at higher hydrogen gas concentrations. The second curve **904B**, shows consistently longer response times compared to the first curve **902B**. The difference in response times is more pronounced at lower hydrogen gas concentrations. The flexible hydrogen detection sensor with the molecular sieve coating maintains its functionality over a six-month period. The sensitivity slightly improves over time, particularly at higher hydrogen gas concentrations. The response time increases over the six-month period, indicating a slight decrease in the speed of response time. The trade-off between improved sensitivity and slightly slower response time suggests some changes in the characteristics over time of the flexible hydrogen detection sensor with the molecular sieve coating, due to ageing effects or environmental factors.

The graphical representation **900A** and the graphical representation **900B** demonstrate the long-term stability and performance evolution of the flexible hydrogen detection sensor with the molecular sieve coating, which is crucial information for assessing its suitability for practical, long-term hydrogen sensing applications.

FIGs. 9C and 9D are graphical representations illustrating the six-month stability of the flexible hydrogen detection sensor without the molecular sieve coating, in accordance with an embodiment of the present disclosure. FIGs. 9C and 9D are described in conjunction with elements from FIGs. 1 to 9B. With reference to FIG. 9C, there is shown a graphical representation **900C** illustrating the comparison between the average sensitivity of the flexible hydrogen detection sensor without the molecular sieve coating, as observed at the beginning versus at the end of the six-month period. The abscissa axis represents the square root of the hydrogen gas concentration expressed in percentage. The ordinate axis represents the average sensitivity expressed in percentage.

The graphical representation **900C** includes a first curve **902C** and a second curve **904C**. The first curve **902C** represents the performance of the flexible hydrogen detection sensor at the beginning of the six-month period, i.e., May month. The second curve **904C** represents the performance of the flexible hydrogen detection sensor at the end of the six-month period, i.e., December month.

Both the curves, i.e., the first curve **902C** and the second curve **904C**, show a linear increase in the sensitivity as the hydrogen gas concentration increases. The first curve **902C**, and the second curve **904C**, are almost overlapping each other, suggesting little change in sensitivity over the six-month period. The sensitivity ranges from about 2% at low hydrogen gas concentrations to about 5.5% at high hydrogen gas concentrations.

With reference to FIG. 9D, there is shown a graphical representation **900D** illustrating the comparison between the average response time of the flexible hydrogen detection sensor without the molecular sieve coating, as observed at the beginning versus at the end of the six-month period. The abscissa axis represents the hydrogen gas concentration expressed in volume percentage. The ordinate axis represents the average response time expressed in seconds.

The graphical representation **900D** includes a first curve **902D** and a second curve **904D**. The first curve **902D** represents the performance of the flexible hydrogen detection sensor at the beginning of the six-month period, i.e., May month. The second curve **904D** represents the performance of the flexible hydrogen detection sensor at the end of the six-month period, i.e., December month.

Both the curves, i.e., the first curve **902D** and the second curve **904D**, show a general trend of decreasing response time as the hydrogen gas concentration increases. The first curve **902D** shows a more pronounced decrease in the response time, especially at higher hydrogen gas concentrations. The second curve **904D** shows a slight upturn in the response time at the highest hydrogen concentration.

Overall, the graphical representation **900C** and the graphical representation **900D** suggest that while the sensitivity of the flexible hydrogen detection sensor without the molecular sieve coating remained stable over the six-month period, but response time characteristics changed with slight variations.

FIGs 10A and 10B are graphical representations illustrating the response of the flexible hydrogen detection sensor with the molecular sieve coating under tension and compression, in accordance with an embodiment of the present disclosure. FIGs. 10A and 10B are described in conjunction with elements from FIGs. 1 to 9D. With reference to FIG. 10A, there is shown a graphical representation **1000A** illustrating the comparison between the average sensitivity of the flexible hydrogen detection sensor with the molecular sieve coating under tension and compression. The abscissa axis represents the square root of the hydrogen gas concentration expressed in percentage. The ordinate axis represents the average sensitivity expressed in percentage.

The graphical representation **1000A** includes a first curve **1002A**, and a second curve **1004A**. The first curve **1002A** depicts the response of the flexible hydrogen detection sensor with the molecular sieve coating under compression. The second curve **1004A** depicts the response of the flexible hydrogen detection sensor with the molecular sieve coating under tension.

Both the curves, i.e., the first curve **1002A** and the second curve **1004A**, show increasing sensitivity with increasing hydrogen concentration. The second curve **1004A**, consistently shows slightly higher sensitivity than the first curve **1002A**, across all hydrogen gas concentrations. The sensitivity ranges from about 2% at low hydrogen gas concentrations to about 5-5.5% at high hydrogen gas concentrations. The difference in sensitivity between tension and compression becomes more pronounced at higher hydrogen gas concentrations.

With reference to FIG. 10B, there is shown a graphical representation **1000B** illustrating the comparison between the average response time of the flexible hydrogen detection sensor with the molecular sieve coating under tension versus compression. The abscissa axis represents the hydrogen gas concentration expressed in volume percentage. The ordinate axis represents the average response time expressed in seconds.

The graphical representation **1000B** includes a first curve **1002B**, and a second curve **1004B**. The first curve **1002B**, depicts the average response time of the flexible hydrogen detection sensor with the molecular sieve coating under compression as a function of hydrogen gas concentration. The second curve **1004B**, depicts the average response time of the flexible hydrogen detection sensor with the molecular sieve coating under tension as a function of hydrogen gas concentration.

Both curves, i.e., the first curve **1002B** and the second curve **1004B**, show a general trend of decreasing response time with increasing hydrogen gas concentration. The second curve **1004B**, consistently shows longer average response times as compared to the first curve **1002B**. Average response times range from about 18 seconds at low hydrogen gas concentrations to 9-12 seconds at higher hydrogen gas concentrations. The difference in response time between tension and compression is most pronounced at lower hydrogen concentrations and becomes smaller at higher concentrations.

FIGs 10C and 10D are graphical representations illustrating the response of the flexible hydrogen detection sensor without the molecular sieve coating under tension and compression, in accordance with an embodiment of the present disclosure. FIGs. 10C and 10D are described in conjunction with elements from FIGs. 1 to 10B. With reference to FIG. 10C, there is shown a graphical representation **1000C** illustrating the response of the flexible hydrogen detection sensor without the molecular sieve coating (with reference to average sensitivity) under tension and compression. The abscissa axis represents the square root of the hydrogen gas concentration expressed in percentage. The ordinate axis represents the average sensitivity expressed in percentage.

The graphical representation **1000C** includes a first curve **1002C** and a second curve **1004C**. The first curve **1002C** depicts the response of the flexible hydrogen detection sensor (without the molecular sieve coating) under compression. The second curve **1004C** depicts the response time of the flexible hydrogen detection sensor without the molecular sieve coating under tension.

Both the first curve **1002C**, and the second curve **1004C** show increasing sensitivity with increasing hydrogen concentration. The second curve **1004C** shows slightly higher sensitivity than the first curve **1002**C, but the difference is less pronounced compared to the flexible hydrogen detection sensor (without the molecular sieve coating). The sensitivity ranges from about 2% at low hydrogen gas concentrations to about 5-5.5% at high hydrogen gas concentrations.

With reference to FIG. 10D, there is shown a graphical representation **1000D** illustrating the comparison between the average response time of the flexible hydrogen detection sensor (without the molecular sieve coating) under tension and compression. The abscissa axis represents the hydrogen gas concentration expressed in volume percentage. The ordinate axis represents the average response time expressed in seconds.

The graphical representation **1000D** includes a first curve **1002D** and a second curve **1004D**. The first curve **1002D** depicts the average response time of the flexible hydrogen detection sensor (without the molecular sieve coating) under compression as a function of hydrogen gas concentration. The second curve **1004D** depicts the average response time of the flexible hydrogen detection sensor (without the molecular sieve coating) under tension as a function of hydrogen gas concentration.

Both the curves, i.e., the first curve **1002D** and the second curve **1004D**, show a general trend of decreasing average response time with increasing hydrogen gas concentration. The first curve **1002D** shows longer response times compared to the second curve **1004D**, but the difference is less pronounced than in the flexible hydrogen detection sensor with molecular sieve coating. Response times range from about 14-18 seconds at low concentrations to 9-12 seconds at high hydrogen gas concentrations. The difference in response time between tension and compression is consistent across all hydrogen gas concentrations. The molecular sieve coating does not significantly affect the sensitivity of the first curve **1002D** and the second curve **1004D** but does impact the response time. The flexible hydrogen detection sensor with and without molecular sieve coating shows higher sensitivity and longer response times under tension compared to compression.

The molecular sieve coating amplifies the differences in average response time between tension and compression, especially at lower hydrogen gas concentrations.

Overall, the mechanical strain (tension vs compression) affects the performance of the flexible hydrogen detection sensor, and the molecular sieve coating interacts with mechanical strain, particularly in terms of response time.

FIGs. 11A and 11B are graphical representations illustrating the effect of platinum content on the flexible hydrogen detection sensor having the molecular sieve coating, in accordance with an embodiment of the present disclosure. FIGs 11A and 11B are described in conjunction with elements from the FIGs 1 to 10D. With reference to FIG. 11A, there is shown a response of the flexible hydrogen detection sensor containing 10 mol% of platinum and 90 mol% of the palladium. With reference to FIG. 11A, there is shown a graphical representation **1100A** depicting the response of the flexible hydrogen detection sensor when exposed to two different hydrogen gas concentrations, with three cycles for each hydrogen gas concentration. The time is measured in seconds (sec) in an abscissa axis. The sensitivity is expressed in percentage in an ordinate axis.

The graphical representation **1100A** includes a region **1102A** depicting exposure to 3.25 % of hydrogen gas concentration and a region **1104A** depicting exposure to 0.63% of hydrogen gas concentration. For the region **1102A**, **s**ensitivity ranges from about -1% to 2%. The region **1102A** shows larger amplitude changes compared to region **1104A**. The overall trend shows a gradual decrease in baseline sensitivity over time.

With reference to FIG. 11B, there is shown a response of the flexible hydrogen detection sensor containing 5 mol% of platinum and 95 mol% of the palladium. With reference to FIG. 11B, there is shown a graphical representation **1100B** depicting the response of the flexible hydrogen detection sensor when exposed to two cycles of different hydrogen gas concentrations. The time is measured in seconds in an abscissa axis. The sensitivity is expressed in percentage in an ordinate axis.

The graphical representation **1100B** includes a region **1102B** depicting exposure to 3.25 % of hydrogen gas concentration, a region **1104**B depicting exposure to 1.27% of hydrogen gas concentration, a region **1106**B depicting exposure to 0.63% of hydrogen gas concentration and a region **1108**B depicting exposure to 2.42% of hydrogen gas concentration.

The flexible hydrogen detection sensor containing 5 mol% of platinum and 95 mol% of the palladium (represented by FIG. 11B) shows higher sensitivity (larger resistance changes) for both the hydrogen gas concentrations compared to the flexible hydrogen detection sensor containing 10 mol% of platinum and 90 mol% of the palladium (represented by FIG. 11A).

The response time of the flexible hydrogen detection sensor containing 10 mol% of platinum and 90 mol% of palladium has a slightly faster response time than the flexible hydrogen detection sensor with 5 mol% of platinum and 95 mol% of the palladium, but the flexible hydrogen detection sensor with 5 mol% of platinum and 95 mol% of the palladium sensor shows more pronounced changes in sensitivity.

FIGs. 12A and 12B are graphical representations illustrating the limit of detection of the hydrogen gas by flexible hydrogen detection sensor with molecular sieve coating, in accordance with an embodiment of the present disclosure. With reference to FIG. 12A, there is shown a graphical representation **1200A** depicting the response curve for exposure of deposition of molecular sieve for two hours. The time is measured in seconds in an abscissa axis. The sensitivity is expressed in percentage in an ordinate axis. The hydrogen concentration peaks at about 0.10%. The response curve is smoother and less reactive.

With reference to FIG. 12B, there are shown two graphical representations a first graphical representation **1200B** and a second graphical representation **1202B**, when the flexible hydrogen gas detection sensor with molecular sieve coating is exposed to hydrogen gas for forty-five minutes. The time is measured in seconds in an abscissa axis. The sensitivity is expressed in percentage in an ordinate axis. The second graphical representation **1202B** depicts multiple cycles are visible, with peaks at 3.26% of hydrogen gas concentration, 1.26% of hydrogen concentration, 0.64% of hydrogen gas concentration, and 2.41% of hydrogen gas concentration. The flexible hydrogen gas detection sensor responds quickly to changes in hydrogen gas concentration, shown by sharp changes in electrical resistance. The second graphical representation **1202B**, depicts sensitivity for lower hydrogen gas concentration, i.e. 0.1%.

Overall, the flexible hydrogen detection sensor is responsive to both high and low hydrogen gas concentrations Response is faster and more pronounced for higher concentrations (as shown in **1200B**). The flexible hydrogen detection sensor shows good repeatability across multiple cycles. For 45-minute exposure, the molecular sieve coating allows detection of both high hydrogen concentrations (for example, 3.26% of hydrogen gas) and low hydrogen gas concentrations (for example, 0.10% of hydrogen gas).

FIGs. 12C and 12D are graphical representations illustrating the limit of detection of the hydrogen gas by flexible hydrogen detection sensor without the molecular sieve coating, in accordance with an embodiment of the present disclosure. With reference to FIG. 12C, there is shown a graphical representation **1200C** depicting response curve. The time is measured in seconds in an abscissa axis. The sensitivity is expressed in percentage in an ordinate axis. The graphical representation **1200C** depicts multiple cycles are visible with peaks at 3.28% of hydrogen gas, 1.27% of hydrogen gas, 0.64% of hydrogen gas, and 2.41% of hydrogen gas. Sharp changes in electrical resistance indicate rapid response to changes in hydrogen gas concentration.

With reference to FIG. 12D, there is shown a graphical representation **1200D** depicting response curve. The time is measured in seconds in an abscissa axis. The sensitivity is expressed in percentage in an ordinate axis. The graphical representation **1200**D depicts sensitivity for lower hydrogen concentration (i.e., 0.10% of hydrogen gas).

The flexible hydrogen detection sensor without molecular sieve coating is highly responsive to both high and low hydrogen gas concentrations. Response amplitude obtained without molecular sieve coating is larger compared to the with molecular sieve coatings. The flexible hydrogen detection sensor without molecular sieve coating shows good repeatability across multiple cycles, and the recovery phases are more pronounced, especially for the low concentrations.

Example 1

An example illustrating the fabrication of the flexible hydrogen detection sensor through a series of steps:

I. Preparing the polyimide-polyester assembly:

Material used: A polyimide tape, transparent polyester sheet, plastic tray, Labolene or any other soap, paperweight.

Steps to prepare polyimide-polyester assembly:

1) Some labolene detergent was put in the plastic tray and then filled with tap water.

2) A piece of polyimide tape was cut and immersed in the tray so that it became completely wet

3) The polyimide tape was removed and laid flat on the polyester sheet. The composite sheet was kept under running tap water to flush out the detergent solution.

4) Since there still was water between the polyimide and the polyester sheet, it was pressed out by moving a paperweight on the polyimide sheet.

5) The composite sheet was covered with tissue paper to absorb any leftover water between the tape and the sheet. Paperweights were kept on top to prevent the tissues from flying off. After overnight drying, the polyimide and polyester composite sheet were ready for further processing.

II. KOH pre-treatment

The polyimide and polyester composite sheet were pre-treated with a solution of KOH in the following manner, as per an adaptation of the procedure:

1) The polyimide was cut into smaller pieces and immersed for 15 minutes in a detergent solution by mixing **825** mg of LaboleneTM in 30 ml of deionized water.

2) The polyimide pieces were removed and washed thoroughly with deionized water to flush out all the detergent solution.

3) 0.5 M KOH solution was prepared by adding 20 ml of deionized water to **560** mg KOH in a petri dish. The polyimide pieces were immersed in this solution and kept for 15 minutes.

4) The polyimide pieces were thoroughly washed with deionized water and then stored in a desiccator for future use.

III. Preparing the aluminium-polyimide assembly

The aluminium tape consisted of aluminium on one side and an adhesive with a paper backing on the other. The backing was removed, and a cello tape was stuck instead. After the aluminium was stuck on the cello-tape, the sides of this assembly were cut with scissors to expose the aluminium edges. The length of the electrically conductive metal nanoparticle deposits predefined depended on the aluminium tape used. So, the assembly was cut further as per a predefined length.

Cutting the aluminium tape involves the following steps:

1. The aluminium tape was placed flat on a rubber mat (for example, AnezusTM self-healing cutting mat, A3 size, PVC, green) and wiped with an ethanol-soaked tissue to clear any dust.

2. A ruler was taken and positioned 1 mm off the aluminium edge.

3. A pen knife was used to gently cut in the direction along the edge using multiple strokes. The ruler was firmly held in place so that it would not move while the penknife was being used along its edge.

4. The pen knife blade was wiped with an ethanol-soaked tissue before use to clear any dust that may have accumulated during storage. A slightly blunt blade was advisable, as brand-new sharp blades tended not to move freely while cutting. Hence, whenever a new blade was fitted in the pen knife, it was used several times on spare aluminium tapes to make it blunt enough for our use.

IV. Aluminium-polyimide assembly:

1. A piece of cello tape was stuck on one end of the strip, and the strip was then placed on polyimide

2. The cello tape was stuck so that it would hold the aluminium strip in place

3. The aluminium strip was then flattened with a roller (in our case, we used the core of a cello-tape roll), and another piece of cello tape was stuck at the other end to yield the aluminium-polyimide assembly

V. Preparing the “inverted assembly” setup:

The procedure for creating the inverter assembly is mentioned below.

1. A double-sided tape was cut into two pieces; each stuck some distance apart. The distance between these pieces was determined by the length of the aluminium-polyimide assembly.

2. The aluminium-polyimide assembly was placed so each end rested on the double-sided tape pieces. It must be noted that the aluminium-polyimide assembly was positioned such that the aluminium tape faced downwards.

3. A precursor solution was prepared:

To prepare **250** mM of palladium chloride (For 1 ml of precursor solution), 0.8 ml of ethanol, 0.2 ml of deionized water, 25 µl of hydrochloric acid and 44 mg of the palladium chloride were mixed, and the palladium chloride solution was left undisturbed overnight in ambient conditions so that pallidum chloride would dissolve completely. To prepare **200** mM of potassium tetrachloroplatinate (for 1 ml of precursor solution), 1 ml of deionized water and 83 mg of potassium tetrachloroplatinate are mixed together to form a potassium tetrachloroplatinate solution. To prepare 4 M potassium bromide, 1 ml of deionized water and **476** mg of potassium bromide were mixed to form a potassium bromide solution. Further, acidic ethanol was obtained by mixing 1 ml of ethanol and **200** µl of hydrochloric acid. The standard precursor solution was obtained by adding 85 µl of palladium chloride solution, 5 µl of potassium tetrachloroplatinate solution, 30 µl of potassium chloride solution, 60 µl of acidic ethanol and 60 µl of deionised water.

4. Once the aluminium-polyimide assembly was affixed to the double-sided tape, a specific volume of the solution was drop-cast right next to the clearance between the aluminium and the base. Due to capillary action, the whole clearance was filled with the precursor solution. After around 4-5 minutes, the reaction between the precursor and the aluminium was completed. The precursor solution was washed away with deionized water. The aluminium polyimide assembly was removed from the double-sided tape, and the aluminium tape was removed from the polyimide-aluminium assembly. The electrically conductive metal nanoparticle deposit obtained on the polyimide was washed by squirting deionized water on it for 5-10 seconds. Subsequently, the polyimide was kept on a Kimwipe to absorb the remaining water from the deposit.

VI. Post Treatment Step:

Once the electrically conductive metal nanoparticle deposit was fabricated, it underwent a “post-treatment” step. Here, fresh precursor solution was dropped on the electrically conductive metal nanoparticle deposit and remained there for typically one minute (unless stated otherwise). The volume of precursor solution was not explicitly estimated here, but the minimum volume that would cover the entire deposit was used. e.g., For the 3 cm long electrically conductive metal nanoparticle deposit, 50 µL of the precursor solution was used for post-treatment.

Upright assembly approach:

1. An aluminium tape with a cello tape backing was stuck on a piece of polyimide.

2. A one-piece “container-frame” was cut from an electrical tape and stuck around the aluminium tape.

3. A specific volume of the same precursor solution was dropped inside the container frame, and the reaction was allowed to proceed for 4-5 minutes. Once the

reaction was complete, the precursor was washed away with deionized water. Both the container frame and the residual aluminium tape were removed. The electrically conductive metal nanoparticle deposit was again washed with deionized water, and the excess water was absorbed on a Kimwipe tissue.

By following these steps, the flexible hydrogen detection sensor was fabricated.

Modifications to embodiments of the present disclosure described in the foregoing are possible without departing from the scope of the present disclosure as defined by the accompanying claims. Expressions such as "including", "comprising", "incorporating", "have", "is" used to describe, and claim the present disclosure are intended to be construed in a non-exclusive manner, namely allowing for items, components or elements not explicitly described also to be present. Reference to the singular is also to be construed to relate to the plural. The word "exemplary" is used herein to mean "serving as an example, instance or illustration". Any embodiment described as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments and/or to exclude the incorporation of features from other embodiments. The word "optionally" is used herein to mean "is provided in some embodiments and not provided in other embodiments". It is appreciated that certain features of the present disclosure, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the present disclosure, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable combination or as suitable in any other described embodiment of the disclosure.

CLAIMS

We claim:

1. A method **(100)** for fabrication of a flexible hydrogen detection sensor, comprising:

preparing a polyimide-substrate assembly;

pre-treating the polyimide-substrate assembly with an alkaline solution;

creating an aluminium-polyimide assembly by affixing an aluminium tape (**204B**) to the pre-treated polyimide-substrate assembly;

preparing a precursor solution comprising palladium and platinum compounds;

applying the precursor solution to the aluminium-polyimide assembly (**200B**), allowing the precursor solution to contact the aluminium tape (**204B**);

allowing a reaction between the precursor solution and the aluminium tape (**204B**) to proceed for a first predetermined time period;

removing the precursor solution and separating the aluminium tape (**204B**) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly; and

performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period, wherein the electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and wherein the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration.

2. The method **(100)** as claimed in claim 1, further comprising washing the electrically conductive metal nanoparticle deposit with deionized water after removing the precursor solution and before performing the post-treatment step.

3. The method (**100)** as claimed in claim 1, wherein the alkaline solution is a potassium hydroxide solution.

4. The method (**100)** as claimed in claim 1, wherein the first predetermined time period is between 60 to **1200** seconds.

5. The method (**100)** as claimed in claim 1, wherein the second predetermined time period is 10 to **1000** seconds.

6. The method (**100)** as claimed in claim 1, wherein the preparing the polyimide-substrate assembly comprises adhering a polyimide tape (**202B**) to a polyester sheet (**206B**).

