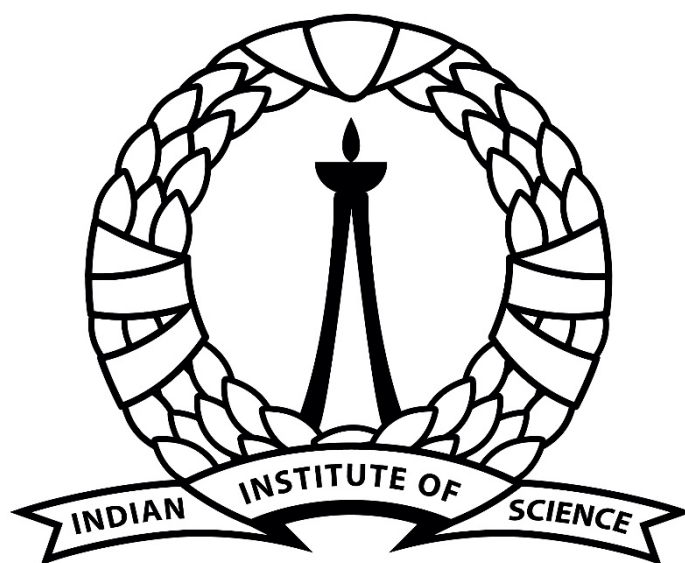


CHARACTERISTICS OF ELECTROLYZER AND FUEL CELL WITH PEM

Report Submitted under
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भारतीय विज्ञान संस्थान

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Chapter 1

Introduction

The history of renewable energy can be dated back up to 2000 years back in Europe [1]. It started with waterwheels, which were majorly used to do mechanical work. Ever since, the mankind was always fascinated to search for a much more reliable source of energy as the fossil fuels are non-renewable forms of energy. One of the oldest forms of renewable energy is the wind energy, which is in commercial use to produce electricity from as early as the 20th century. Since then, many forms of renewable energy have been commercialised like the solar energy, biomass, tidal energy to name a few.

Fuel cells are comparatively new among the available renewable energy resources, which rose to popularity from the mid-20th century. Various types of fuel cells exist namely proton-exchange-membrane fuel cells, alkaline fuel cells, solid oxide fuels cells, etc. All these shared the same basic aim, to produce electricity. Proton Exchange Membrane Fuel Cell technology (PEMFC), also known as polymer electrolyte membrane fuel cell, is a type of fuel cells which was mainly developed for use in vehicles as well as for stationary and portable power applications, is promising and highly energy efficient that converts chemical energy into electrical energy. This is an eco-friendly technology as it does not produce CO₂, CO, SO_x or NO_x emissions instead, the by-product is pure water. Hydrogen is the fuel used in PEMFCs which has the highest calorific value [2] among the feasible energy sources and is one of the promising fuels for the future. High power density, wide operational range and ability to stack the cells to extract more power output forces us to explore better ways to produce the catalyst which remains a major hurdle in its commercialization. The catalysts used in a PEMFC are platinum-based materials [3].

Here at the Laboratory of Nanoparticle Engineering, a cost-effective method to produce silver nanostructures has already been formulated, *Print-Expose-Develop method*, which is used in this study so as to provide maximum area of contact for the electrocatalysts. This method is mostly employed to develop silver nanostructures, here. The procedures of this method will be explained in the coming sections. Silver nanostructures of different loadings are developed on chromatographic paper so as to get a basic idea of the procedures and the

precautions to be taken for their proper development. The conductance (or resistance) of the developed structures was measured, which is one of the fundamental properties of the nanostructures.

As mentioned above, PEMFCs uses a proton-exchange membrane (PEM) for transferring protons which is the basic requirement in the fuel cell. The commonly used PEM is Nafion developed by DuPont [3]. The electrocatalysts are coated on either side of the membrane. The study here focuses on developing low-cost nanostructure-based electrocatalysts. The same principle of *Print-Expose-Develop* was employed to develop silver nanostructures on the Nafion membrane.

Since the catalysts are platinum-based materials, electrodeposition of platinum over silver needs to be studied. Deposition of platinum over silver thin films were conducted to study about the deposition process by modified self-terminating electrodeposition process.

Additionally, I also operated the PEM electrolyser and fuel cell purchased from H TEC Education. Electrolyser works on the reverse principle of fuel cell. It converts electrical energy into chemical energy – splitting water into hydrogen and oxygen. Similar to the PEMFC, PEM electrolyser uses a proton-exchange membrane to transfer the hydrogen ions (protons) formed on the anode side to the cathode side where it can be collected as hydrogen gas. This gas is then given as the feed to the PEMFC where electricity is produced.