7. The method (**100)** as claimed in claim 1, wherein the precursor solution comprises 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate.

8. The method (**100)** as claimed in claim 1, further comprising applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection.

9. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is placed in an upright orientation with an aluminium side of the aluminium tape (**204B**) facing downward during the application of the precursor solution.

10. The method (**100)** as claimed in claim 9, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: creating a container-frame (**402B**) around the aluminium tape on the polyimide-substrate assembly; filling the container-frame (**402B**) with the precursor solution; and allowing the precursor solution to react with the aluminium tape in the upright orientation.

11. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is placed in an inverted orientation with an

aluminium side of the aluminium tape (**204B**) facing upward during the application of the precursor solution.

12. The method (**100)** as claimed in claim 11, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: securing the aluminium-polyimide assembly (**200B**) in an inverted orientation with the aluminium side of the aluminium tape (**204B**) facing upward; creating the clearance (**304)** between the aluminium tape and the supporting surface; applying the precursor solution to fill the clearance (**304)**; and allowing the precursor solution to react with the aluminium tape in the inverted orientation.

13. The method (**100)** as claimed in claim 1, further comprising attaching electrical contacts to the electrically conductive metal nanoparticle deposit for measuring the change in electrical resistance.

14. The method (**100)** as claimed in claim 1, wherein the concentration of the precursor solution used in the post-treatment step is the same as the concentration used when initially applying the precursor solution to the aluminium-polyimide assembly (**200B**).

15. The method (**100)** as claimed in claim 1, wherein the volume of precursor solution applied is proportional to the length of the aluminium tape used in the aluminium-polyimide assembly (**200B**).

Dated this 05th day of September 2024

Bikash Lohia

Bikash Lohia
IN/PA – 1714
Agent for the Applicant

METHOD FOR FABRICATION OF FLEXIBLE HYDROGEN DETECTION SENSOR

ABSTRACT

A method (**100)** for fabrication of a flexible hydrogen detection sensor is disclosed. The method (**100)** includes preparing a polyimide-substrate assembly and pre-treating the polyimide-substrate assembly with an alkaline solution. The method (**100)** further includes creating an aluminium-polyimide assembly by affixing an aluminium tape (**204B**). Further, the method (**100)** includes preparing a precursor solution comprising palladium and platinum compounds to apply the precursor solution to the aluminium-polyimide assembly (**200B**) and allowing the precursor solution to contact the aluminium tape (**204B**). The method (**100)** further includes allowing a reaction between the precursor solution and the aluminium tape (**204B**) to proceed for a first predetermined time period. Further, the method (**100)** includes removing the precursor solution and separating the aluminium tape (**204B**) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit and performing a post-treatment step to the electrically conductive metal nanoparticle deposit for a second predetermined time period.

FIG. 1

We claim:

1. A method **(100)** for fabrication of a flexible hydrogen detection sensor, comprising:

preparing a polyimide-substrate assembly;
pre-treating the polyimide-substrate assembly with an alkaline solution;
creating an aluminium-polyimide assembly by affixing an aluminium tape (**204B**) to the pre-treated polyimide-substrate assembly;
preparing a precursor solution comprising palladium and platinum compounds;
applying the precursor solution to the aluminium-polyimide assembly (**200B**), allowing the precursor solution to contact the aluminium tape (**204B**);
allowing a reaction between the precursor solution and the aluminium tape (**204B**) to proceed for a first predetermined time period;
removing the precursor solution and separating the aluminium tape (**204B**) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly; and
performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period, wherein the electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and wherein the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration.

2. The method **(100)** as claimed in claim 1, comprising washing the electrically conductive metal nanoparticle deposit with deionized water after removing the precursor solution and before performing the post-treatment step.

3. The method (**100)** as claimed in claim 1, wherein the alkaline solution is a potassium hydroxide solution.

4. The method (**100)** as claimed in claim 1, wherein the first predetermined time period is between 60 to **1200** seconds.

5. The method (**100)** as claimed in claim 1, wherein the second predetermined time period is 10 to **1000** seconds.

6. The method (**100)** as claimed in claim 1, wherein the preparing the polyimide-substrate assembly comprises adhering a polyimide tape (**202B**) to a polyester sheet (**206B**).

7. The method (**100)** as claimed in claim 1, wherein the precursor solution comprises 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate.

8. The method (**100)** as claimed in claim 1, further comprising applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection.

9. The method (**100**) as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is placed in an upright orientation with an aluminium side of the aluminium tape (**204B**) facing downward during the application of the precursor solution.

10. The method (**100**) as claimed in claim 9, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: creating a container-frame (**402B**) around the aluminium tape on the polyimide-substrate assembly; filling the container-frame (**402B**) with the precursor solution; and allowing the precursor solution to react with the aluminium tape in the upright orientation.

11. The method (**100**) as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is alternatively placed in an inverted orientation with an

aluminium side of the aluminium tape (**204B**) facing upward during the application of the precursor solution.

12. The method (**100)** as claimed in claim 11, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: securing the aluminium-polyimide assembly (**200B**) in an inverted orientation with the aluminium side of the aluminium tape (**204B**) facing upward; creating the clearance (**304)** between the aluminium tape and the supporting surface; applying the precursor solution to fill the clearance (**304)**; and allowing the precursor solution to react with the aluminium tape in the inverted orientation.

13. The method (**100)** as claimed in claim 1, comprising attaching electrical contacts to the electrically conductive metal nanoparticle deposit for measuring the change in electrical resistance.

14. The method (**100)** as claimed in claim 1, wherein the concentration of the precursor solution used in the post-treatment step is the same as the concentration used when initially applying the precursor solution to the aluminium-polyimide assembly (**200B**).

15. The method (**100)** as claimed in claim 1, wherein the volume of precursor solution applied is proportional to the length of the aluminium tape used in the aluminium-polyimide assembly (**200B**).

Dated this 05th day of September 2024

Bikash Lohia

Bikash Lohia

IN/PA – 1714

Agent for the Applicant

We claim:

1. A method **(100)** for fabrication of a flexible hydrogen detection sensor, comprising:

preparing a polyimide-substrate assembly;

pre-treating the polyimide-substrate assembly with an alkaline solution;

creating an aluminium-polyimide assembly by affixing an aluminium tape (**204B**) to the pre-treated polyimide-substrate assembly;

preparing a precursor solution comprising palladium and platinum compounds;

applying the precursor solution to the aluminium-polyimide assembly (**200B**), allowing the precursor solution to contact the aluminium tape (**204B**);

allowing a reaction between the precursor solution and the aluminium tape (**204B**) to proceed for a first predetermined time period;

removing the precursor solution and separating the aluminium tape (**204B**) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly; and

performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period, wherein the electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and wherein the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration.

2. The method **(100)** as claimed in claim 1, ~~further~~ comprising washing the electrically conductive metal nanoparticle deposit with deionized water after removing the precursor solution and before performing the post-treatment step.

3. The method (**100)** as claimed in claim 1, wherein the alkaline solution is a potassium hydroxide solution.

4. The method (**100)** as claimed in claim 1, wherein the first predetermined time period is between 60 to **1200** seconds.

5. The method (**100)** as claimed in claim 1, wherein the second predetermined time period is 10 to **1000** seconds.

6. The method (**100)** as claimed in claim 1, wherein the preparing the polyimide-substrate assembly comprises adhering a polyimide tape (**202B**) to a polyester sheet (**206B**).

7. The method (**100)** as claimed in claim 1, wherein the precursor solution comprises 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate.

8. The method (**100)** as claimed in claim 1, further comprising applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection.

9. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is placed in an upright orientation with an aluminium side of the aluminium tape (**204B**) facing downward during the application of the precursor solution.

10. The method (**100)** as claimed in claim 9, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: creating a container-frame (**402B**) around the aluminium tape on the polyimide-substrate assembly; filling the container-frame (**402B**) with the precursor solution; and allowing the precursor solution to react with the aluminium tape in the upright orientation.

11. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is alternatively placed in an inverted orientation with an

aluminium side of the aluminium tape (**204B**) facing upward during the application of the precursor solution.

12. The method (**100)** as claimed in claim 11, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: securing the aluminium-polyimide assembly (**200B**) in an inverted orientation with the aluminium side of the aluminium tape (**204B**) facing upward; creating the clearance (**304)** between the aluminium tape and the supporting surface; applying the precursor solution to fill the clearance (**304)**; and allowing the precursor solution to react with the aluminium tape in the inverted orientation.

13. The method (**100)** as claimed in claim 1, ~~further~~ comprising attaching electrical contacts to the electrically conductive metal nanoparticle deposit for measuring the change in electrical resistance.

14. The method (**100)** as claimed in claim 1, wherein the concentration of the precursor solution used in the post-treatment step is the same as the concentration used when initially applying the precursor solution to the aluminium-polyimide assembly (**200B**).

15. The method (**100)** as claimed in claim 1, wherein the volume of precursor solution applied is proportional to the length of the aluminium tape used in the aluminium-polyimide assembly (**200B**).

Dated this 05th day of September 2025

Bikash Lohia

Bikash Lohia

IN/PA – 1714

Agent for the Applicant

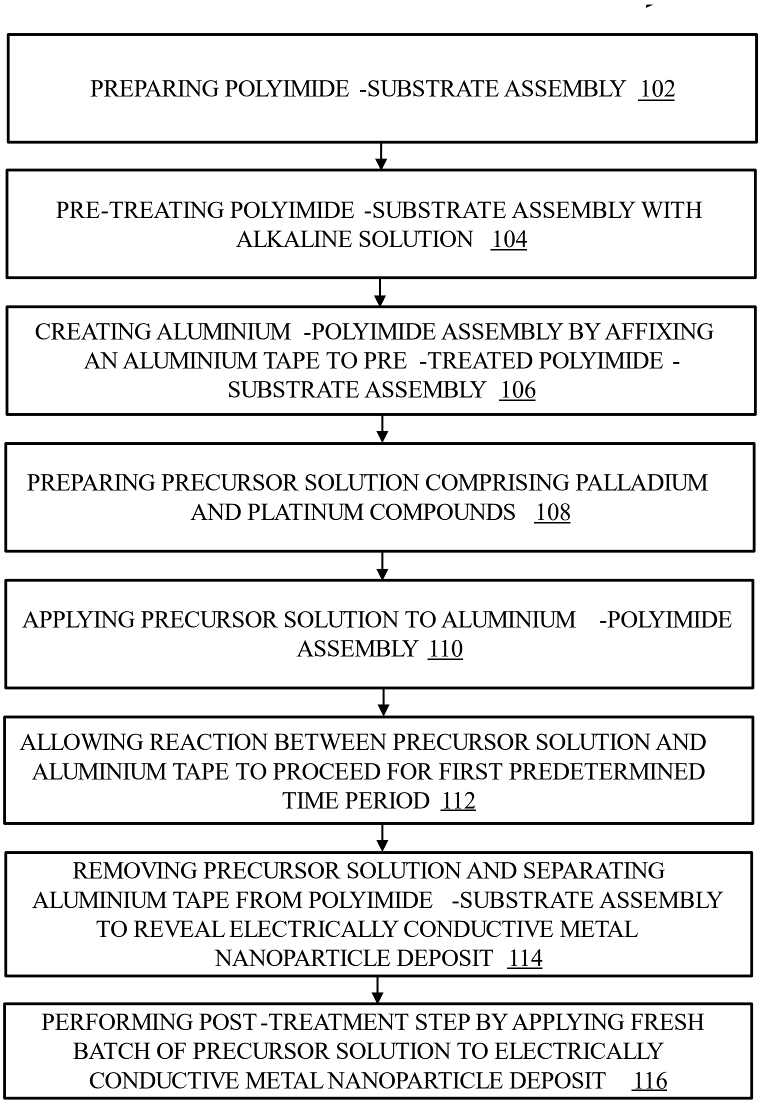

FIG. 1

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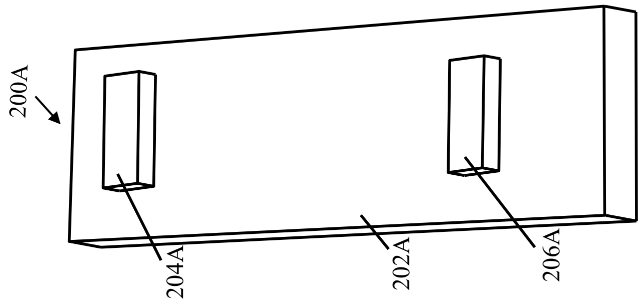

FIG. 2A

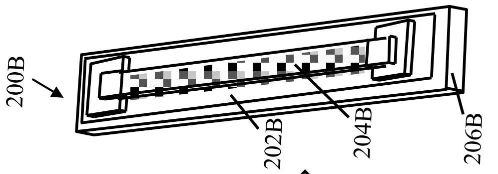

FIG. 2B

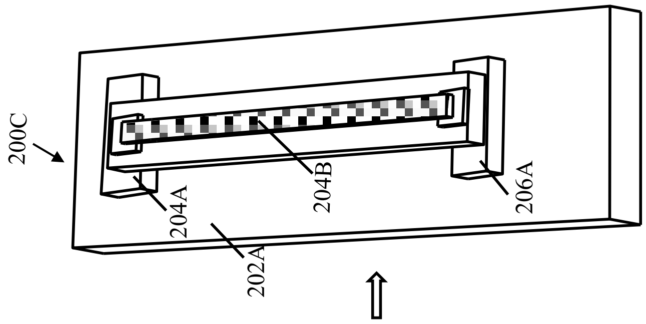

FIG. 2C

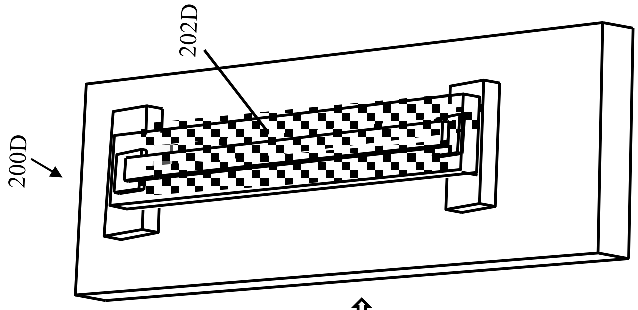

FIG. 2D

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Bikash Lohia

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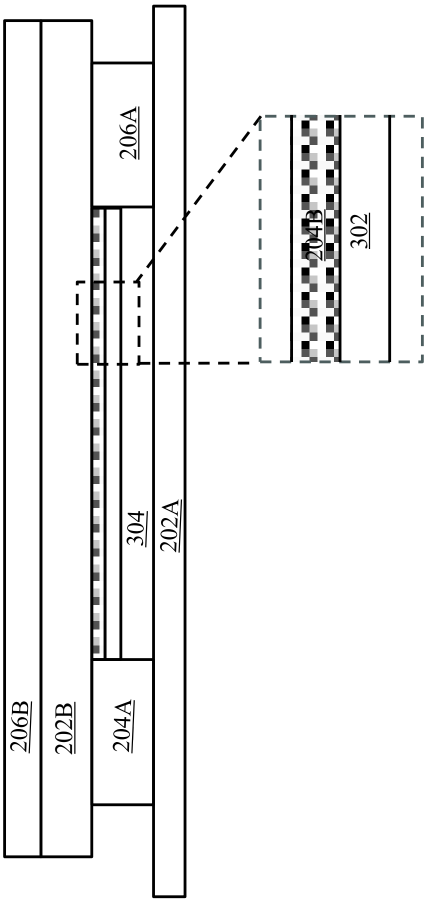

FIG. 3

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Indian Institute of Science **No. of Sheets: 17**

Application No.: 202441067213 **Sheet No.:4**

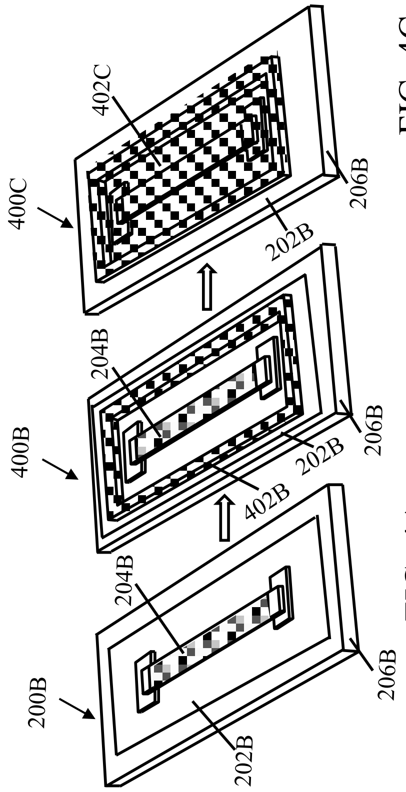

FIG. 4C

FIG. 4B

FIG. 4A

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Bikash Lohia

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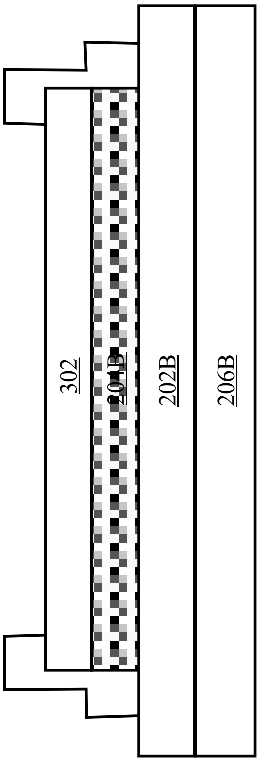

FIG. 5

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Bikash Lohia

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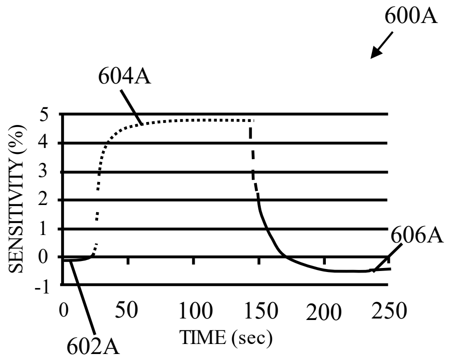

FIG. 6A

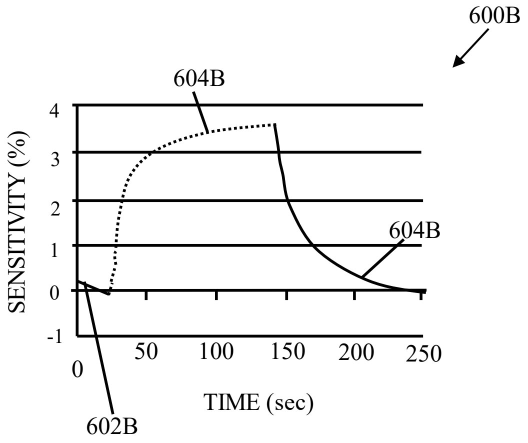

FIG. 6B

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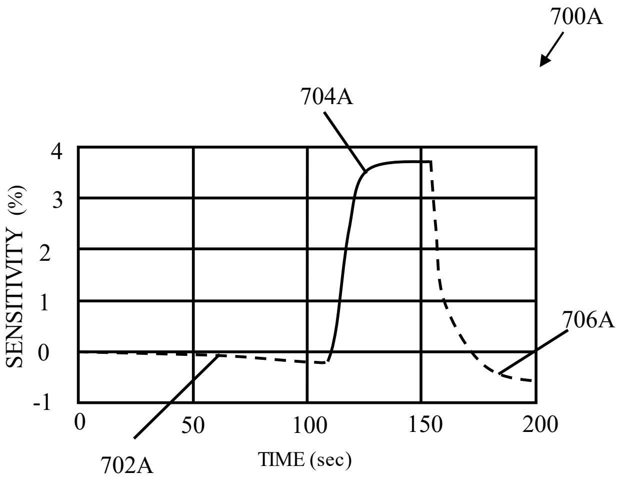

FIG. 7A

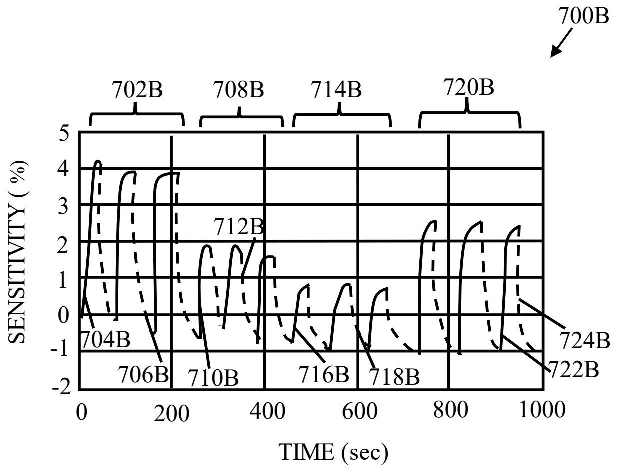

FIG. 7B

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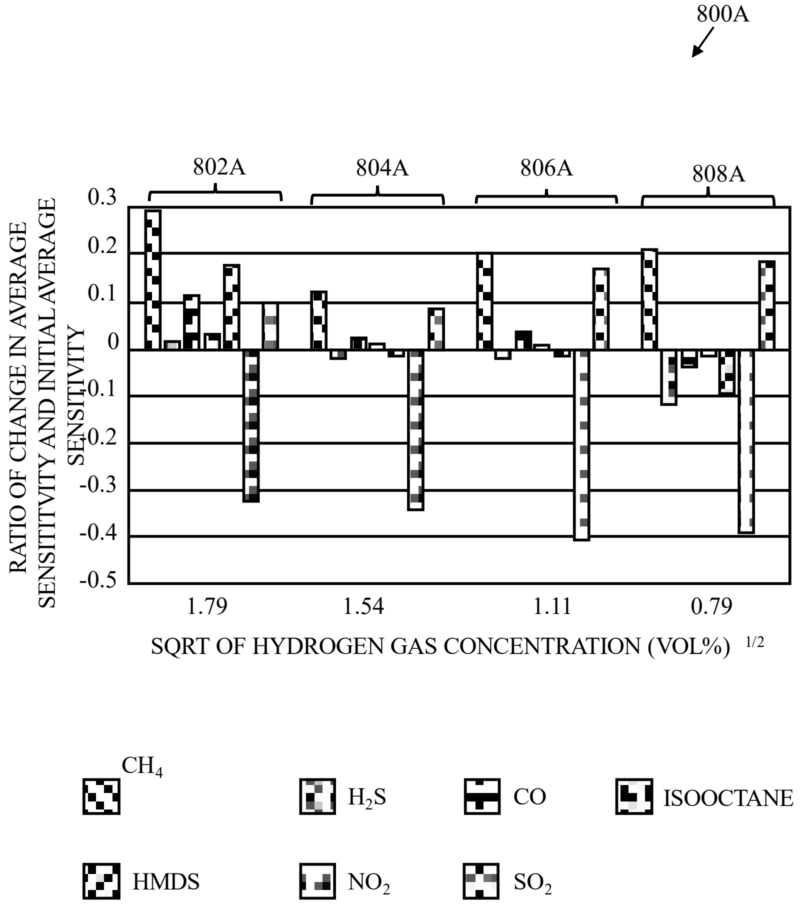

FIG. 8A

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

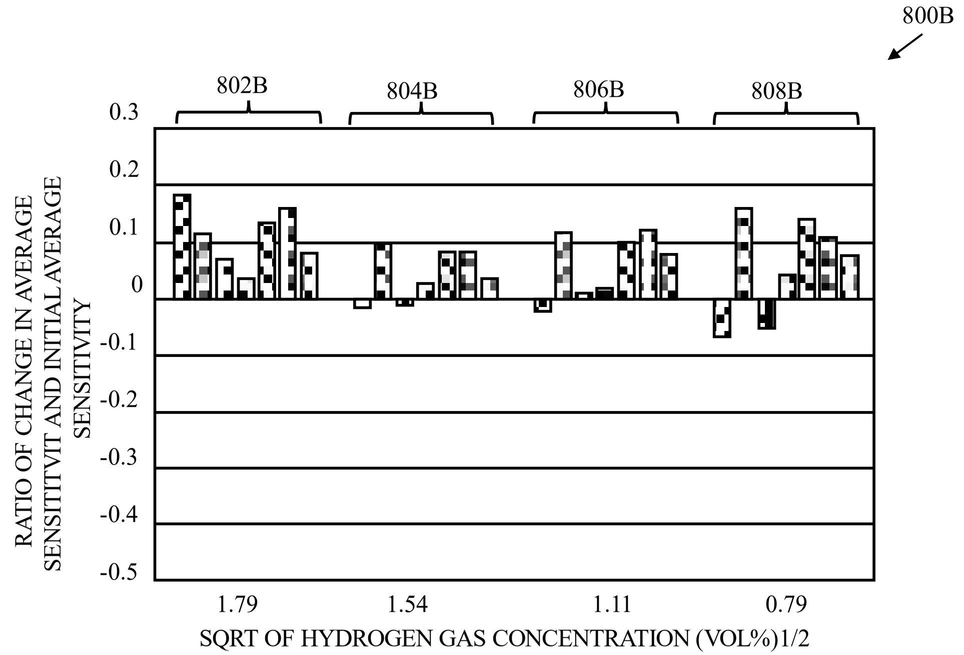

FIG. 8B

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Bikash Lohia

Bikash Lohia

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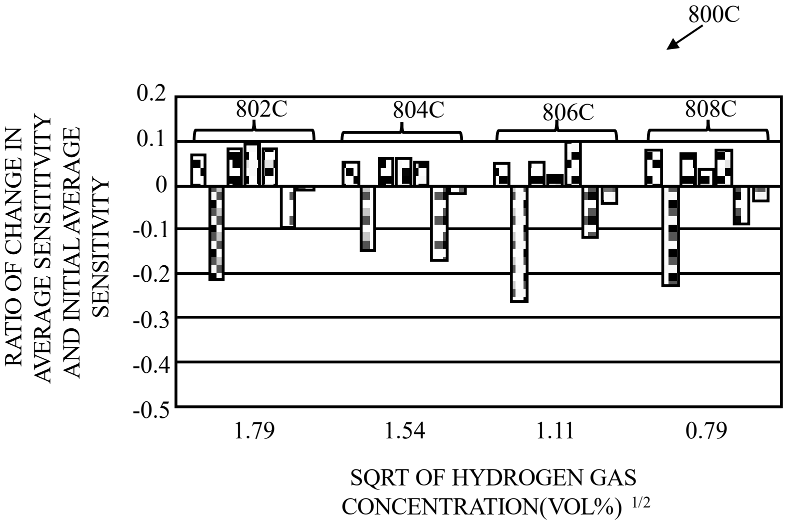

FIG. 8C

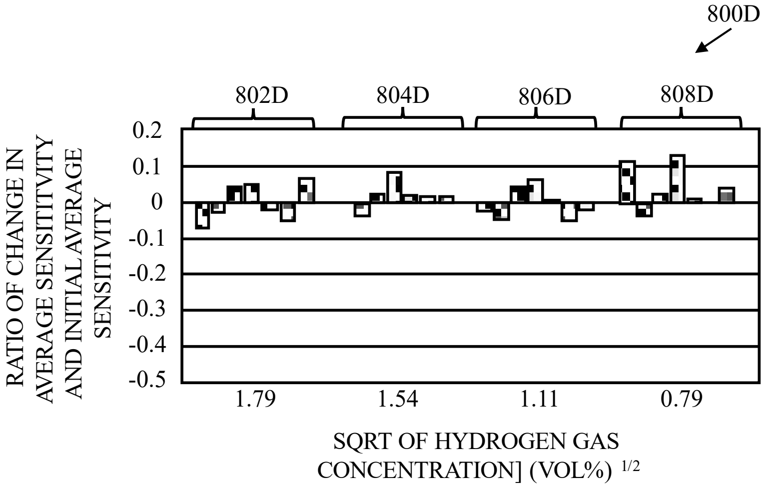

FIG. 8D

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Bikash Lohia

Bikash Lohia

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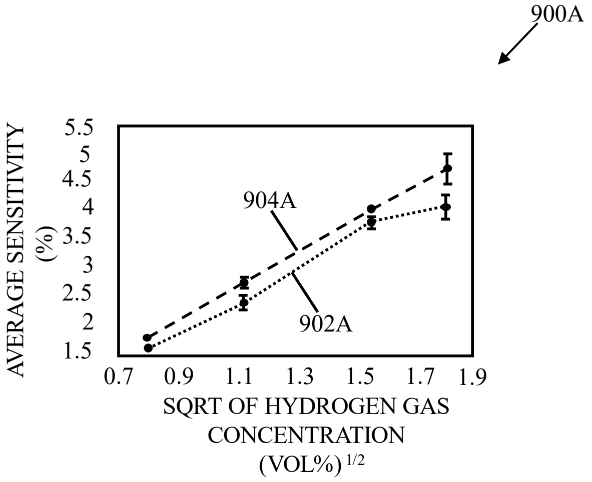

FIG. 9A

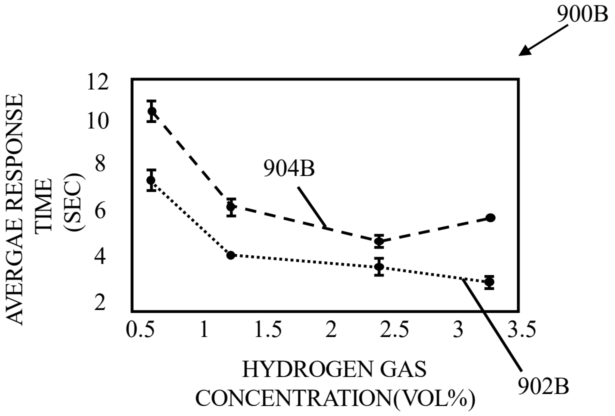

FIG. 9B

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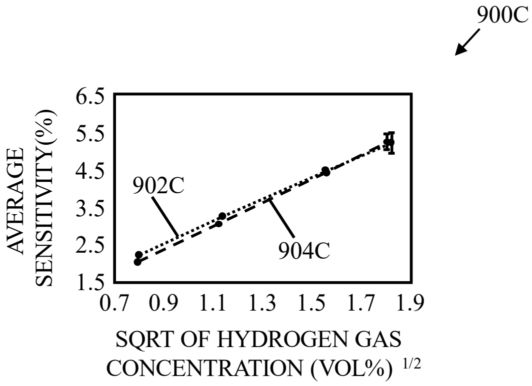

FIG. 9C

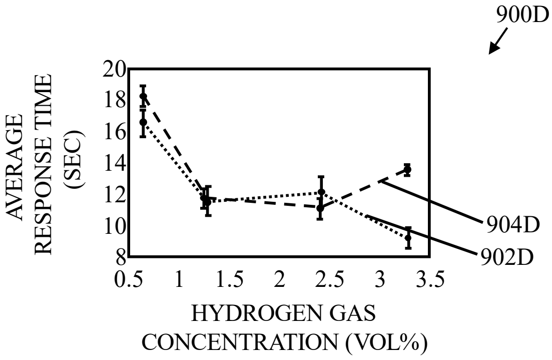

FIG. 9D

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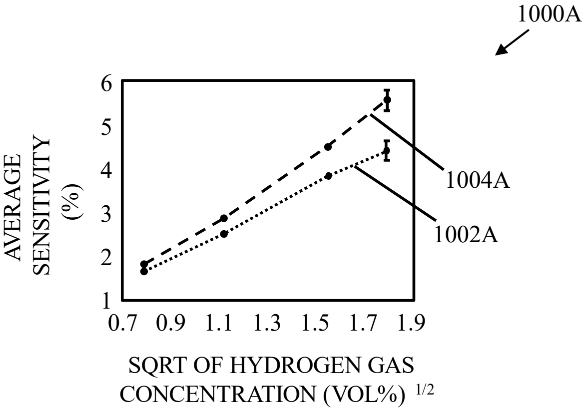

FIG. 10A

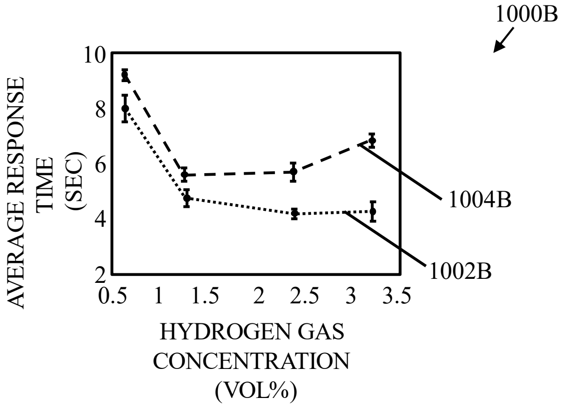

FIG. 10B

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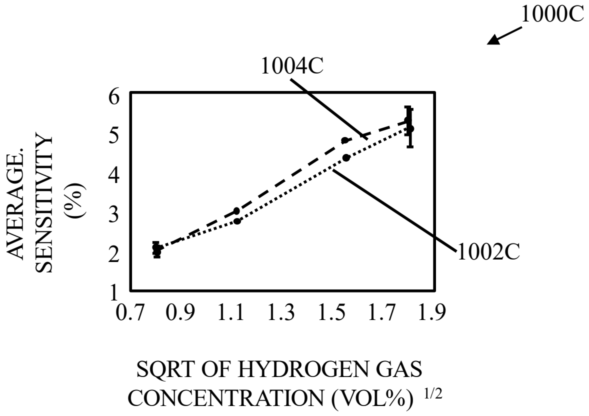

FIG. 10C

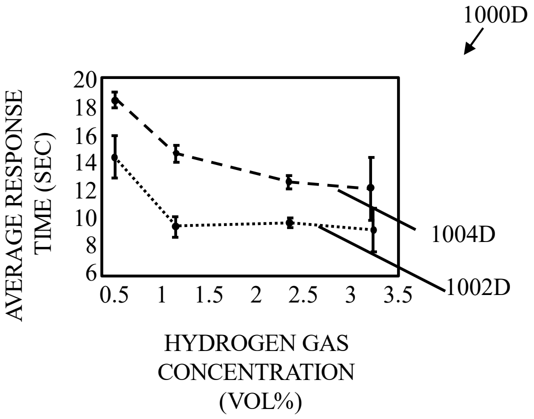

FIG. 10D

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Bikash Lohia

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Agent for the Applicant

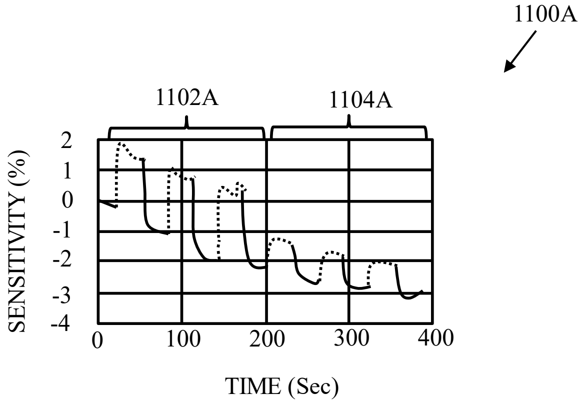

FIG. 11A

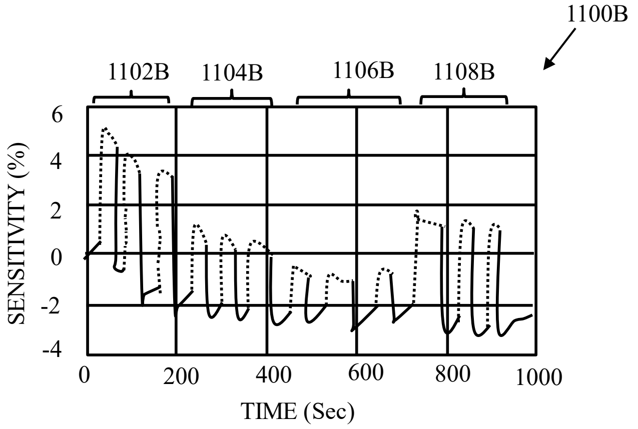

FIG. 11B

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Bikash Lohia

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Agent for the Applicant

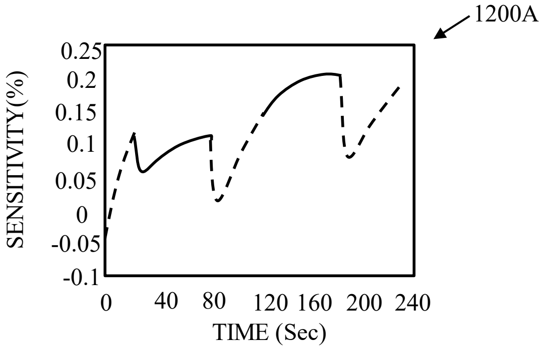

FIG. 12A

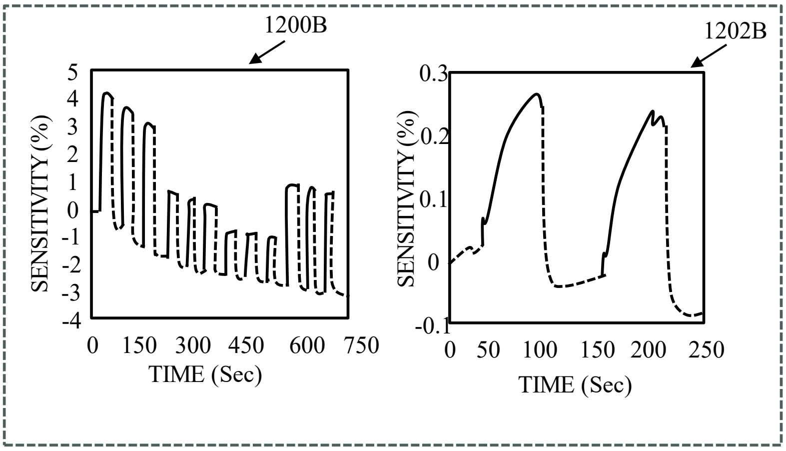

FIG. 12B

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Bikash Lohia

IN/PA - 1714

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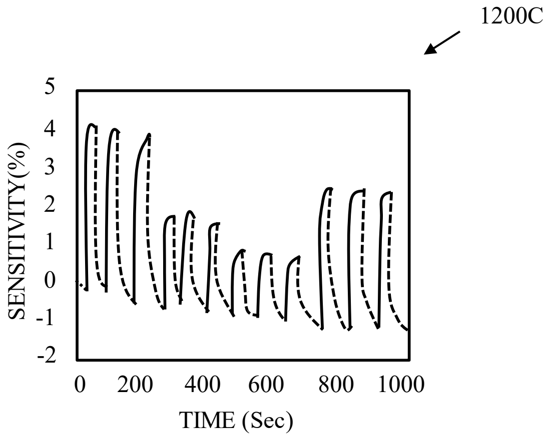

FIG. 12C

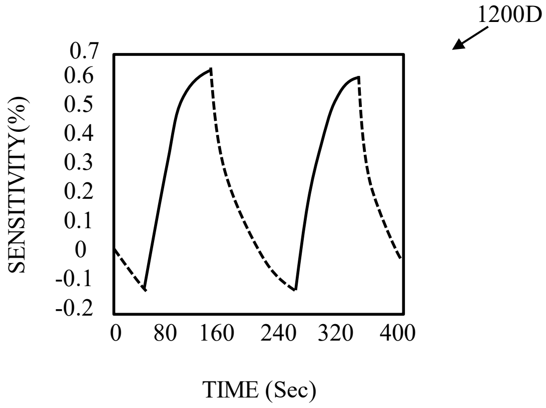

FIG. 12D

Dated this on 05th day of September 2024

Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

Dated: March 31, 2025

Via Electronic Filing

Controller of Patents: Manoj Kumar
Letter Ref.: Application No. 202441067213

The Controller of Patents
The Patent Office
Intellectual Property Office Building,
GST Road, Guindy,
Chennai, 600032

Last Date to File Response to the First Examination Report: 29th July 2025

Re: **Indian Patent Application No.** : 202441067213
Date of Filing : 05th September 2024
Title : METHOD FOR FABRICATION OF FLEXIBLE HYDROGEN DETECTION SENSOR
Applicant : Indian Institute of Science
Date of First Examination Report : 29th January 2025

Respected Sir,

We write in response to your above-referenced letter dated 29th January 2025 with regard to the above-identified Indian Patent Application.

In wake of the issuance of the First Examination Report *(FER)*, the claims have been amended to overcome the objections raised by the Controller. Thus, the amended claim set is submitted herewith for further consideration by the Controller.

In the Applicant's response, *"Applicant's pending claim set"* pertains to the Applicant's claim set presently on file, and "*Applicant's amended claim set"* pertains to the proposed claim set submitted herewith.
Our detailed response to the objections is as follows:

AMENDMENTS TO THE CLAIMS:

The Applicant respectfully submits that the claims have been amended to overcome the objections raised by the Controller. Following is the listing of claim amendments:

Pending claims 2 and 13 have been amended by deleting the term "further" to impart clarity.

Pending claim 11 has been amended by adding "**alternative**" to make the claim read as "*The method (100) as claimed in claim 1, wherein the aluminium-polyimide assembly (200B) is alternatively placed in an alternative inverted orientation, with an aluminium side of the aluminium tape (204B) facing upward during the application of the precursor solution*", in order to place the claim in a better form. Support can be found on page 16, line 20 to page 17, line 15 of the specification as originally filed.

Thus, amended claims set 1-15 are submitted herewith for further consideration by the Controller.

Clean copy of amended claims along with marked copy are attached herewith.

Objection 1: INVENTIVE STEP:

Referring to the Controller's assertion of the inventive step, the Applicant respectfully submits the response for further consideration by the Controller. The Controller has objected that the subject matter of the pending claims set lacks an inventive step in view of the cited prior art documents D1-D3.

The Applicant respectfully disagrees with the Controller's assertion in light of the pending claims set and submits the following arguments.

Submission:

It is well-settled that in determining the differences between the prior art and the claims, the question under consideration is not whether the differences themselves would have been obvious, but whether the claimed invention as a whole would have been obvious. To this end, a prior art reference must be considered in its entirety, i.e., as a whole, including portions **that would lead away from the claimed invention**.

[**Emphasis** Added] To establish a prima facie case of obviousness, three basic criteria must be met: (1) there must be some suggestion or motivation to modify the reference or to combine reference teachings; (2) there must be reasonable expectation of success; and (3) **the prior art reference must teach or suggest all the claim limitations**. Thus, Applicant respectfully traverses the objection because the approach disclosed in D1-D3 and approach claimed in the present invention are not only different, but portions of D1-D3 upon which the Controller relied do not render the claimed invention obvious and in fact teaches away from the claimed invention.

The Controller contends that the subject matter of pending claims 1-15 as claimed in present invention does not constitute an invention under section 2(1)(ja) of the Patents Act, 1970 (as amended) because it does not involve an inventive step in view of following documents:

D1: Fast and robust hydrogen sensors based on discontinuous palladium films on polyimide, fabricated on a wafer scale IOP Publishing Ltd Nanotechnology;

D2: Flexible H2 sensor fabricated by layer-by-layer self-assembly of thin films of polypyrrole and modified in situ with Pt nanoparticles; and

D3: Fabrication of a flexible H2 sensor based on Pd nanoparticles modified polypyrrole films.

Technical Problem of the Present Invention: The technical problem addressed by the present invention concerns the challenge of achieving improved sensitivity and reliability in flexible hydrogen sensors while maintaining a cost-effective fabrication process. Existing hydrogen sensors often face limitations in terms of sensitivity, stability, and fabrication complexity, which can impact their practical applicability.

The present invention overcomes these limitations by providing a method for fabricating a flexible hydrogen detection sensor through the deposition of an electrically conductive metal nanoparticle network onto a polyimide substrate. The fabrication process involves pre-treating the substrate, affixing aluminium tape, and applying a palladium-platinum precursor solution to initiate a reaction with aluminium, leading to the formation of metal nanoparticles. Once the aluminium tape is removed, a post-treatment step enhances the conductive network, enabling reliable hydrogen detection based on variations in electrical resistance. This approach ensures improved sensor performance while maintaining an efficient and scalable fabrication process.

Particularly, the method involves creating an aluminium-polyimide assembly, where an aluminium tape is affixed to a pre-treated polyimide substrate. Further, a palladium-platinum precursor solution is prepared and applied to the aluminium-polyimide assembly, allowing direct interaction between the precursor and the aluminium tape, this reaction naturally initiates the formation of Pd-Pt nanoparticles, ensuring uniform distribution on the substrate. The aluminium tape facilitates controlled and selective deposition, avoiding issues of random particle agglomeration, which is a common challenge in solution-based methods. Moreover, the precursor solution is allowed to react with the aluminium tape for a predetermined time period which is between 60 to 1200 seconds, enabling the gradual formation of an electrically conductive nanoparticle network. The aluminium tape is then removed, exposing a well-structured, conductive metal deposit on the polyimide surface. For further enhancement of the conductivity and stability of the sensor, a post-treatment step is performed by reapplying a fresh batch of precursor solution for a second predetermined time period which is between 10 to 1000 seconds.

The applicant respectfully submits that the present invention is completely different from the cited documents D1-D3 in terms of structural organization and functional integration of components. To be precise, the present invention has features of (1) **a structured aluminium-polyimide assembly, where an aluminium tape is affixed to a pre-treated polyimide-substrate assembly,** and (2) **a sequential deposition process in which a palladium- and platinum-containing precursor solution is applied to the aluminium-polyimide assembly, initiating a reaction with the aluminium tape for a controlled duration, followed by a post-treatment step involving the application of a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit, thereby forming an electrically conductive network on the polyimide-substrate assembly**, which are not disclosed in D1-D3.

In light of the foregoing, while **D1 merely hydrogen sensors utilizing discontinuous palladium (Pd) films on polyimide layers, D2 only shows hydrogen (H_2) gas sensor fabrication using a layer-by-layer (LBL) self-assembly process, by a polypyrrole (PPy) thin film deposition on a polyester (PET) substrate, and D3 only encapsulation of metal-ion/chelate complexes. None of the cited documents, either individually or in combination, teach or suggest the specific structural and functional integration of the present invention where aluminum is used as a template for depositing conductive metal nanoparticles, incorporates a crucial post-treatment step to transform the deposition into a functional catalyst for hydrogen sensing, and employs an optimized precursor solution to enhance performance**.

Thus, none of the cited documents, i.e., D1-D3, discloses structured fabrication as claimed in the present invention. Thus, D1-D3 does not teach or suggest the present invention. (refer to the differences laid out with D1-D3). (**Emphasis** Added)

Now comparing the present invention with each of the documents D1-D3 to clearly present differences and establish non-obviousness with each of the cited documents.

D1: FAST AND ROBUST HYDROGEN SENSORS BASED ON DISCONTINUOUS PALLADIUM FILMS ON POLYIMIDE, FABRICATED ON A WAFER SCALE IOP PUBLISHING LTD NANOTECHNOLOGY

D1 discloses fast hydrogen sensors based on discontinuous palladium films on supporting polyimide layers, fabricated by electron-beam evaporation with a nominal thickness of 1.5 nm. The films consist of isolated Pd islands separated by nanoscopic gaps. On hydrogenation, the volume expansion of Pd brings initially separated islands into contact which leads to the creation of new electrical pathways through the film.

As a preliminary matter, D1 merely discloses hydrogen sensors utilizing discontinuous palladium (Pd) films on polyimide layers, fabricated through a wafer-compatible process. While it discusses the deposition of Pd islands via electron-beam evaporation and their expansion upon hydrogenation to create electrical pathways, it does not suggest or imply sensor flexibility. Further, it is also submitted that since Pd is deposited on polyimide, the sensor is not flexible as the substrate is rigid. it fails to teach or suggest the specific structural and functional integration of the present invention where aluminum is used as a template for depositing conductive metal nanoparticles, incorporates a crucial post-treatment step to transform the deposition into a functional catalyst for hydrogen sensing, and employs an optimized precursor solution to enhance performance.

Furthermore, D1 does not mention pre-treatment with an alkaline solution. Aluminium is used as an electrode alongside titanium, rather than as a sacrificial template for metal nanoparticle deposition. Palladium is deposited using e-beam evaporation at a pressure of 5×10^{-7} mbar, without the use of platinum or a precursor solution, as it is not a wet-chemical method. The deposition followed a top-down evaporation process without aluminium as a template, and no post-treatment is applied to the deposited palladium.

Therefore, the features of claim 1 of the present invention collectively represent an inventive approach over the teachings of D1, achieving improved sensitivity and reliability in flexible hydrogen sensors while maintaining a cost-effective fabrication process.

D2: FLEXIBLE H2 SENSOR FABRICATED BY LAYER-BY-LAYER SELF-ASSEMBLY OF THIN FILMS OF POLYPYRROLE AND MODIFIED IN SITU WITH PT NANOPARTICLES

The applicant respectfully states that, while D2 discloses techniques for flexible hydrogen (H_2) gas sensor fabrication using a layer-by-layer (LBL) self-assembly process, where a polypyrrole (PPy) thin film is deposited on a polyester (PET) substrate. A platinum (Pt)-based complex is then self-assembled and reduced in situ, forming Pt nanoparticles on the PPy film surface. These Pt nanoparticles enhanced the sensor's sensitivity by providing catalytically active sites for H_2 gas detection. The sensor's limit of detection (LOD) is influenced by NH_3 interference in binary gas mixtures. The H_2 sensing mechanism is attributed to the catalytic effects of Pt and charge carrier formation in PPy.

D2's hydrogel preparation involves grafting and crosslinking reactions between polymers but does not suggest or teach the deliberate binding of different metal-binding compounds (polyphenol and chelating agent) to different polymers. The present invention's approach of creating a dual-functionality matrix through specific binding relationships between functional compounds and polymers is neither disclosed nor suggested in D2.

Therefore, the features of claim 1 of the present invention represent inventive approach over the teachings of D2.

D3: FABRICATION OF A FLEXIBLE H2 SENSOR BASED ON PD NANOPARTICLES MODIFIED POLYPYRROLE FILMS

D3 relates to flexible H_2 gas sensor fabrication using a layer-by-layer self-assembly method, where a Pd-based complex and polypyrrole (PPy) thin films are deposited on a plastic substrate and then reduced in situ to form a Pd-PPy thin film. Microstructural analysis revealed the formation of Pd nanoparticles (Pd NPs) on the PPy surface, which enhanced sensor response and stability by providing catalytically active sites for H_2 gas detection.

In this regard, the applicant respectfully notes that, although D3 discloses flexible hydrogen gas sensors incorporating Pd-based complexes and polypyrrole (PPy) thin films, it fundamentally differs from the present invention’s approach. The cited disclosure merely relies on self-assembly of Pd-based complexes and in-situ reduction without utilizing aluminum as a template for conductive metal nanoparticle deposition. Additionally, it lacks any teaching regarding a crucial post-treatment step to transform the deposition into a functional catalyst for hydrogen sensing or the use of an optimized precursor solution to enhance sensor performance. These key distinctions enable the present invention to achieve superior catalytic efficiency and improved sensor response.

The present invention creates a specific structural arrangement where two different types of metal-binding compounds are selectively bound to different polymers in the matrix, whereas D3 only teaches encapsulation of metal-ion/chelate complexes. This fundamental difference in the structural organization and binding relationships of the functional components clearly distinguishes the present invention from D3.

Consequently, D1-D3 disclose various fabrication techniques, however, none teach the specific method where:

a) Use of aluminium as a template for the deposition of conductive metal nanoparticles

b) Post-treatment step key for turning the deposition into a usable catalyst for H2 sensing

c) Using an optimised precursor solution

The present invention gives a structured fabrication method which leads to a faster response time, higher reliability, and improved hydrogen detection accuracy, while also ensuring scalability and reproducibility for industrial applications requiring consistent and high-performance hydrogen sensing.

The present invention gives a structured method which involves pre-treating the substrate, affixing aluminium tape, and applying a palladium-platinum precursor solution to initiate a reaction with aluminium, forming metal nanoparticles. After removing the aluminium tape, a post-treatment step enhances the conductive network, enabling hydrogen detection through resistance variation. Such a method is not suggested or taught by any of D1-D3 individually or in combination. Such structural and functional arrangement method leads to higher reliability and improved hydrogen detection accuracy that would not be obvious from simply combining the components known in D1-D3.

Thus, nowhere do D1-D3 collectively disclose the claimed features: **a structured aluminium-polyimide assembly, where an aluminium tape is affixed to a pre-treated polyimide-substrate assembly, and a sequential deposition process in which a palladium- and platinum-containing precursor solution is applied to the aluminium-polyimide assembly, initiating a reaction with the aluminium tape for a controlled duration, followed by a post-treatment step involving the application of a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit, thereby forming an electrically conductive network on the polyimide-substrate assembly**" as disclosed in the independent claim 1 of the present invention.

In light of the aforementioned, Applicant humbly submits to the Controller that at least the above-mentioned features of the independent claim 1 of the present invention are not disclosed by D1-D3. Therefore, claim 1 involves an inventive step over D1-D3. Further, amended dependent claims 2-15 also involve an inventive step by virtue of dependency on independent claim 1. The Applicant humbly requests the Ld. Controller to kindly waive off the above objection.

Objection 2: NON-PATENTABILITY:

Claim(s) (1-15) are statutorily non-patentable under the provision of clause (d) of Section 3 for the following reasons:

Claims 1-15 disclose mere use of a known method; with no comparative examples/supportive data highlighting the improvement in the claimed subject-matter over the prior art, said claims fall under section 3(d) of Indian patent act, 1970 are not allowable.

Submission:

Without acquiescing to any of the assertions in the objection, Applicant respectfully submits that amended claims 1-15 are patent eligible and that the claims do **NOT** attract the provision of sub section (d) of section 3 of the Patents Act, 1970 at least for the following reasons.

At the outset, the Applicant submits that Section 3(d) is not applicable for the claims of the present application. The claims of the present application are novel as has also been acknowledged by the Controller. Thus, the claimed method can be construed as a “new process” as none of the cited prior arts disclose the same. The claims thereby do not fall under the purview of Section 3(d).

Further, the Applicant has also established the inventiveness of the present application vis-à-vis the cited documents D1-D3 in the above section. As discussed in detail above, none of D1-D3 either alone or in combination envisage the claimed method for the fabrication of a flexible hydrogen detection sensor by depositing an electrically conductive metal nanoparticle network onto a polyimide substrate. The process involves pre-treating the substrate, affixing aluminium tape, and applying a palladium-platinum precursor solution to initiate a reaction with aluminium, forming metal nanoparticles. After removing the aluminium tape, a post-treatment step enhances the conductive network, enabling hydrogen detection through resistance variation.

As disclosed, the present specification demonstrates the advanced technical effects of the claimed method, the alkaline pre-treatment of the polyimide-substrate assembly improves adhesion and surface properties, ensuring that subsequent metal deposition occurs in a uniform and controlled manner. Further, preparation of a palladium-platinum precursor solution provides the active sensing material, enabling hydrogen adsorption-induced resistance changes for detection. Applying this solution to the aluminium-polyimide assembly initiates a self-assembly reaction, forming a uniform, conductive nanoparticle network without external reducing agents and the use of aluminium tape as a reaction facilitator enables a localized chemical reaction with the precursor solution, leading to the formation of an electrically conductive metal nanoparticle network. This eliminates the need for external reducing agents or additional adhesion layers, thereby simplifying the fabrication process while ensuring consistent nanoparticle formation across the substrate. Furthermore, the two-step metal deposition process, consisting of an initial reaction between the precursor solution and aluminium tape, followed by a post-treatment step with a fresh batch of precursor solution, significantly enhances the conductivity, stability, and uniformity of the metal nanoparticle network, where the post-treatment step ensures further growth and interconnection of metal nanoparticles, improving charge transport pathways and resulting in greater sensitivity and long-term durability of the sensor. This approach enables a more stable and uniform conductive network, leading to enhanced electrical response and improved hydrogen detection accuracy. Therefore, the structured fabrication method, with controlled deposition and post-treatment leads to a hydrogen sensor with faster response times, higher reliability, and increased sensitivity to hydrogen concentration variations, and enhances scalability and reproducibility. *(Support can be found on page 9, page 10, page 12, page 14, and page 14 of the specification as filed).*

Thus, the present application provides evidence of the advanced technical effect of the novel and inventive method claimed herein. The Applicant submits that the method of the present application cannot be arrived without inventive merit and cannot be construed as a mere use of a known process; and thereby does not fall under the ambit of Section 3(d) of the Act. The Controller is hence requested to withdraw the objection raised in this regard.

Objection 3: SUFFICIENCY OF DISCLOSURE:

The complete specification does not fully and particularly disclose the alleged invention and its operation or use and the method by which it is to be performed. it does not disclose the best method of performing the invention, which is known to the applicant. The disclosure in the specification is so insufficient that it does not disclose everything with data or experimental evidence, which is technically required to perform the claimed invention and to perform the method. Thus, in all, the complete specification fails to meet the requirements of Section 10(4)(a) and (b) of the Act.

Submission:

The Applicant respectfully submits that the application meets the requirements of Section 10(4) of the act.

With regards to the objection, the Applicant submits that the specification provides a detailed and clear description of the invention and the specification discloses the best method of performing the invention, in compliance with Section 10(4), where the specification highlights the fabrication method is described comprehensively, including its components for depositing an electrically conductive metal nanoparticle network onto a polyimide substrate, pre-treating the substrate. In an example the potassium hydroxide solution is prepared by mixing 0.4-0.6 M of potassium hydroxide with 18 -20 ml of deionized water. The potassium hydroxide treatment implants K+ ions into a polyimide surface of the polyimide-substrate assembly, which are replaced with metal ions, forming a metal interlayer that enhances the adhesion of electrically conductive metal nanoparticle deposits. After treating the pieces of the polyimide-substrate assembly with the alkaline solution, the pre-treated polyimide-substrate assembly is washed with the deionized water *(support can be found on page 9, lines 15-22 of the specification as filed)*, affixing aluminium tape. In an example pen knife may be used to cut along the edge using multiple strokes gently. After that, the aluminium tape is placed on the pre-treated polyimide-substrate assembly, ensuring the aluminium side faces the polyimide side of the pre-treated polyimide-substrate assembly *(support can be found on page 10, lines 5-8 of the specification as filed)*, and applying a palladium-platinum precursor solution to initiate a reaction with aluminium *(support can be found on page 10, line 11 to page 11 line 11 of the specification as filed)*, forming metal nanoparticles, and their respective functionalities, and the specification outlines the step-by-step operation of the method.

Therefore, the Applicant requests the Controller to waive the said objection under Section 10(4) of the Patents Act, 1970.

Objection 4: CLARITY AND CONCISENESS:

1. The subject matter of claims consists of numerous numbers of embodiments. In order for a method claim to be clearly defined all essential components, all process steps with all conditions (such as Temperature, Pressure etc) and distinguish features with prior art should be given in main method claim (under section 10(4) of Indian Patent Act 1970).

2. Recitation "further comprising" used in dependent claims is vague and unclear and makes the scope of the claims indefinite for which protection is sought

Submission:

With regards to point (1), the Applicant respectfully submits the claim 1 includes all the essential components and further the other components have been claimed in the dependent claims as well. Further, the Applicant believes that incorporating all the suggested components in claim 1 would render the claim more difficult to understand and make the scope of claim 1 narrow. Particularly, including specific conditions such as temperature, pressure, or other operational parameters in the main method claim would unnecessarily narrow the scope of the invention. The method is intended to be broadly applicable across a range of conditions and embodiments, and specifying these conditions could limit its coverage to a particular set of scenarios, thus undermining the breadth of the claim. Including such parameters may exclude valid embodiments that fall outside the specified range, which would not reflect the full scope of the inventive concept. The invention is designed to operate under varying conditions, and the claim should allow for this flexibility to maintain broad protection. Furthermore, the key inventive features that distinguish the method from the prior art are adequately defined in the main claim. The claim is sufficiently clear and concise in compliance with Section 10(4) of the Indian Patent Act, focusing on the essential elements of the invention without unduly restricting its application. Therefore, the Applicant requests the Controller to waive the said objection.

With regards to point (2), the Applicant respectfully submits that pending claims 2 and 13 have been amended by deleting the term further to impart clarity, as suggested by the Controller. Therefore, the Applicant requests the Controller to waive the said objection.

Objection 5: OTHER REQUIREMENTS:

(I) In case the applicant decides to amend the claims subsequent to this report, the same shall be drafted to include the technical advancement over the prior art cited in FER as required u/s 2(1) (j) of the Patent’s Act. Please indicate in the response communication the support for such amendments claims in the original specification, as required u/s 10(4) of the Act. Care shall be taken that requirement section 59 (1) of the Act is also met. Please provide an additional copy of marked up amendments (highlighting the amendments) wherever applicable.

Submission:

The Applicant understands that any amendments must comply with Section 59 of the Patents Act. Therefore, detailed marked copies indicating the changes are submitted along with this response, ensuring that the amendments fall within the permissible scope of the original disclosure.

FORMAL REQUIREMENTS:

Format of Drawings

Application number and applicant name shall be stated at the left-hand side top corner of the drawing sheets. Number of sheets and sheet number shall be stated at the right-hand side top corner of each of the drawing sheets. Name and Signature of the applicant or his agent shall be bear in the right-hand bottom corner of each of the drawing sheets as per Rule 15 (6) of the Patents Rules 2003.

Submission:

With respect to the objection, Applicant herewith submits updated drawings in accordance with Rule 15 of The Patent Rules 2003. The Controller is respectfully requested to take the same on record and withdraw the present objection.

Other Deficiencies

1. Form-1 should be updated and filed in prescribed manner along with all requirements and columns.
2. Form-5 and Form-3 shall refill with application number as prescribed in the Second Schedule of Patent Rules 2003.

Submission:

With respect to the objection raised in point (1), the Applicant submits updates Form 1 in prescribed manner along with all requirements and columns.

With respect to the objection raised in point (2), the Applicant submits updated Form 3 and Form 5, refilled with application number as prescribed in the Second Schedule of Patent Rules 2003.

The Controller is requested to take the same on record and withdraw the present objection.

In view of the above submissions, the Applicant believes that the entire objections have been met and requests the Learned Controller to allow the Application to proceed for grant. In case you require any clarifications or documents, we would be pleased to provide the same on behalf of the applicant.

Any communication in connection with the above applications may be sent to us directly as the Agent for the applicants. The Applicant respectfully states that any decision adverse to the Applicant in this regard should not be taken without giving the Applicant or their representative a personal hearing on this issue.

We thank you in advance for your cooperation in this regard.

Yours Sincerely,

Bikash Lohia

Bikash Lohia
IN/PA – 1714
Agent for the Applicant
Email: paralegal@arcticinvent.com

Enclosures: -

1. *Clean copy of Claims*
2. *Marked-up copy of Claims*
3. *Updated drawings*
4. *Updated Form-1*
5. *Updated Form-3 and Form-5*

We claim:

1. A method (**100)** for fabrication of a flexible hydrogen detection sensor, comprising:

preparing a polyimide-substrate assembly;

pre-treating the polyimide-substrate assembly with an alkaline solution;

creating an aluminium-polyimide assembly by affixing an aluminium tape (**204B**) to the pre-treated polyimide-substrate assembly;

preparing a precursor solution comprising palladium and platinum compounds;

applying the precursor solution to the aluminium-polyimide assembly (**200B**), allowing the precursor solution to contact the aluminium tape (**204B**);

allowing a reaction between the precursor solution and the aluminium tape (**204B**) to proceed for a first predetermined time period;

removing the precursor solution and separating the aluminium tape (**204B**) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly; and

performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period, wherein the electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and wherein the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration.

2. The method (**100)** as claimed in claim 1, comprising washing the electrically conductive metal nanoparticle deposit with deionized water after removing the precursor solution and before performing the post-treatment step.

3. The method (**100)** as claimed in claim 1, wherein the alkaline solution is a potassium hydroxide solution.

4. The method (**100)** as claimed in claim 1, wherein the first predetermined time period is between 60 to **1200** seconds.

5. The method (**100)** as claimed in claim 1, wherein the second predetermined time period is 10 to **1000** seconds.

6. The method (**100)** as claimed in claim 1, wherein the preparing the polyimide-substrate assembly comprises adhering a polyimide tape (**202B**) to a polyester sheet (**206B**).

7. The method (**100)** as claimed in claim 1, wherein the precursor solution comprises 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate.

8. The method (**100)** as claimed in claim 1, further comprising applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection.

9. The method (**100**) as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is placed in an upright orientation with an aluminium side of the aluminium tape (**204B**) facing downward during the application of the precursor solution.

10. The method (**100**) as claimed in claim 9, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: creating a container-frame (**402B**) around the aluminium tape on the polyimide-substrate assembly; filling the container-frame (**402B**) with the precursor solution; and allowing the precursor solution to react with the aluminium tape in the upright orientation.

11. The method (**100**) as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is alternatively placed in an inverted orientation with an

aluminium side of the aluminium tape (**204B**) facing upward during the application of the precursor solution.

12. The method **(100)** as claimed in claim 11, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: securing the aluminium-polyimide assembly (**200B**) in an inverted orientation with the aluminium side of the aluminium tape (**204B**) facing upward; creating the clearance **(304)** between the aluminium tape and the supporting surface; applying the precursor solution to fill the clearance **(304)**; and allowing the precursor solution to react with the aluminium tape in the inverted orientation.

13. The method **(100)** as claimed in claim 1, comprising attaching electrical contacts to the electrically conductive metal nanoparticle deposit for measuring the change in electrical resistance.

14. The method **(100)** as claimed in claim 1, wherein the concentration of the precursor solution used in the post-treatment step is the same as the concentration used when initially applying the precursor solution to the aluminium-polyimide assembly (**200B**).

15. The method **(100)** as claimed in claim 1, wherein the volume of precursor solution applied is proportional to the length of the aluminium tape used in the aluminium-polyimide assembly (**200B**).

Dated this 05th day of September 2024

Bikash Lohia

Bikash Lohia

IN/PA – 1714

Agent for the Applicant

We claim:

1. A method **(100)** for fabrication of a flexible hydrogen detection sensor, comprising:

preparing a polyimide-substrate assembly;

pre-treating the polyimide-substrate assembly with an alkaline solution;

creating an aluminium-polyimide assembly by affixing an aluminium tape (**204B**) to the pre-treated polyimide-substrate assembly;

preparing a precursor solution comprising palladium and platinum compounds;

applying the precursor solution to the aluminium-polyimide assembly (**200B**), allowing the precursor solution to contact the aluminium tape (**204B**);

allowing a reaction between the precursor solution and the aluminium tape (**204B**) to proceed for a first predetermined time period;

removing the precursor solution and separating the aluminium tape (**204B**) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly; and

performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period, wherein the electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and wherein the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration.

2. The method **(100)** as claimed in claim 1, ~~further~~ comprising washing the electrically conductive metal nanoparticle deposit with deionized water after removing the precursor solution and before performing the post-treatment step.

3. The method (**100)** as claimed in claim 1, wherein the alkaline solution is a potassium hydroxide solution.

4. The method (**100)** as claimed in claim 1, wherein the first predetermined time period is between 60 to **1200** seconds.

5. The method (**100)** as claimed in claim 1, wherein the second predetermined time period is 10 to **1000** seconds.

6. The method (**100)** as claimed in claim 1, wherein the preparing the polyimide-substrate assembly comprises adhering a polyimide tape (**202B**) to a polyester sheet (**206B**).

7. The method (**100)** as claimed in claim 1, wherein the precursor solution comprises 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate.

8. The method (**100)** as claimed in claim 1, further comprising applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection.

9. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is placed in an upright orientation with an aluminium side of the aluminium tape (**204B**) facing downward during the application of the precursor solution.

10. The method (**100)** as claimed in claim 9, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: creating a container-frame (**402B**) around the aluminium tape on the polyimide-substrate assembly; filling the container-frame (**402B**) with the precursor solution; and allowing the precursor solution to react with the aluminium tape in the upright orientation.

11. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is alternatively placed in an inverted orientation with an

aluminium side of the aluminium tape (**204B**) facing upward during the application of the precursor solution.

12. The method (**100)** as claimed in claim 11, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: securing the aluminium-polyimide assembly (**200B**) in an inverted orientation with the aluminium side of the aluminium tape (**204B**) facing upward; creating the clearance (**304)** between the aluminium tape and the supporting surface; applying the precursor solution to fill the clearance (**304)**; and allowing the precursor solution to react with the aluminium tape in the inverted orientation.

13. The method (**100)** as claimed in claim 1, ~~further~~ comprising attaching electrical contacts to the electrically conductive metal nanoparticle deposit for measuring the change in electrical resistance.

14. The method (**100)** as claimed in claim 1, wherein the concentration of the precursor solution used in the post-treatment step is the same as the concentration used when initially applying the precursor solution to the aluminium-polyimide assembly (**200B**).

15. The method (**100)** as claimed in claim 1, wherein the volume of precursor solution applied is proportional to the length of the aluminium tape used in the aluminium-polyimide assembly (**200B**).

Dated this 05th day of September 2025

Bikash Lohia

Bikash Lohia

IN/PA – 1714

Agent for the Applicant

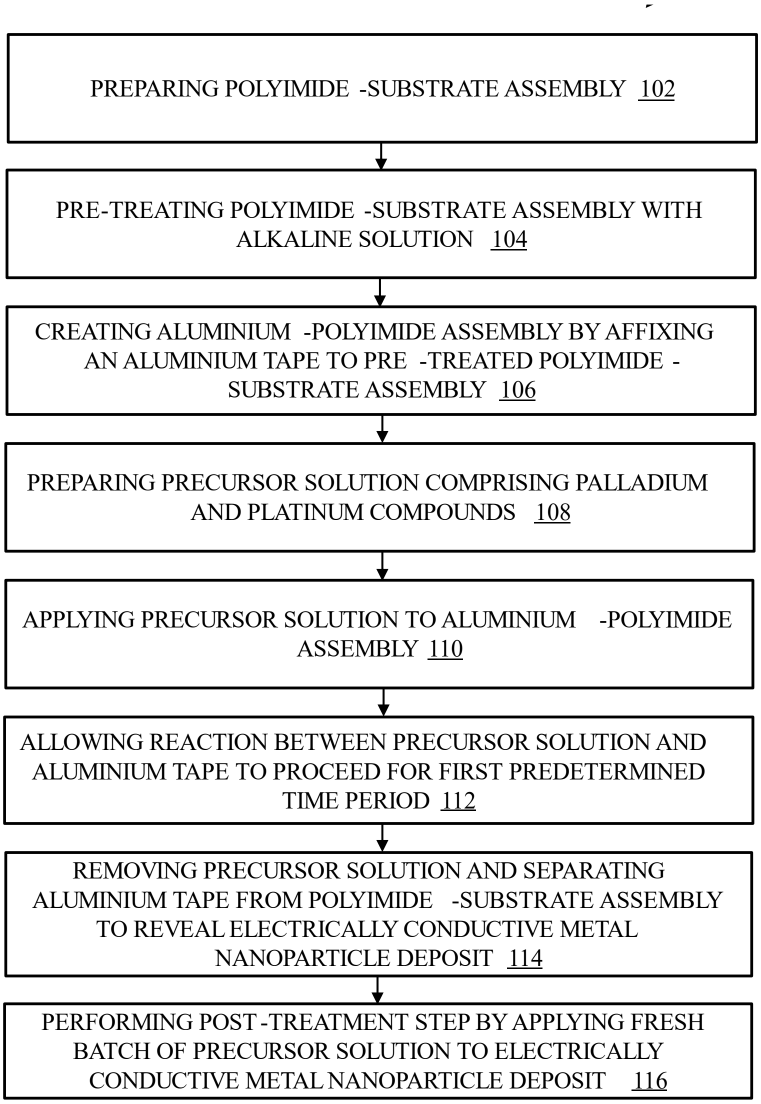

FIG. 1

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

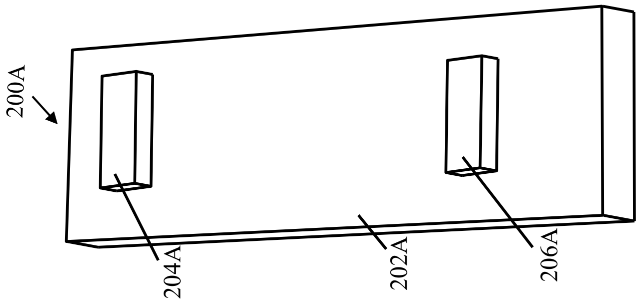

FIG. 2A

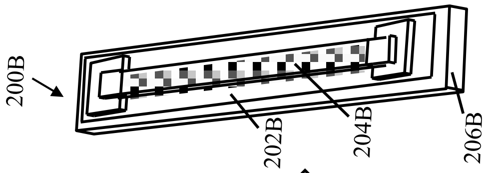

FIG. 2B

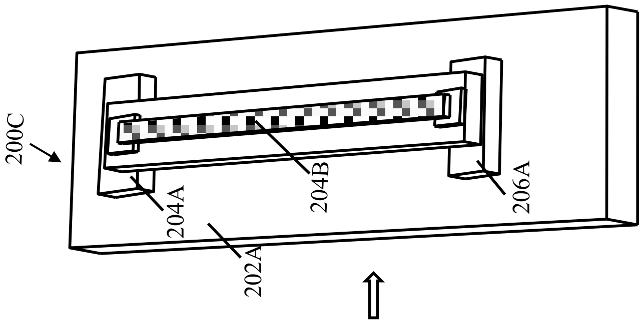

FIG. 2C

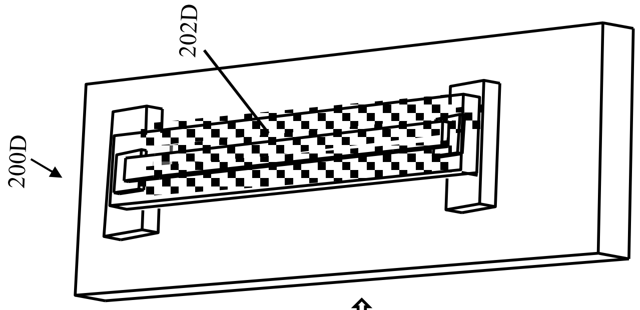

FIG. 2D

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

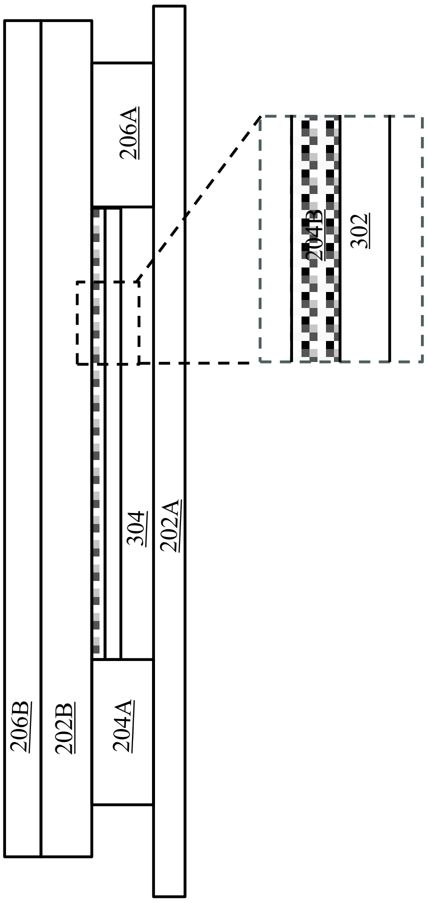

FIG. 3

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

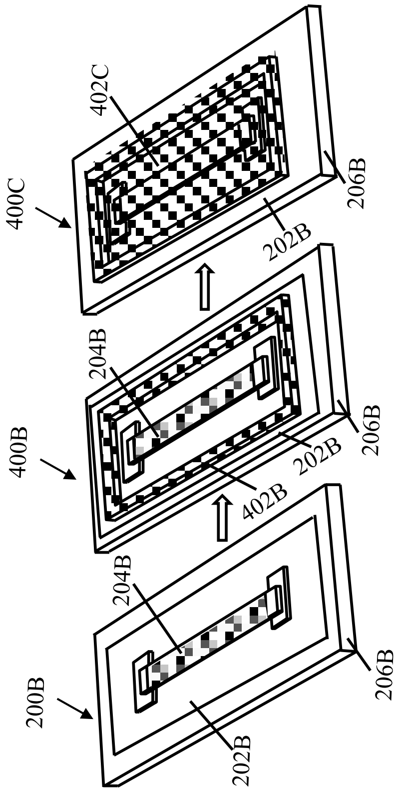

FIG. 4C

FIG. 4B

FIG. 4A

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

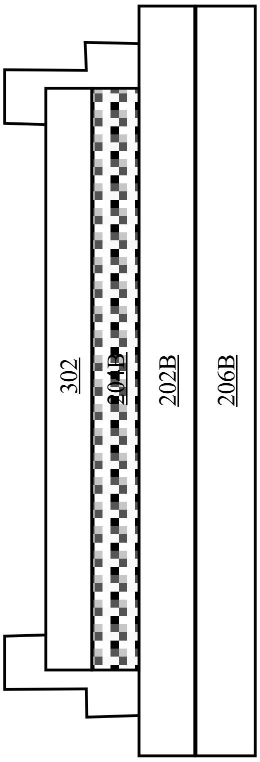

FIG. 5

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

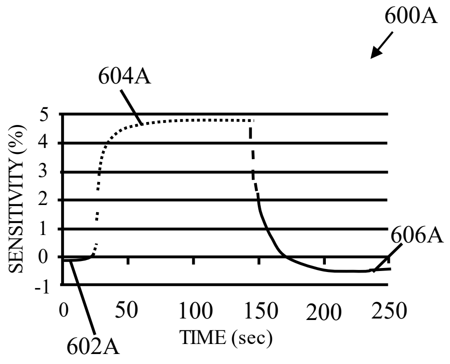

FIG. 6A

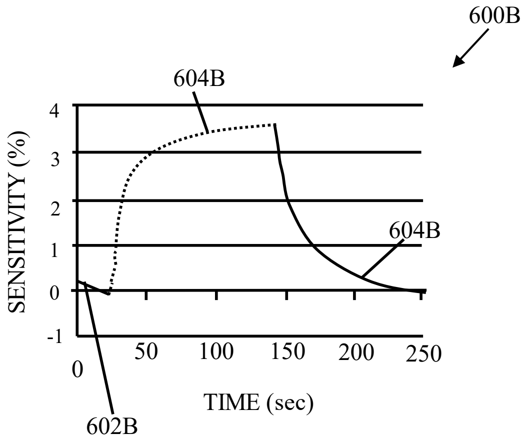

FIG. 6B

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

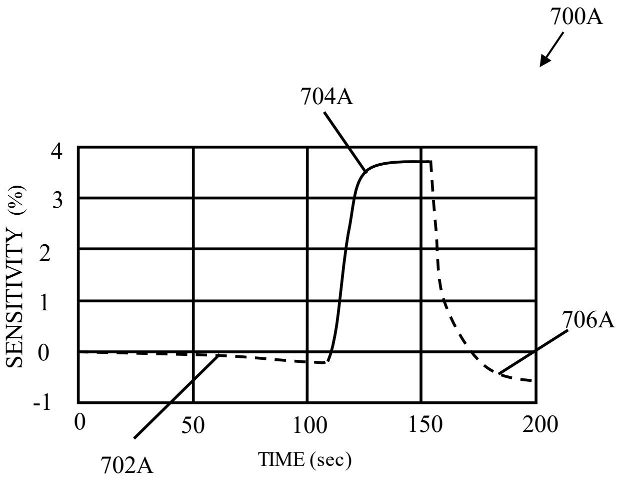

FIG. 7A

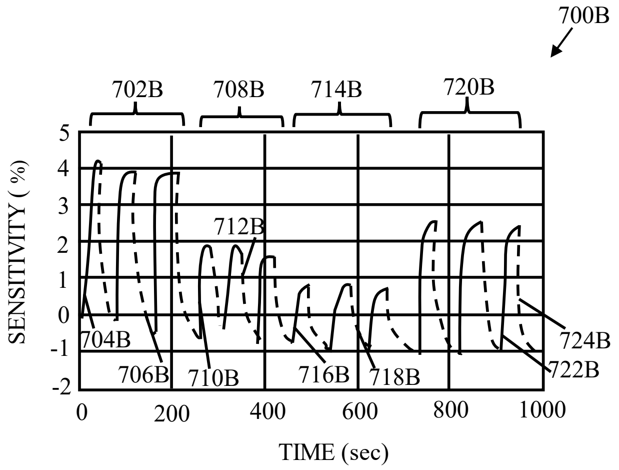

FIG. 7B

Dated this on 05th day of September 2024

Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

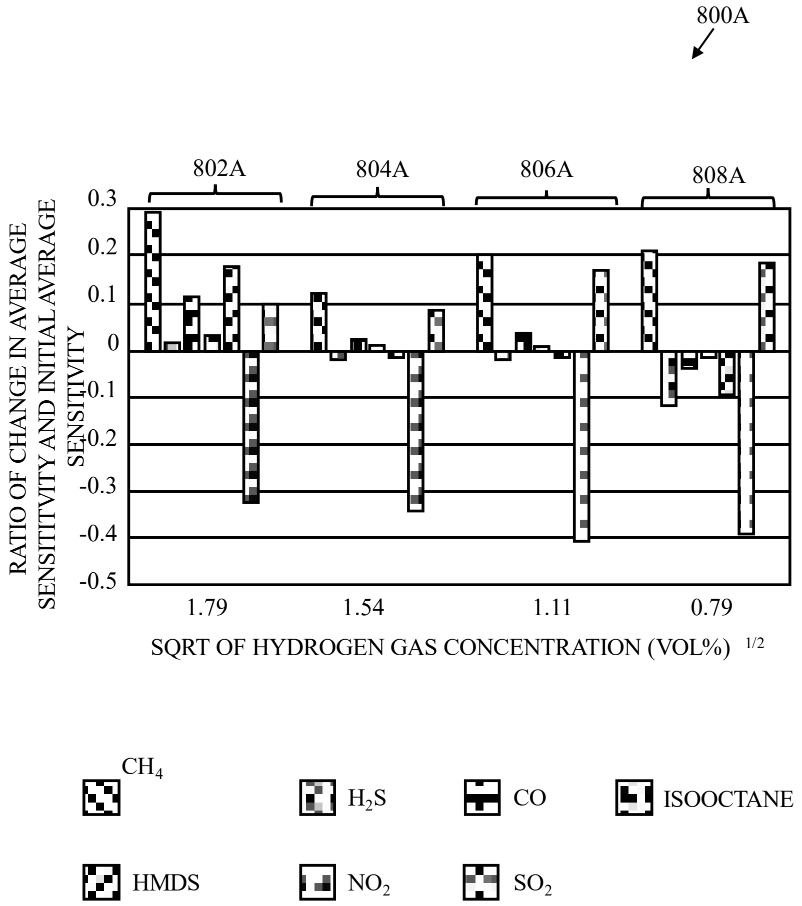

FIG. 8A

Dated this on 05th day of September 2024

Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

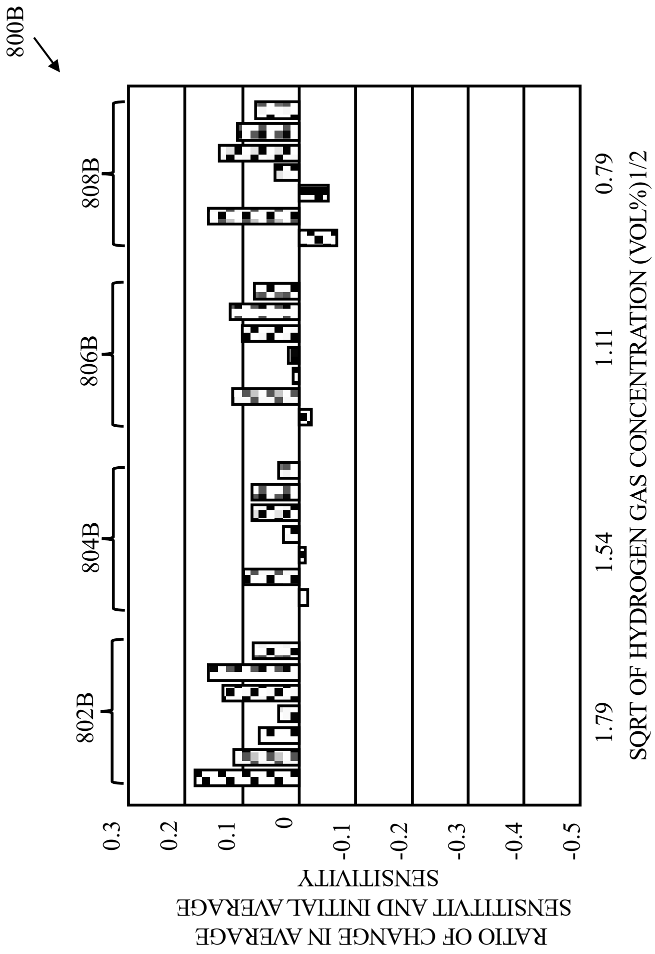

FIG. 8B

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

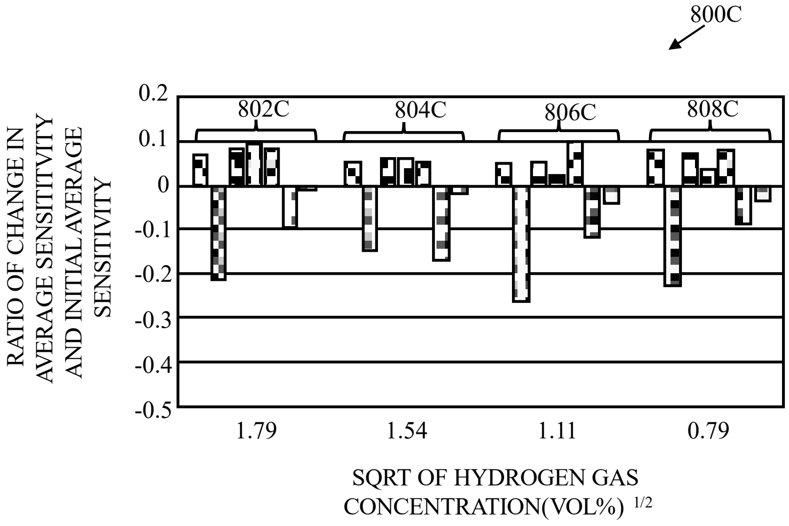

FIG. 8C

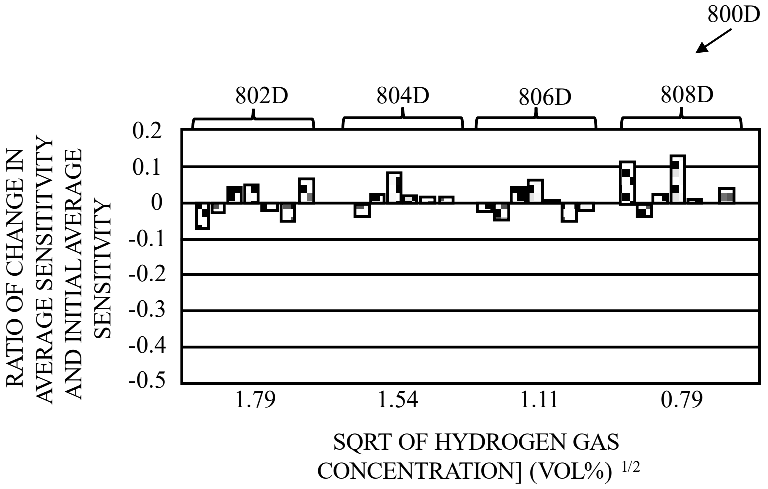

FIG. 8D

Dated this on 05th day of September 2024

Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

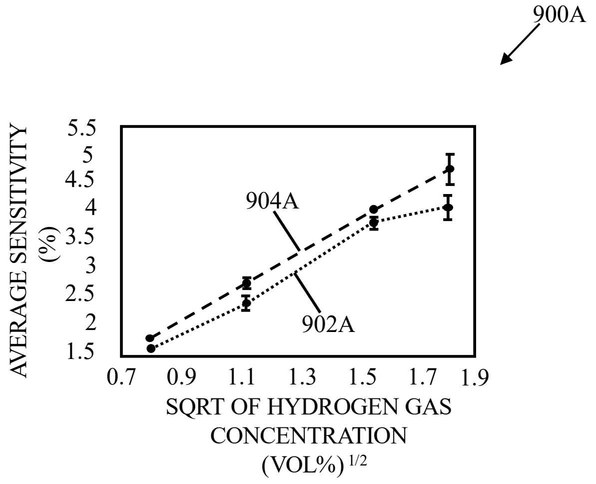

FIG. 9A

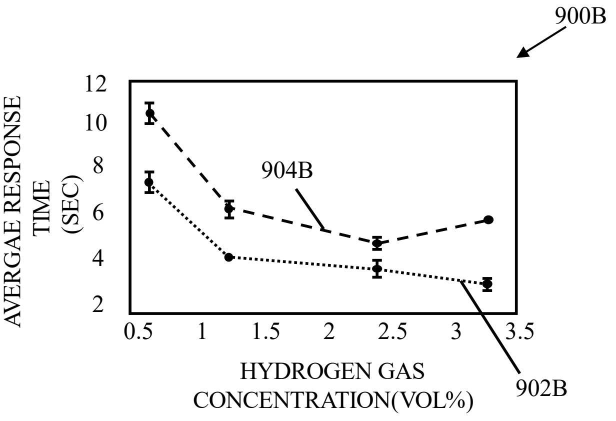

FIG. 9B

Dated this on 05th day of September 2024

Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

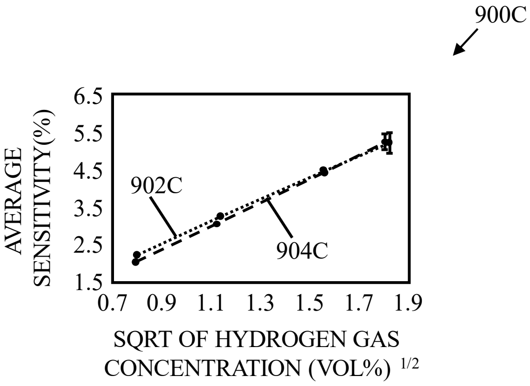

FIG. 9C

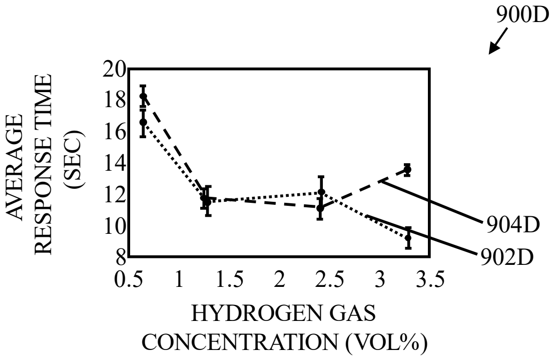

FIG. 9D

Dated this on 05th day of September 2024

Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

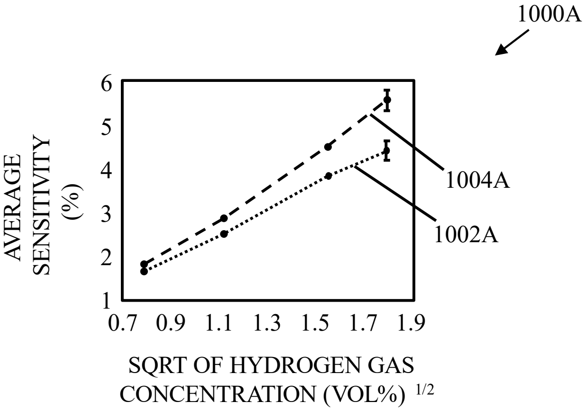

FIG. 10A

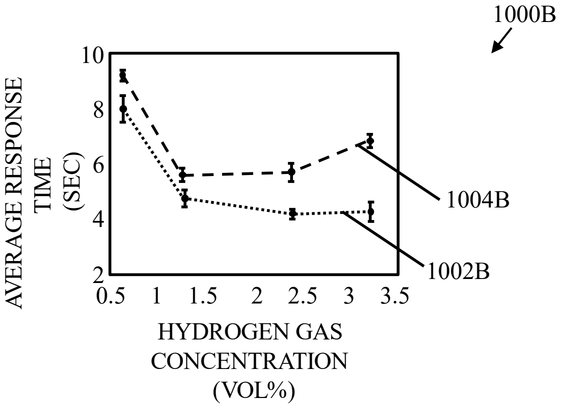

FIG. 10B

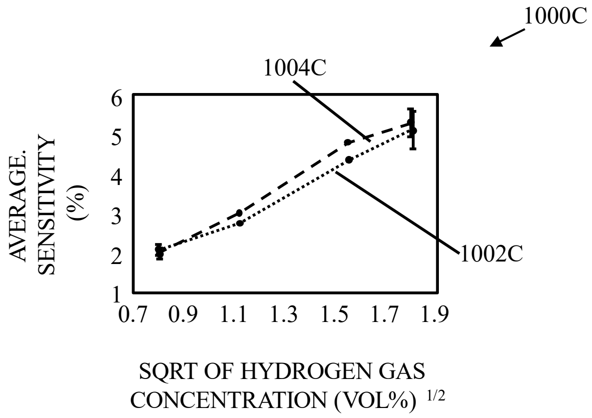

FIG. 10C

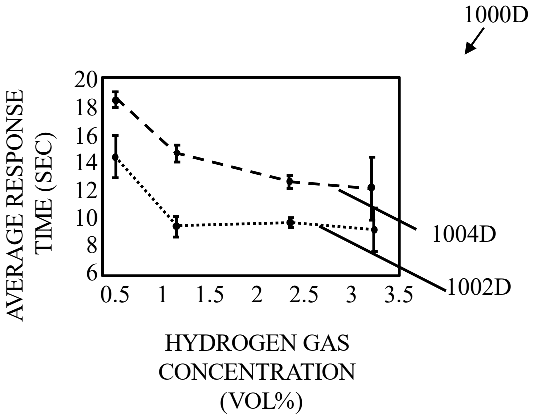

FIG. 10D

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

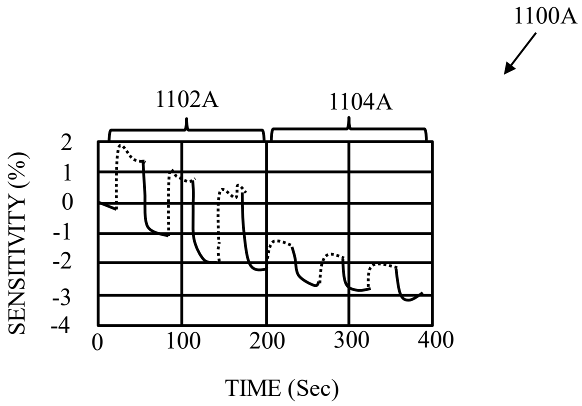

FIG. 11A

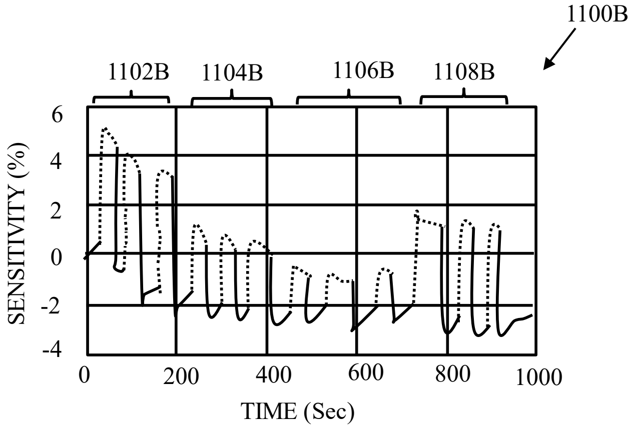

FIG. 11B

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

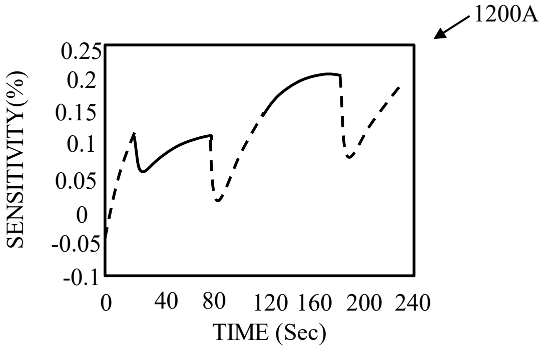

FIG. 12A

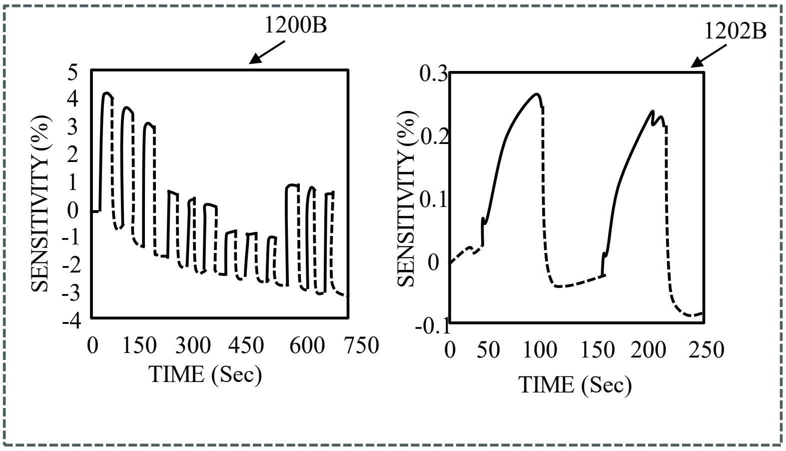

FIG. 12B

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

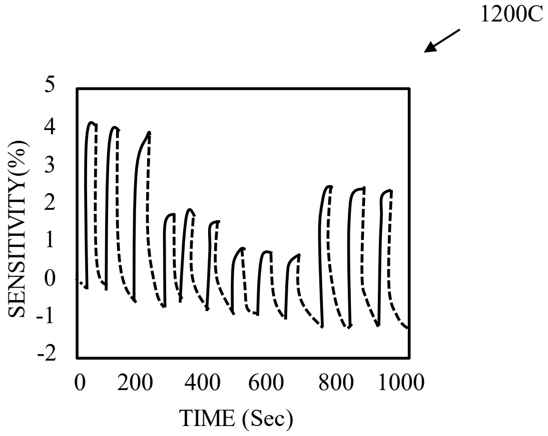

FIG. 12C

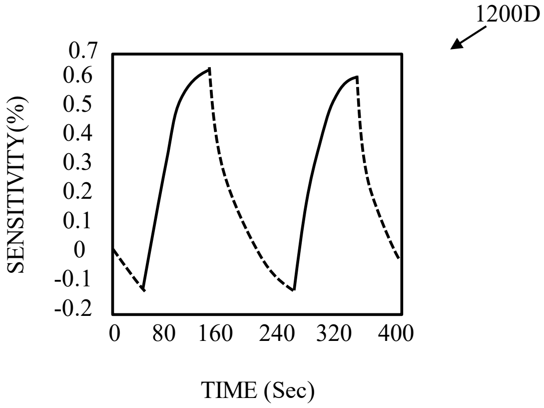

FIG. 12D

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Bikash Lohia

Bikash Lohia

IN/PA - 1714

Agent for the Applicant

FORM 1 THE PATENTS ACT 1970 (39 of 1970) and THE PATENTS RULES, 2003 **APPLICATION FOR GRANT OF PATENT** (See section 7, 54 and 135 and sub-rule (1) of rule 20)	**(FOR OFFICE USE ONLY)**

	Application No.	
	Filing date:	
	Amount of Fee paid:	
	CBR No:	
	Signature:	
1. APPLICANT'S REFERENCE / IDENTIFICATION NO. (AS ALLOTTED BY OFFICE)		

2. TYPE OF APPLICATION [Please tick (√) at the appropriate category]

Ordinary (√)		Convention ( )		PCT-NP ( )		PPH ( )
Divisional ( )	Patent of Addition ( )	Divisional ( )	Patent of Addition ( )	Divisional ( )	Patent of Addition ( )	

3A. APPLICANT(S)

Name in Full	Nationality	Country of Residence	Address of the Applicant
Indian Institute of Science	India	India	Sir C V Raman Road, Bangalore, 560012, Karnataka, India

3B. CATEGORY OF APPLICANT [Please tick (√) at the appropriate category]

Natural Person ( )	Other than Natural Person			Educational Institution (√)
	Small Entity ( )	Startup ( )	Others ( )	

4. INVENTOR(S) [Please tick (√) at the appropriate category]

Are all the inventor(s) same as the applicant(s) named above?	Yes ( )	No (√)

If "No", furnish the details of the inventor(s)

Name in Full	Nationality	Country of Residence	Address of the Applicant
Prof. S. Venugopal	India	India	Indian Institute of Science, Sir C V Raman Road, Bangalore,

			560012, Karnataka, India
Abhishek Ranade	India	India	Indian Institute of Science, Sir C V Raman Road, Bangalore, 560012, Karnataka, India

5. TITLE OF THE INVENTION

METHOD FOR FABRICATION OF FLEXIBLE HYDROGEN DETECTION SENSOR

6. AUTHORISED REGISTERED PATENT AGENT(S)	IN/PA No.	**IN/PA –1714**
	Name	**Bikash Lohia**
	Mobile No.	**+91-9628235468**
7. ADDRESS FOR SERVICE OF APPLICANT IN INDIA	Name	**Bikash Lohia**
	Postal Address	**C block Sector 2, C-44 First Floor, Noida, Uttar Pradesh 201301, India**
	Telephone No.	
	Mobile No.	**+91-9628235468**
	Fax No.	
	E-mail ID	**paralegal@arcticinvent.com**

~~8. IN CASE OF APPLICATION CLAIMING PRIORITY OF APPLICATION FILED IN CONVENTION COUNTRY, PARTICULARS OF CONVENTION APPLICATION~~

Country	Application Number	Filing date	Name of the Applicant	Title of the Invention	IPC (as classified in the convention country)

~~9. IN CASE OF PCT NATIONAL PHASE APPLICATION, PARTICULARS OF INTERNATIONAL APPLICATION FILED UNDER PATENT CO-OPERATION TREATY (PCT)~~

International application number	International filing date

~~10. IN CASE OF DIVISIONAL APPLICATION FILED UNDER SECTION 16, PARTICULARS OF ORIGINAL (FIRST) APPLICATION~~

Original (first) application No.	Date of filing of original (first) application

~~11. IN CASE OF PATENT OF ADDITION FILED UNDER SECTION 54, PARTICULARS OF MAIN APPLICATION OR PATENT~~

Main application/patent No.	Date of filing of main application

12. DECLARATIONS

(i) Declaration by the inventor(s)

(In case the applicant is an assignee: the inventor(s) may sign herein below or the applicant may upload the assignment or enclose the assignment with this application for patent or send the assignment by post/electronic transmission duly authenticated within the prescribed period).

I/We, the above named inventor(s) is/are the true & first inventor(s) for this Invention and declare that the applicant(s) herein is/are my/our assignee or legal representative.

a. Signature :
b. Name : Prof. S. Venugopal
c. Date : 05-09-2024

a. Signature : Abhishek
b. Name : Abhishek Ranade
c. Date : 05-09-2024

~~(ii) Declaration by the applicant(s) in the convention country~~

(In case the applicant in India is different than the applicant in the convention country: the applicant in the convention country may sign herein below or applicant in India may upload the assignment from the applicant in the convention country or enclose the said assignment with this application for patent or send the assignment by post/electronic transmission duly authenticated within the prescribed period)

I/We, the applicant(s) in the convention country declare that the applicant(s) herein is/are my/our assignee or legal representative.

(iii) Declaration by the applicant(s)

I/We the applicant(s) hereby declare(s) that: -

- I am/ We are in possession of the above-mentioned invention.
- The ~~Provisional/~~Complete specification relating to the invention is filed with this application.
- There is no lawful ground of objection(s) to the grant of the Patent to me/us.
- I am/we are the true & first inventor(s).
- I am/we are the assignee or legal representative of true & first inventor(s).

13. FOLLOWING ARE THE ATTACHMENTS WITH THE APPLICATION

(a) Form 2

Item	**Details**	**Fee**	**Remarks**
Complete~~/Provisional~~ specification	No. of pages = 42	**5280**	
No. of Claim(s)	No. of claims = 15 and No. of pages = 3	**1600**	
Abstract	No. of pages = 1		

No. of Drawing(s)	No. of drawings = 32 and No. of pages = 17		

In case of a complete specification, if the applicant desires to adopt the drawings filed with his provisional specification as the drawings or part of the drawings for the complete specification under rule 13(4), the number of such pages filed with the provisional specification are required to be mentioned here.

(b) Complete~~/Provisional~~ specification ~~(in conformation with the international application)/as amended before the International Preliminary Examination Authority (IPEA), as applicable (2 copies).~~

(c) ~~Sequence listing in electronic form~~

(d) Drawings ~~(in conformation with the international application)/as amended before the International Preliminary Examination Authority (IPEA), as applicable (2 copies).~~

(e) ~~Priority document(s) or a request to retrieve the priority document(s) from DAS (Digital Access Service) if the applicant had already requested the office of first filing to make the priority document(s) available to DAS.~~

(f) ~~Translation of priority document/Specification/International Search Report/International Preliminary Report on Patentability.~~

(g) Statement and Undertaking on Form 3

(h) Declaration of Inventorship on Form 5

(i) Power of Authority

(j)……………………………………………………………………………………………………..

Total fee INR 1600 + 5280 + 1600 = INR 8480.

We hereby declare that to the best of our knowledge, information and belief the fact and matters slated herein are correct and We request that a patent may be granted to us for the said invention.

Dated this 05th day of September 2024

Bikash Lohia

Bikash Lohia

(IN/PA –1714)

Agent for the applicant

To

The Controller of Patents

The Patent Office, At Chennai

FORM – 3
THE PATENTS ACT, 1970
(39 of 1970)
&
THE PATENTS RULES, 2003
STATEMENT AND UNDERTAKING UNDER SECTION 8
(See Section 8; sub rule (2) and (3) of Rule 12)

We **Indian Institute of Science** an **Indian** organization of **Sir C V Raman Road, Bangalore, 560012, Karnataka, India, hereby authorize,**

(i) that we have made this application No. **202441067213** dated **05 September 2024** for the same/substantially same invention, application(s) for patent in the other countries, the particulars of which are given below:

Name of the Country	Date of Application	Application No.	Status of Application	Date of Publication	Publication no	Patent No.	Grant Date
NA	NA	NA	NA	NA	NA	NA	NA

(ii) that the rights in the application(s) has/have been assigned to **no one**.

(iii) that I/We undertake that upto the date of grant of the patent by the Controller, I/We would keep him informed in writing regarding the details of corresponding applications for patents filed outside India in accordance with the provisions contained in section 8 and rule 12.

Dated this 31st day of March 2025

Bikash Lohia

Bikash Lohia
(IN/PA –1714)
Agent for the applicant

To
The Controller of Patents
The Patent Office, At Chennai

FORM 5
THE PATENTS ACT, 1970
(39 of 1970)
&
The Patents Rules, 2003
DECLARATION AS TO INVENTORSHIP
[See section 10(6) and rule 13(6)]

1. NAME OF APPLICANT(S):

We **Indian Institute of Science** an **Indian** organization of **Sir C V Raman Road, Bangalore, 560012, Karnataka, India,** hereby authorize,

that the true and first inventor(s) of the invention disclosed in the complete specification filed in pursuance of my/our application numbered **202441067213** dated **05 September 2024** is/are.

2. INVENTOR(S)

Name	Nationality	Address
Prof. S. Venugopal	India	Indian Institute of Science, Sir C V Raman Road Bengaluru, Bangalore, 560012, Karnataka, India
Abhishek Ranade	India	Indian Institute of Science, Sir C V Raman Road Bengaluru, Bangalore, 560012, Karnataka, India

Dated this 05th day of September 2024

Bikash Lohia

Bikash Lohia
(IN/PA –1714)
Agent for the applicant

To

The Controller of Patents

The Patent Office, At Chennai

Dated: September 08, 2025

To,
The Controller of Patents
The Patent Office
I.P.O. Building,
G.S.T. Road, Guindy,
Chennai, 600032

RE: **WRITTEN SUBMISSION AFTER HEARING**

Kind Attn: Manoj Kumar
(Assistant Controller of Patents & Designs)

Regarding Indian Patent Application No.: **202441067213**
Filing Date: **05th September 2024**
Applicant: **Indian Institute of Science**

Dear Sir,

With reference to your hearing notice dated July 23, 2025, and hearing held on August 25, 2025 in the matter of the above identified Application, we have the honor to submit herewith our reply in this regard.

In wake of the issuance of the Hearing Notice, the claims have been amended to overcome the objections raised by the learned Controller. Thus, the amended claims set is submitted herewith for further consideration by the learned Controller.

In the Applicant's response, *"Pending claims set"* pertains to the Applicant's claims set presently on file, and "*Amended claims set*" pertains to the proposed claims set submitted herewith.

Our detailed response to the objections is as follows:

AMENDMENTS TO THE CLAIMS

The Applicant respectfully submits that the claims have been amended to overcome the objections raised by the learned Controller. Following is the listing of claims amendments based on the discussion held in the hearing:

Pending claims set 1-15 have been replaced by the amended claims set 1-8. Amended claims set 1-8 are pending hereinafter.

In particular, the key amendments include incorporating and narrowing down the specific processing parameters of the first predetermined time period (60-1200 seconds), second predetermined time period (10-1000 seconds), and precursor solution composition (35.4 %v/v palladium chloride and 2.1 %v/v potassium tetrachloroplatinate) from the presently pending dependent claims 2-8 into the presently pending independent claim 1 as suggested by the controller. Furthermore, as suggested by the controller to narrow down the broad scope, we have specified that the alkaline solution is potassium hydroxide solution (presently pending claim 3), the polyimide-substrate assembly preparation comprises adhering a polyimide tape to a polyester sheet (presently pending claim 6), and the method includes washing the electrically conductive metal nanoparticle deposit with deionized water (presently pending claim 2) and applying a molecular sieve coating for enhanced selectivity (presently pending claim 8).

Moreover, the presently pending claims 2-8 have been incorporated into the amended independent claim 1 to form a comprehensive method that clearly defines the specific fabrication parameters and processing steps as suggested by the Controller to significantly narrow the scope of the invention while maintaining the required technical features of the present invention.

Additionally, the Applicant submits that no new subject matter is added that extends beyond the content of the application as originally filed and amendments made to the claims are in conformity with Section 57/59 of The Patents Act, as amended.

Thus, claims 1-8 of the Applicant's amended claims set are submitted herewith for further consideration by the learned Controller.

Fresh pages of amended claims set along with marked-up copy are attached herewith.

PART II - DETAILED TECHNICAL REPORT

REPLY TO OBJECTIONS

Clarity and Conciseness

1. The subject matter of claims consists of numerous numbers of embodiments. In order for a method claim to be clearly defined all essential components, all process steps with all conditions (such as Temperature, Pressure etc) and distinguish features with prior art should be given in main method claim (under section 10(4) of Indian Patent Act 1970).
2. Recitation "further comprising" used in dependent claims is vague and unclear and makes the scope of the claims indefinite for which protection is sought.

Our Submission

With regard to part (1) the objection, the Applicant respectfully submits that the presently pending claims have been amended accordingly. Therefore, the Applicant requests the Ld. Controller to kindly waive off the objection.

With regard to part (2) of the objection, the Applicant respectfully submits that the term “further comprising” has been deleted from the amended claims set. Therefore, the Applicant requests the Ld. Controller to waive off the objection.

Invention u/s 2(1) (ja)

1. Claims 1-15 lack inventive step under section 2 (1) (ja) of Indian patent act 1970 in view of cited documents D1-D3.

As per the Indian Patent Act, an invention is considered to involve an inventive step if it features:

"a technical advance as compared to the existing knowledge or having economic significance or both, and that makes the invention not obvious to a person skilled in the art."

The cited documents clearly show:

Use of polyimide or other flexible substrates is standard in H_2 sensors (D1).

Use of Pd and/or Pt nanoparticles for resistive hydrogen sensing is well-established (D1–D3).

Concepts of solution deposition, post-treatment, and nanoparticle networks are common general knowledge in the art.

The only arguable feature is the use of aluminium tape, which acts as a sacrificial layer or deposition template. However, the use of metal substrates or supports in nanoparticle deposition is known, and its application in the claimed method does not lead to any unforeseen technical effect. Therefore, it is an obvious substitution.

Further, the Applicant in the reply statement has contended that the present invention provides a structured fabrication method resulting in faster response time, higher reliability, improved hydrogen detection accuracy, and ensures scalability and reproducibility suitable for industrial applications requiring consistent and high-performance hydrogen sensing. However, it is respectfully submitted that no experimental data, performance benchmarks, or comparative analysis have been provided in the specification to substantiate these claims. Support on page 9, page 10, page 12, page 14, and page 14 of the specification cannot be substantiated as the experimental evidence. In the absence of empirical evidence, such statements remain unverified and speculative and cannot be relied upon to establish inventive step or technical advancement as required under Section 2(1)(ja) of the Indian Patent Act.

Our Submission

It is well-settled that in determining the differences between the prior art and the claims, the question under consideration is not whether the differences themselves would have been obvious, but whether the claimed invention as a whole would have been obvious.

To this end, a prior art reference must be considered in its entirety, i.e., as a whole, including portions that would lead away from the claimed invention. [Emphasis Added] To establish a prima facie case of obviousness, three basic criteria must be met: (1) there must be some suggestion or motivation to modify the reference or to combine reference teachings; (2) there must be reasonable expectation of success; and (3) **the prior art reference must teach or suggest all the claim limitations.** Thus, Applicant respectfully traverses the objection because the approach disclosed in D1-D3 and approach claimed in the present invention are not only different, but portions of D1-D3 upon which the Ld. Controller relied do not render the claimed invention obvious and in fact teaches away from the claimed invention. The learned Controller contends that the subject matter of presently pending claims 1-15 as claimed in instant application does not constitute an invention under section 2(1) (ja) of the Patents Act, 1970 (as amended) because it does not involve an inventive step in view of following documents:

D1: Fast And Robust Hydrogen Sensors Based on Discontinuous Palladium Films on Polyimide, fabricated on a Wafer Scale Iop Publishing Ltd Nanotechnology
D2: Flexible H2 Sensor Fabricated by Layer-By-Layer Self Assembly of Thin Films of Polypyrrole and Modified In Situ with Pt Nanoparticles
D3: Fabrication Of a Flexible H2 Sensor Based on Pd Nanoparticles Modified Polypyrrole Films

Technical Problem of the Present Invention: Conventional hydrogen detection systems often face significant limitations that hinder the performance of the conventional hydrogen detection systems and usability in industrial environments. Furthermore, the conventional hydrogen detection systems are rigid and lack the required flexibility to conform to non-uniform surfaces, making the hydrogen detection system unsuitable for applications where leaks are likely to occur, such as joints or curved pipelines. Furthermore, conventional hydrogen detection system is complex, resource-intensive, and time-consuming, leading to increased production costs and challenges in large-scale deployment. In addition, the conventional hydrogen detection system requires manual inspection or are single use, limiting the efficiency and increasing maintenance needs. The inability of the hydrogen detection systems to provide reliable, continuous, and easily deployable leak detection contributes to increased safety risks and operational inefficiencies in hydrogen-utilizing industries.

The prior arts, such as D1, D2, and D3, have explored different approaches for hydrogen leak detection sensors. D1 discloses a flexible hydrogen detection film utilizing palladium-based composites integrated onto polymer substrates, focusing primarily on achieving basic flexibility but lacking efficient response time and sensitivity for industrial-grade applications. D2 relates to a hydrogen leak detection tape incorporating metallic nanoparticles on an adhesive base, configured for temporary attachment on pipeline joints, but limited by single-use functionality and reliance on manual inspection for leak identification. D3 describes a stretchable hydrogen detection layer prepared using complex fabrication steps under extreme processing conditions, aiming to enhance conformability, but the high production complexity restricts scalability and cost-effectiveness for widespread deployment. The prior arts primarily address partial aspects of flexibility or adhesion but fail to provide a scalable, fast-responding, and easily manufacturable hydrogen leak detection solution suitable for continuous monitoring in high-risk industrial environments.

The Applicant respectfully submits that the present invention is completely different from the cited documents D1, D2, and D3 in terms of materials employed, structural configuration, fabrication approach, and functional mechanism for hydrogen leak detection. The applicant further submits that the present invention involves substantial technical advancement over the cited documents. To be very precise, the present invention has features of *"preparing a polyimide-substrate assembly by adhering a polyimide tape (202B) to a polyester sheet; pre-treating the polyimide-substrate assembly with an alkaline solution, wherein the alkaline solution is a potassium hydroxide solution; creating an aluminium-polyimide assembly by affixing an aluminium tape (204B) to the pre-treated polyimide-substrate assembly; preparing a precursor solution comprising 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate; applying the precursor solution to the aluminium-polyimide assembly (200B), allowing the precursor solution to contact the aluminium tape (204B); allowing a reaction between the precursor solution and the aluminium tape (204B) to proceed for a first predetermined time period of 60 to 1200 seconds;removing the precursor solution and separating the aluminium tape (204B) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly; washing the electrically conductive metal nanoparticle deposit with deionized water; and performing a post-*

treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period of 10 to 1000 seconds; and applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection; wherein the electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and wherein the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration".

The present invention achieves significant technical advantages over conventional hydrogen detection sensors through an aluminum-templated fabrication method, wherein palladium-platinum nanoparticles are deposited using a novel aluminum tape templating method combined with specific precursor solutions containing palladium chloride (35.4% v/v) and potassium tetrachloroplatinate (2.1% v/v) (Refer Page 10 of the specification), and potassium bromide as primary components. The method incorporates a dual-phase deposition process with initial aluminum-mediated reduction for a first predetermined time period between 240 to 300 seconds (Refer Page 11 of the specification) followed by post-treatment reinforcement for 50 to 70 seconds (Refer Page 13 of the specification) to create highly conductive nanoparticle networks operating at ambient conditions. Moreover, the flexible hydrogen sensor incorporates ZIF-8 molecular sieve coatings that demonstrate 77% blocking efficiency against hydrogen sulfide interference while maintaining consistent Pd:Pt ratios of 95-96% Pd and 4-5% Pt across multiple samples, achieving superior repeatability with electrical resistance variations of only 35-45 Ω compared to conventional approaches requiring elevated temperatures, complex equipment, and extended processing times. The disclosed method enables industrial-scale fabrication of flexible hydrogen detection sensors for safety monitoring in hydrogen storage facilities, fuel cell systems, chemical processing plants, and pipeline leak detection applications.

Further, with regard to the experimental data required by the Ld. Controller, the comparative performance data presented in Table 1 below corresponds to the fabrication process disclosed in the specification (page 5). The data shows that the disclosed hydrogen sensor, fabricated under ambient conditions with a processing time of approximately 6 minutes, demonstrates a response time of t_{90} = 5 seconds, a sensitivity of 2.6%, and an operating detection range of 1000–40,000 ppm on a flexible polyimide substrate (0.8–2cm^2). Compared to conventional sensors listed in Table 1, which require high-temperature treatments and prolonged deposition processes (e.g., Reference [5] with t_{90} = 12 seconds and 155% sensitivity), these results reflect the performance achieved using the method and materials described in the specification.

S. No.	Sensing Element	Fabrication Method	Substrate	Sensor Area (cm^2)	Deposition Time	Fabrication Condition	Sensitivity	Response Time	Range (ppm)	Reference
1	Pd@Pt NWs	Hydrothermal, UV-O treatment	Paper	1 cm^2	>16 hours	Pd NWs: 200 C for 6h	3%	t_{90}~5 s	100–10,000	[1]
2	Pd NPs on SWNTs	CVD, E-beam evaporation	PET	0.25 cm^2	–	900 °C, 1.5 × 10^{-6} torr	130%	$T_{36.8}$~ 1.5 s	30–10,000	[2]
3	Pd NPs@ SWNTs	CVD, E-beam evaporation	PET	0.3 cm^2	> 20 minutes	900 °C	300%	$T_{36.8}$~ 8 s	100–10,000	[3]
4	Pd NPs @ MWCNTs	LbL self-assembly	PET	0.3 cm^2	> 24 hours	850 °C	16.44%	t_{90} ~ 300 s	200–40,000	[4]
5	Epi-MOF-Pd	CVD, Magnetron sputtering	PET	0.25 cm^2	Multiple hours	Pd sputtering-0.8 Pa	155%	t_{90}~12 s	3–10,000	[5]
6	Pd-Pt NPs	Aluminium-added deposition	Polyimide	0.8–2cm^2	6 minutes	Ambient	2.6%	t_{90}~8s $t_{36.8}$~3s	1000–40,000	This work

TABLE 1

Furthermore, FIG. 1 below depicts three samples from the same batch prepared using the aluminium template, demonstrating repeatability of the fabrication process disclosed in the specification (Refer page 5 of the specification). Each sample, approximately 3 cm in length, shows uniform deposition and consistent surface coverage, indicating that the disclosed method reliably produces similar structures across multiple samples under identical processing conditions.

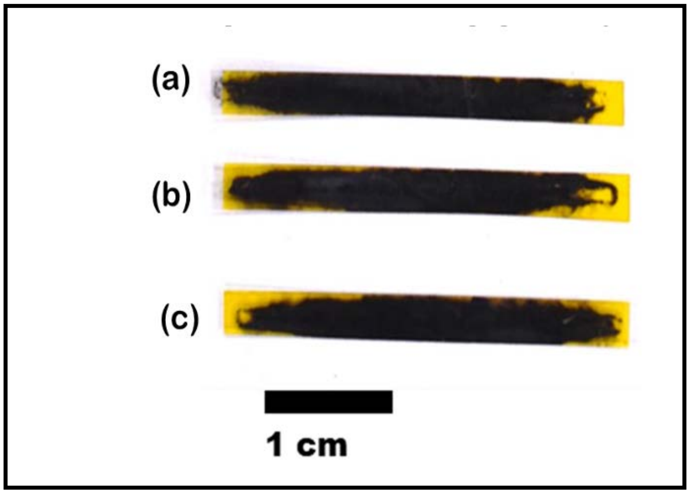


FIG: 1

FIG. 1A below depicts an electron micrograph of a Pd-Pt deposition obtained using the aluminium template approach. The morphology shows uniform surface coverage with interconnected nanoparticle networks, consistent with the intended deposition pattern. The elemental composition measured using Energy Dispersive X-ray Spectroscopy (EDS, a technique that identifies elements based on the characteristic X-rays they emit), confirmed a Pd:Pt ratio close to the expected value. The electrical resistance of comparable samples was measured between 35–45 Ω across a 0.5-inch length, indicating reliable conductivity. The results demonstrate that the disclosed method yields homogeneous nanostructured films with consistent physical and electrical properties across different trials.

FIG. 1B below depicts another electron micrograph of a Pd-Pt deposition prepared from a different sample within the same experimental batch. The deposition morphology closely resembles that observed in FIG. 1A, with similar growth features and surface coverage. EDS analysis again confirmed a Pd:Pt ratio in line with the intended stoichiometry, underscoring the reproducibility of the aluminium template method. The minimal variation between independently prepared samples highlights the robustness of the disclosed method in delivering repeatable structural and compositional outcomes under identical fabrication conditions.

FIG. 1C below depicts an electron micrograph of a Pd-Pt deposition prepared from a third independent sample using the aluminium template approach. The morphology is consistent with those observed in FIG. 1A and FIG. 1B, showing uniform nanostructured growth with dendritic features and surface coverage that are highly reproducible. Elemental composition measured using Energy Dispersive X-ray Spectroscopy (EDS) again confirmed a Pd:Pt ratio close to the intended value, with only minor variation across different regions of the sample. The close agreement in both morphology and composition across three independently prepared samples underscores the high repeatability of the aluminium template method, demonstrating its capability to reliably produce consistent depositions under identical fabrication conditions.

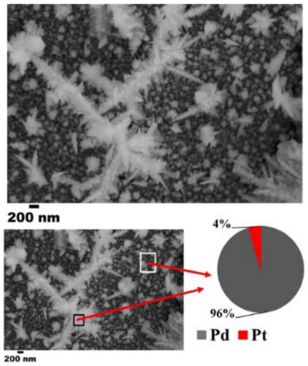


FIG: 1A

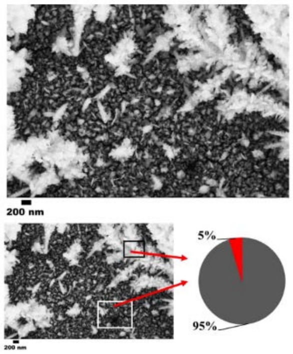


FIG: 1B

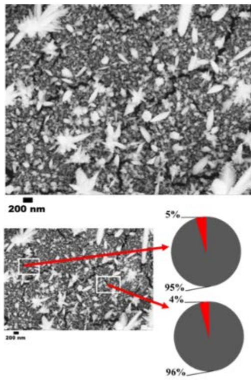


FIG: 1C

FIG. 2 below depicts digital photographs of Pd-Pt samples fabricated using the aluminium template approach, showcasing the scalability of the disclosed method. The figure illustrates samples of different lengths, ranging from approximately 2.5 cm to several centimetres, all exhibiting uniform deposition along the surfaces. The FIG.2 demonstrates that the fabrication process is not constrained by sample size and can be readily extended to larger dimensions without loss of uniformity. Importantly, subsequent hydrogen sensing measurements confirmed that each of these samples, regardless of length, delivered comparable performance. The observations validate the scalability of the aluminium template approach while maintaining consistent functionality across different sized samples.

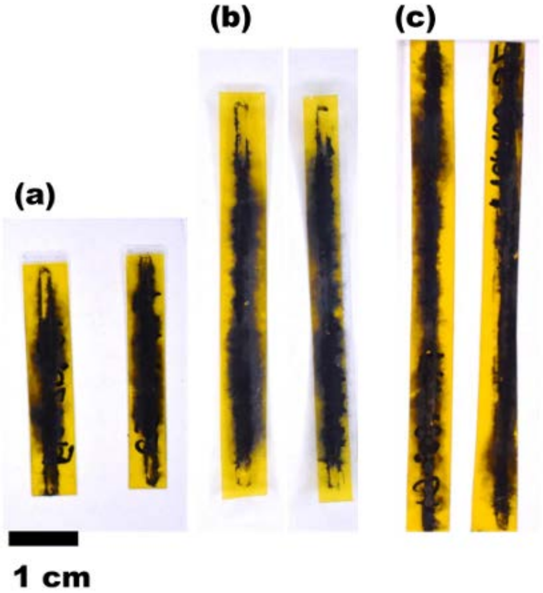


FIG: 2

FIG. 3A below depicts hydrogen sensing responses of Pd-Pt samples fabricated using the aluminium template approach, measured at varying hydrogen concentrations. The plots show that upon exposure to hydrogen (3.27–3.28%), the sensor exhibits a sharp increase in sensitivity, followed by stable signal saturation and clear recovery when hydrogen is removed. Reproducible cyclic responses are observed at multiple concentrations, confirming both sensitivity and repeatability. The experimental observations are in line with the disclosure in the complete specification (refer page 23 of the specification), where the Pd-Pt nanoparticle network formed on the polyimide substrate is described to undergo measurable changes in electrical resistance upon hydrogen exposure. Thus, the results shown in figure 3A substantiate the claimed functionality of the disclosed hydrogen detection sensor by experimentally validating its rapid response, reversibility, and stability under repeated hydrogen cycling.

FIG. 3B below depicts hydrogen sensing responses of Pd-Pt samples fabricated using the aluminium template approach, tested at varying hydrogen concentrations. The plots show that upon exposure to hydrogen (3.27–3.29%), the sensors exhibit a rapid and stable increase in sensitivity, followed by clear recovery once hydrogen is removed. Multiple cyclic exposures at different concentrations (0.63–3.29%) confirm reproducible behaviour and demonstrate consistent performance across independently prepared samples, despite differences in baseline resistance (R_0). These results directly support the disclosure in the complete specification (refer page 23 of the specification), which describes how the Pd-Pt nanoparticle networks exhibit measurable and repeatable resistance changes upon hydrogen exposure. Thus, the data presented in this figure further validates the disclosed sensor’s sensitivity, reversibility, and repeatability under practical hydrogen cycling conditions.

FIG. 3C below depicts hydrogen sensing responses of Pd-Pt samples fabricated using the aluminium template approach, tested under hydrogen concentrations ranging from ~0.63% to 3.27%. The results show a clear and rapid increase in sensitivity upon exposure to hydrogen (3.26–3.27%), followed by stable saturation and distinct recovery when hydrogen was removed. Repeated cyclic exposures further demonstrate reproducibility and stable sensor performance, even across samples exhibiting different baseline resistance (R_0 values). These findings are consistent with the disclosure provided in the complete specification (refer page 23 of the specification), which describes the Pd-Pt nanoparticle network as undergoing measurable resistance changes in response to hydrogen gas. Accordingly, the figure 3C further validates the robustness, repeatability, and reliability of the disclosed hydrogen detection sensor under cyclic operating conditions.

FIG. 3D below presents tabulated data of the hydrogen sensing performance of Pd-Pt samples fabricated using the aluminium template approach. The table summarizes the measured sensitivities and corresponding response times for samples of different geometries (75°, 120°, and 180°) across a range of hydrogen concentrations (0.63–3.28 vol%). The results demonstrate that the sensors consistently exhibit high sensitivity with rapid response times, even at low hydrogen concentrations, with only minor variations between different sample sets. Thus, the data presented in this figure provides a consolidated validation of the experimental results shown in FIGs. 3A–3C, reinforcing the robustness and reliability of the disclosed hydrogen detection sensor.

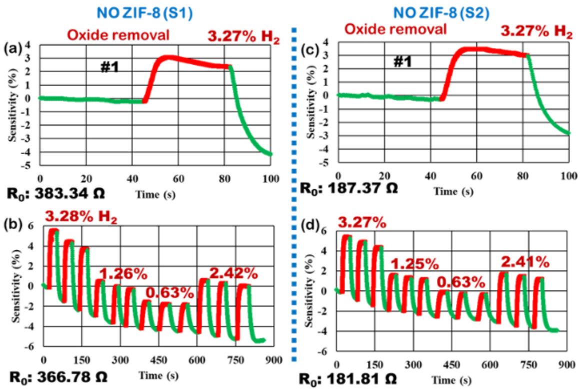


FIG: 3A

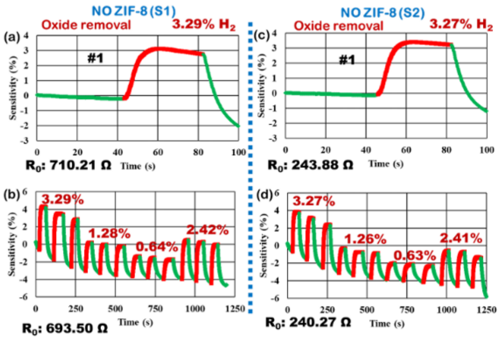


FIG: 3B

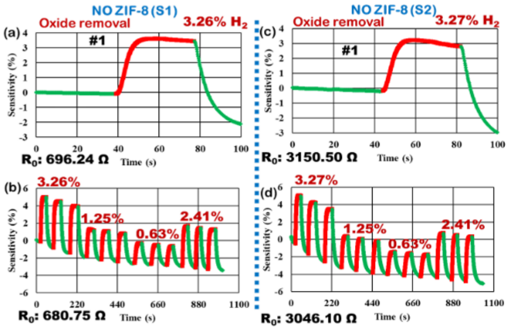
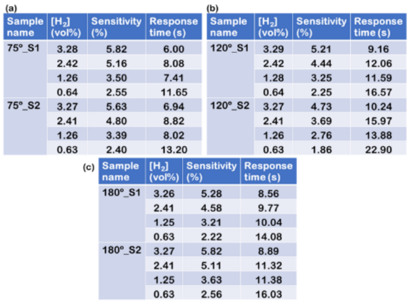


FIG: 3C


(a)

Sample name	$[H_2]$ (vol%)	Sensitivity (%)	Response time (s)
75°_S1	3.28	5.82	6.00
	2.42	5.16	8.08
	1.26	3.50	7.41
	0.64	2.55	11.65
75°_S2	3.27	5.63	6.94
	2.41	4.80	8.82
	1.26	3.39	8.02
	0.63	2.40	13.20

(b)

Sample name	$[H_2]$ (vol%)	Sensitivity (%)	Response time (s)
120°_S1	3.29	5.21	9.16
	2.42	4.44	12.06
	1.28	3.25	11.59
	0.64	2.25	16.57
120°_S2	3.27	4.73	10.24
	2.41	3.69	15.97
	1.26	2.76	13.88
	0.63	1.86	22.90

(c)

Sample name	$[H_2]$ (vol%)	Sensitivity (%)	Response time (s)
180°_S1	3.26	5.28	8.56
	2.41	4.58	9.77
	1.25	3.21	10.04
	0.63	2.22	14.08
180°_S2	3.27	5.82	8.89
	2.41	5.11	11.32
	1.25	3.63	11.38
	0.63	2.56	16.03

FIG:3D

Figures 4A and 4B demonstrate the tunability of the aluminum template approach through controlled platinum content variation. Figure 4A shows a 10 mol% Pt sample on polyimide substrate with ZIF-8 coating, while Figure 4B presents electron micrograph analysis confirming precise 91% Pd/9% Pt and 90% Pd/10% Pt compositions compared to standard 95-96% Pd ratios. Furthermore, the FIG:4A and 4B demonstrates the method ability to achieve targeted microstructural compositions while maintaining ambient-temperature processing conditions. Fig. 4C depicts repeatable hydrogen sensing responses of one such sensor when exposed to 3.25% and 0.63% H_2 in air, three times each. This highlights the capability of the aluminium template approach to produce functional sensors consisting of nanostructures, that are compositionally different than the usual 95%Pd/5%Pt ones.

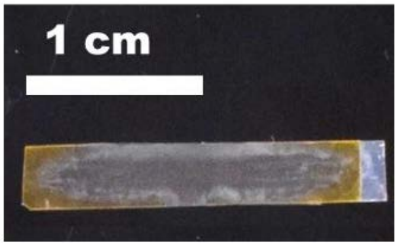


FIG: 4A

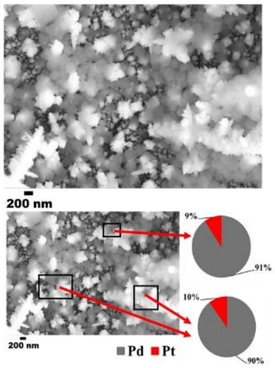
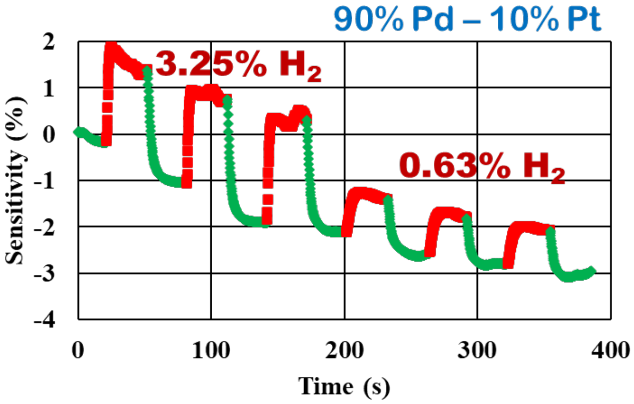


FIG: 4B



$[H_2]$	sqrt$[H_2]$	Avg. Sens	STDEV (Sens)	Avg. t_{90}	STDEV (t_{90})
3.25	1.80	2.14	0.19	2.69	0.51
0.63	0.79	0.84	0.03	5.73	0.12

FIG: 4C

Figure 5 depicts quantitative post-treatment data showing clear before-and-after improvements. The comparative data demonstrates that without post-treatment, samples achieve only ~0.5% maximum sensitivity with irregular, non-saturating behavior and undefined response time, while post-treated samples show ~4% sensitivity representing eightfold improvement with defined ~5 second response time. These findings validate the specification's post-treatment disclosure (Refer Pages 12-13 of the specification) of applying fresh precursor solution to enhance nanoparticle network density. Accordingly, Figure 5 demonstrates the importance of post-treatment in achieving reliable sensor performance with clearly defined response parameters.

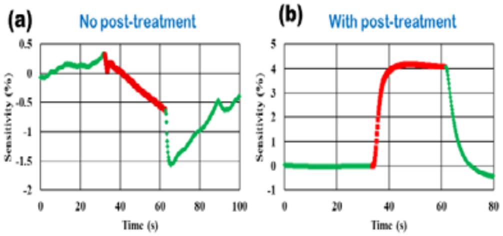


FIG: 5

Figure 6A depicts the comparative molecular sieve coating effectiveness against hydrogen sulfide (H_2S) interference. The data shows that uncoated sensors exhibit approximately 3.5% sensitivity increase when exposed to 48 ppm H_2S over one hour, while ZIF-8 coated sensors show only about 0.8% increase under identical conditions. This corresponds to a calculated blocking efficiency of approximately 77%, determined as (1 – 0.8/3.5) × 100, rather than being a directly measured value. The selectivity ratio of 0.8/3.5 = 23% represents the fraction of H_2S molecules that could pass through the coating. These findings validate the specification's molecular sieve coating disclosure (Refer Pages 15–16 of the specification), which describes selective hydrogen permeation while minimizing interference from larger molecules. Accordingly, Figure 6A illustrates the selective barrier effect of the ZIF-8 molecular sieve.

Figure 6B demonstrates the benefits of the ZIF-8 coating through comparative performance data obtained from a separate experiment conducted independently of the H_2S experiment shown in Figure 6A. In this experiment, hydrogen (H_2) was exposed to both a ZIF-8-coated sensor and a bare sensor. The ZIF-8 coated samples maintain sensitivity (1.57–4.32%) while achieving faster response times (2.96–5.39 seconds) compared to uncoated samples with slower response times (9.03–12.26 seconds) across 0.64–3.28% hydrogen concentrations. This validates the specification's molecular sieve disclosure (Refer Pages 15–16 of the specification), which describes selective hydrogen permeation and enhanced response kinetics.

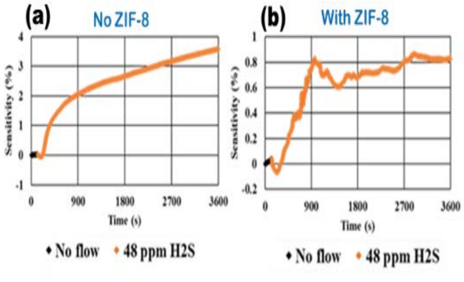
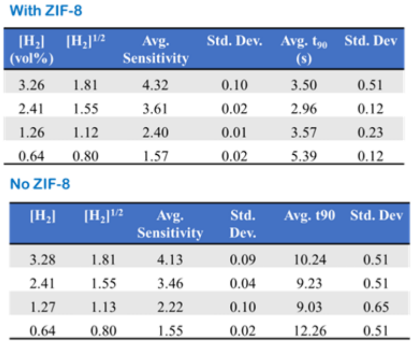


FIG: 6A



With ZIF-8

$[H_2]$ (vol%)	$[H_2]^{1/2}$	Avg. Sensitivity	Std. Dev.	Avg. t_{90} (s)	Std. Dev
3.26	1.81	4.32	0.10	3.50	0.51
2.41	1.55	3.61	0.02	2.96	0.12
1.26	1.12	2.40	0.01	3.57	0.23
0.64	0.80	1.57	0.02	5.39	0.12

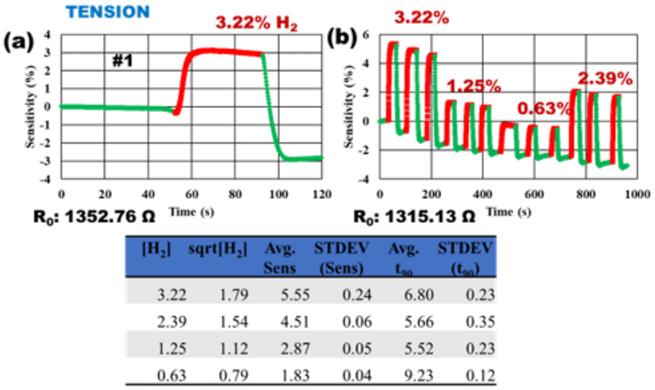
No ZIF-8

$[H_2]$	$[H_2]^{1/2}$	Avg. Sensitivity	Std. Dev.	Avg. t90	Std. Dev
3.28	1.81	4.13	0.09	10.24	0.51
2.41	1.55	3.46	0.04	9.23	0.51
1.27	1.13	2.22	0.10	9.03	0.65
0.64	0.80	1.55	0.02	12.26	0.51

FIG: 6B

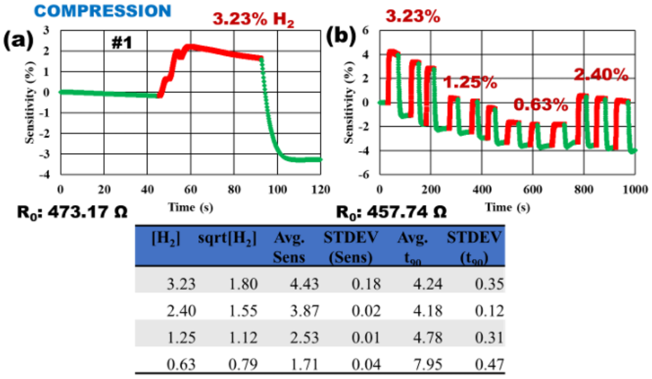
Figure 7A demonstrates mechanical flexibility under tensile strain with sensors maintaining 1.83-5.55% sensitivity and 5.52-9.23 second response times across 0.63-3.22% hydrogen concentrations. The low standard deviations confirm stable performance under mechanical deformation, validating the specification's polyimide flexibility. Accordingly, Figure 7A establishes consistent sensor performance under bending conditions. Figure 7A and Figure 7B represent the responses of a ZIF-8 coated sample under tensile and compressive strain, respectively. Accordingly, Figure 7A establishes consistent sensor performance under bending conditions.

Figure 8A demonstrates mechanical flexibility performance under compressive strain conditions. The data shows ZIF-8 coated sensors maintain 1.71-4.43% sensitivity and 4.18-7.95 second response times across 0.63-3.23% hydrogen concentrations with baseline resistance values of R0: 473.17 Ω and R0: 457.74 Ω. The tabulated data confirms stable performance under compressive deformation with low standard deviations, validating the specification's polyimide flexibility under mechanical stress (Refer Pages 3 and 19 of the specification). Comparative analysis reveals ZIF-8 coated sensors under compression demonstrate faster response times compared to tensile conditions, indicating optimal molecular sieve performance under compressive strain. Accordingly, Figure 8A establishes superior sensor performance under compressive bending with enhanced response kinetics through the disclosed ZIF-8 coating method.



$[H_2]$	$sqrt[H_2]$	Avg. Sens	STDEV (Sens)	Avg. t_{90}	STDEV (t_{90})
3.22	1.79	5.55	0.24	6.80	0.23
2.39	1.54	4.51	0.06	5.66	0.35
1.25	1.12	2.87	0.05	5.52	0.23
0.63	0.79	1.83	0.04	9.23	0.12

FIG: 7A

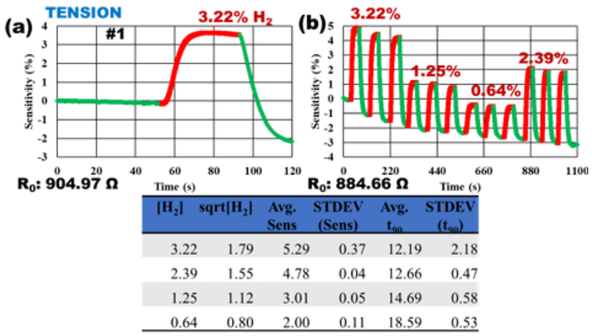


$[H_2]$	$sqrt[H_2]$	Avg. Sens	STDEV (Sens)	Avg. t_{90}	STDEV (t_{90})
3.23	1.80	4.43	0.18	4.24	0.35
2.40	1.55	3.87	0.02	4.18	0.12
1.25	1.12	2.53	0.01	4.78	0.31
0.63	0.79	1.71	0.04	7.95	0.47

FIG: 8A

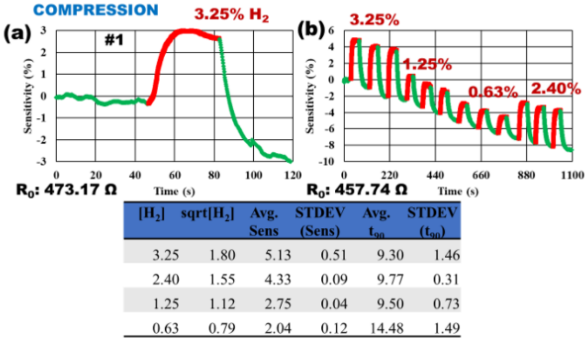
Figure 7B demonstrates mechanical flexibility performance of uncoated sensors under tensile strain. The data shows sensors maintain 2.00-5.29% sensitivity and 12.19-18.59 second response times across 0.64-3.22% hydrogen concentrations with baseline resistance values of R0: 904.97 Ω and R0: 884.66 Ω. Comparative analysis between Figures 7A and 7B reveals that ZIF-8 coated sensors exhibit superior performance with faster response times (5.52-9.23 seconds) compared to uncoated sensors (12.19-18.59 seconds), demonstrating the enhanced kinetics achieved through molecular sieve integration.

Figure 8B demonstrates mechanical flexibility performance of uncoated sensors under compressive strain. The data shows uncoated sensors maintain 2.04-5.13% sensitivity and 9.30-14.48 second response times across 0.63-3.25% hydrogen concentrations with baseline resistance values of R0: 473.17 Ω and R0: 457.74 Ω. The tabulated data confirms stable performance under compressive deformation. Comparative analysis between Figures 8A and 8B reveals that ZIF-8 coated sensors demonstrate superior performance with faster response times (4.18-7.95 seconds) compared to uncoated sensors (9.30-14.48 seconds), confirming the enhanced kinetics achieved through molecular sieve integration.



$[H_2]$	sqrt$[H_2]$	Avg. Sens	STDEV (Sens)	Avg. t_{90}	STDEV (t_{90})
3.22	1.79	5.29	0.37	12.19	2.18
2.39	1.55	4.78	0.04	12.66	0.47
1.25	1.12	3.01	0.05	14.69	0.58
0.64	0.80	2.00	0.11	18.59	0.53

FIG: 7B



$[H_2]$	sqrt$[H_2]$	Avg. Sens	STDEV (Sens)	Avg. t_{90}	STDEV (t_{90})
3.25	1.80	5.13	0.51	9.30	1.46
2.40	1.55	4.33	0.09	9.77	0.31
1.25	1.12	2.75	0.04	9.50	0.73
0.63	0.79	2.04	0.12	14.48	1.49

FIG: 8B

Now comparing the present invention with each of the cited documents D1-D3 to clearly present differences and establish non-obviousness with each of the cited documents.

D1 discloses a method involving aluminum as a permanent electrode in combination with titanium during electron-beam evaporation for hydrogen sensing element fabrication but differs from the present invention in various aspects. D1 does not disclose using aluminum as a temporary reactive surface that chemically reacts with the precursor solution and is subsequently removed. The present invention utilizes aluminum tape as a sacrificial template that facilitates controlled deposition through chemical reaction, followed by its removal, resulting in direct deposition of metal nanoparticles onto the polyimide substrate under ambient conditions. D1 neither teaches nor suggests such a mechanism that eliminates vacuum processing requirements and achieves efficient, uniform deposition.

D2 discloses a chemical vapor deposition (CVD)-based hydrogen sensing fabrication technique using beam evaporation at approximately 900 °C for about 20 minutes and relies on a PET substrate with a sensing area of only 0.25 cm². The process involves multiple high-energy steps and vacuum equipment, making it unsuitable for flexible and scalable fabrication. D2 neither discloses nor suggests the use of a sacrificial aluminum template to induce localized chemical reactions for nanoparticle deposition. In contrast, the present invention achieves deposition under ambient conditions in approximately 6 minutes, on a flexible polyimide substrate with a larger sensing area (0.8–2 cm²), by employing a reactive aluminum surface that is later removed, eliminating the need for prolonged high-temperature treatment.

D3 describes a self-assembly-based hydrogen sensing fabrication method that requires extended processing exceeding 24 hours at around 850 °C and does not provide any secondary treatment or enhancement step to enhance the sensing network. D3 relies on direct deposition without using a template or reactive interface, resulting in limited sensitivity and higher susceptibility to oxidation during storage and use. The present invention (pages 12–13, 25) introduces a two-step method, wherein a fresh precursor solution is reapplied after initial deposition to reinforce the electrically conductive network, ensuring better hydrogen sensitivity and improved stability against atmospheric degradation, while maintaining fabrication under ambient conditions in a fraction of the time required by D3.

In light of the foregoing, none of the cited documents, i.e., D1–D3, discloses a method for fabrication of a flexible hydrogen detection sensor comprising the specific sequence of steps and controlled conditions as defined in the present invention, including the preparation of a polyimide-substrate assembly with pre-treatment, the use of an aluminium tape as a temporary template for initiating a controlled reaction with a precursor solution containing defined concentrations of palladium chloride and potassium tetrachloroplatinate, followed by removal of the aluminium tape to obtain a uniform metal nanoparticle deposit, and a subsequent post-treatment step to reinforce the electrically conductive network. Furthermore, none of D1–D3 teaches or suggests applying a molecular sieve coating after post-treatment to enhance selectivity for hydrogen detection while maintaining flexibility and ambient-condition fabrication, as disclosed in the specification (pages 5, 8–12, Method 100). The cited documents either rely on prolonged high-temperature treatments (D1, D2) or self-assembly processes with extended processing times and rigid substrates (D3), and do not disclose or motivate a skilled person to adopt the combination of aluminium-assisted deposition, controlled precursor application, and post-treatment reinforcement described in the present invention.

Even a combination of D1, D2, and D3 would not enable a person skilled in the art to arrive at the present invention, as the cited documents follow divergent approaches that neither address flexible polyimide-based fabrication under ambient conditions nor provide a two-step precursor treatment to enhance the sensor network. D1 focuses on multi-step high-temperature electrode fabrication, D2 on beam evaporation at around 900 °C, and D3 on prolonged self-assembly deposition without template-assisted control. There is no reasonable expectation that combining these disclosures would result in a sensor with rapid fabrication (~6 minutes), consistent coating distribution, and scalable production as demonstrated by the present method. The specific sequence of steps, use of a sacrificial aluminium template, and incorporation of a molecular sieve layer collectively represent a non-obvious advancement that neither D1, D2, nor D3, individually or in combination, teaches or suggests. Therefore, the Applicant respectfully requests the Ld. Controller to waive the objection.

In view of the above submissions, we request the Ld. Controller to kindly accept this application and proceed to grant a patent. Also, please let us know if we are required to comply with any further requirements. However, before taking any adverse action, we humbly request the Controller of Patents to give the applicant an opportunity to be heard u/s 14 of the Indian Patents Act, 1970.

We thank you in advance for your cooperation in this regard.

Yours Sincerely,

Sarasija

Padmanabhan Sarasija
(IN/PA – **1803**)
Agent for the Applicant

Enclosures:

- Clean copy of claims; and
- Marked-up copy of claims.

We claim:

1. A method (**100)** for fabrication of a flexible hydrogen detection sensor, comprising:

   preparing a polyimide-substrate assembly by adhering a polyimide tape (**202B**) to a polyester sheet;

   pre-treating the polyimide-substrate assembly with an alkaline solution, wherein the alkaline solution is a potassium hydroxide solution;

   creating an aluminium-polyimide assembly by affixing an aluminium tape (**204B**) to the pre-treated polyimide-substrate assembly;

   preparing a precursor solution comprising 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate;

   applying the precursor solution to the aluminium-polyimide assembly (**200B**), allowing the precursor solution to contact the aluminium tape (**204B**);

   allowing a reaction between the precursor solution and the aluminium tape (**204B**) to proceed for a first predetermined time period of 60 to **1200** seconds;

   removing the precursor solution and separating the aluminium tape (**204B**) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly;

   washing the electrically conductive metal nanoparticle deposit with deionized water; and

   performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period of 10 to **1000** seconds; and applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection; wherein the electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and wherein the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration.

2. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is placed in an upright orientation with an aluminium side of the aluminium tape (**204B**) facing downward during the application of the precursor solution.

3. The method (**100)** as claimed in claim 2, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: creating a container-frame (**402B**) around the aluminium tape on the polyimide-substrate assembly; filling the container-frame (**402B**) with the precursor solution; and allowing the precursor solution to react with the aluminium tape in the upright orientation.

4. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is alternatively placed in an inverted orientation with an aluminium side of the aluminium tape (**204B**) facing upward during the application of the precursor solution.

5. The method (**100)** as claimed in claim 4, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: securing the aluminium-polyimide assembly (**200B**) in an inverted orientation with the aluminium side of the aluminium tape (**204B**) facing upward; creating the clearance (**304)** between the aluminium tape and the supporting surface; applying the precursor solution to fill the clearance (**304)**; and allowing the precursor solution to react with the aluminium tape in the inverted orientation.

6. The method **(100)** as claimed in claim 1, comprising attaching electrical contacts to the electrically conductive metal nanoparticle deposit for measuring the change in electrical resistance.

7. The method (**100)** as claimed in claim 1, wherein the concentration of the precursor solution used in the post-treatment step is the same as the concentration used when initially applying the precursor solution to the aluminium-polyimide assembly (**200B**).

8. The method (**100)** as claimed in claim 1, wherein the volume of precursor solution applied is proportional to the length of the aluminium tape used in the aluminium-polyimide assembly (**200B**).

Dated this 05th day of September **2024**

Sarasija

Padmanabhan Sarasija
(IN/PA – **1803**)
Agent for the Applicant

We claim:

1. A method (**100**) for fabrication of a flexible hydrogen detection sensor, comprising:

preparing a polyimide-substrate assembly by adhering a polyimide tape (**202B**) to a polyester sheet;

pre-treating the polyimide-substrate assembly with an alkaline solution, wherein the alkaline solution is a potassium hydroxide solution;

creating an aluminium-polyimide assembly by affixing an aluminium tape (**204B**) to the pre-treated polyimide-substrate assembly;

preparing a precursor solution comprising ~~–~~35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate;~~palladium and platinum compounds~~;

applying the precursor solution to the aluminium-polyimide assembly (**200B**), allowing the precursor solution to contact the aluminium tape (**204B**);

allowing a reaction between the precursor solution and the aluminium tape (**204B**) to proceed for a first predetermined time period of 60 to **1200** seconds;

removing the precursor solution and separating the aluminium tape (**204B**) from the polyimide-substrate assembly to reveal an electrically conductive metal nanoparticle deposit on a surface of the polyimide-substrate assembly;

washing the electrically conductive metal nanoparticle deposit with deionized water; and

performing a post-treatment step by applying a fresh batch of the precursor solution to the electrically conductive metal nanoparticle deposit for a second predetermined time period of 10 to **1000** seconds;~~,~~ and applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection; wherein the electrically conductive metal nanoparticle deposit forms an electrically conductive network on the polyimide-substrate assembly, and wherein the electrically conductive network formed by the electrically conductive metal nanoparticle deposit exhibits a measurable change in electrical resistance upon exposure to hydrogen, said change being correlatable to hydrogen concentration.

~~2. The method **(100)** as claimed in claim 1, comprising washing the electrically conductive metal nanoparticle deposit with deionized water after removing the precursor solution and before performing the post-treatment step.~~

~~3. The method **(100)** as claimed in claim 1, wherein the alkaline solution is a potassium hydroxide solution.~~

~~4. The method **(100)** as claimed in claim 1, wherein the first predetermined time period is between 60 to **1200** seconds.~~

~~5. The method **(100)** as claimed in claim 1, wherein the second predetermined time period is 10 to **1000** seconds.~~

~~6. The method **(100)** as claimed in claim 1, wherein the preparing the polyimide-substrate assembly comprises adhering a polyimide tape **(202B)** to a polyester sheet **(206B)**.~~

~~7. The method **(100)** as claimed in claim 1, wherein the precursor solution comprises 35.4 volume/volume percentage (%v/v) of palladium chloride and 2.1 %v/v of potassium tetrachloroplatinate.~~

~~8. The method **(100)** as claimed in claim 1, further comprising applying a molecular sieve coating to the electrically conductive metal nanoparticle deposit after the post-treatment step to enhance selectivity for hydrogen detection.~~

~~9.~~2. The method **(100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is placed in an upright orientation with an aluminium side of the aluminium tape (**204B**) facing downward during the application of the precursor solution.

~~10.~~3. The method (**100)** as claimed in claim 2~~9~~, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: creating a container-frame (**402B**) around the aluminium tape on the polyimide-substrate assembly; filling the container-frame (**402B**) with the precursor solution; and allowing the precursor solution to react with the aluminium tape in the upright orientation.

~~11.~~4. The method (**100)** as claimed in claim 1, wherein the aluminium-polyimide assembly (**200B**) is alternatively placed in an inverted orientation with an aluminium side of the aluminium tape (**204B**) facing upward during the application of the precursor solution.

~~12.~~5. The method (**100)** as claimed in claim **4**~~11~~, wherein the applying the precursor solution to the aluminium-polyimide assembly (**200B**) comprises: securing the aluminium-polyimide assembly (**200B**) in an inverted orientation with the aluminium side of the aluminium tape (**204B**) facing upward; creating the clearance (**304)** between the aluminium tape and the supporting surface; applying the precursor solution to fill the clearance (**304)**; and allowing the precursor solution to react with the aluminium tape in the inverted orientation.

~~13.~~6. The method (**100**) as claimed in claim 1, comprising attaching electrical contacts to the electrically conductive metal nanoparticle deposit for measuring the change in electrical resistance.

~~14.~~7. The method (**100**) as claimed in claim 1, wherein the concentration of the precursor solution used in the post-treatment step is the same as the concentration used when initially applying the precursor solution to the aluminium-polyimide assembly (**200B**).

~~15.~~8. The method (**100)** as claimed in claim 1, wherein the volume of precursor solution applied is proportional to the length of the aluminium tape used in the aluminium-polyimide assembly (**200B**).

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Sarasija

Padmanabhan Sarasija

(IN/PA – **1803**)

Agent for the Applicant