Chapter 2

Materials and Methods

2.1 Silver Nanostructures on Chromatographic Paper

Inkjet printing is one of the methods to develop nanostructured thin film popular due to its cost effectiveness, variable loading capabilities, ability to be developed into various forms of nanostructures like fryums, particles or wires, adaptability to various substrates, high precision, excellent resolution, accuracy and small footprint. This process of using inkjet printing used to print metal salts, here, provides synthesis of durable conductive metal substrates on flexible surfaces. Photographic development process used to generate images from films was the inspiration for the employment of *Print-Expose-Develop* method for generation of silver nanostructures [4,5]. HP Deskjet 1212 inkjet printer which houses HP 805 black cartridge was used to print the precursor salts.

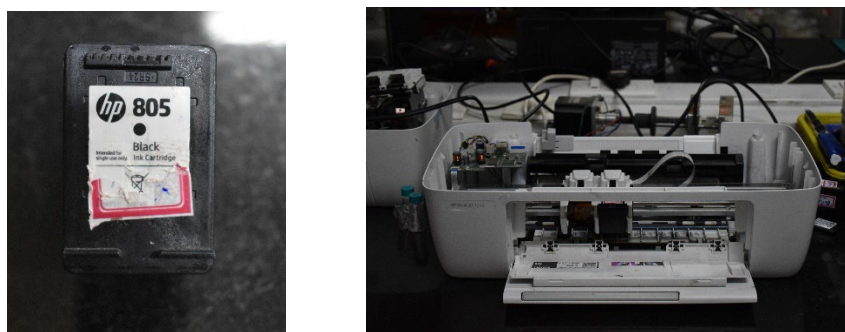


Fig 2.1: HP 805 black cartridge and HP Deskjet 1212 printer loaded with the cartridge

The aim was to prepare silver nanostructures for which 1:2 molar ratio of silver nitrate (AgNO_3) and potassium chloride (KCl) were printed layer-by-layer on the chromatographic paper. Nanowires were developed on a 2x2 inch area (designed in Microsoft Presentation) of different loadings. All the solutions were prepared on DI water. 2M AgNO_3 and 4M solution of KCL each of 5 mL were prepared. Despite the fact the equimolar mixture would be sufficient for reaction to produce silver halide (AgCl), excess concentration of KCl was used to ensure

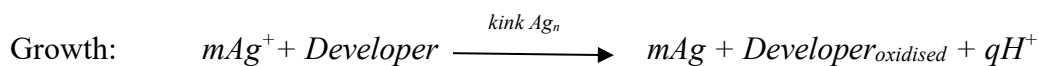
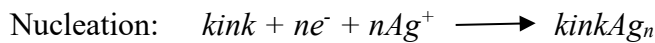
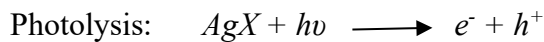
the complete utilization of Ag in AgNO₃ [4,5]. The developer solution (reducing agents which supply electrons) ID78 was prepared according to the standard. Though, other developer solutions like D72 and D76 were used in the lab, we used ID78 as it develops the substrate at a faster rate.

Two separate HP 805 black cartridges were used to print the AgNO₃ and KCl solutions. Prior to their usage for printing, the cartridges were opened (lids) and thoroughly cleaned under running tap water, followed by rinsing with DI (deionised) water and sonication with DI water. Test patterns were printed to assure that no black ink remained in its reservoir. Loading calculations (amount of silver deposited per print) were done beforehand so that the volume of solution dispensed for each print was calculated. Following the printing of desired amount of AgNO₃ and KCl, the substrate was exposed under a halogen lamp for 15 minutes. Then it was dipped in the developer solution for 20 minutes, followed by rinsing the sample in a tray filled with DI water. It was allowed to dry under ambient conditions overnight.



Fig 2.2: Schematics of the *Print-Expose-Develop* method

The reaction scheme for the development of silver nanowires are as follows [2]:



Photoelectrons generated within the silver halide crystal react with silver ions at the crystal defect sites on the surface (kink sites) to form nuclei. The nuclei (latent images) that can be developed have at least four silver atoms. Electron transfer between reducing agent and silver ions occurs during development of nanostructures, catalysed by nuclei acting as electron reservoir.

2.2 Silver Nanowires on Nafion Membrane

Nafion is a class of polymers called ionomers (ion containing polymer) which are generated by copolymerisation of a per-fluorinated vinyl ether co-monomer with tetrafluoroethylene (TFE). It has received a considerable amount of attention as proton-exchange membrane (PEM) in fuel cells due to its excellent thermal and mechanical stability (refer fig 2.3 for structure). Ionic conductivity of Nafion increases with the level of hydration, as water molecule associated with each sulfonic group increases. The hydrophilic nature of ionic groups attracts water molecules which solvates ionic groups and dissociate protons from the sulfonic groups (SO_3H). The dissociated protons travel from one acid site to another through mechanisms facilitated by water molecules and hydrogen bonding. On hydration, interconnected network of hydrophilic domains is formed which allow movement of water and cations.

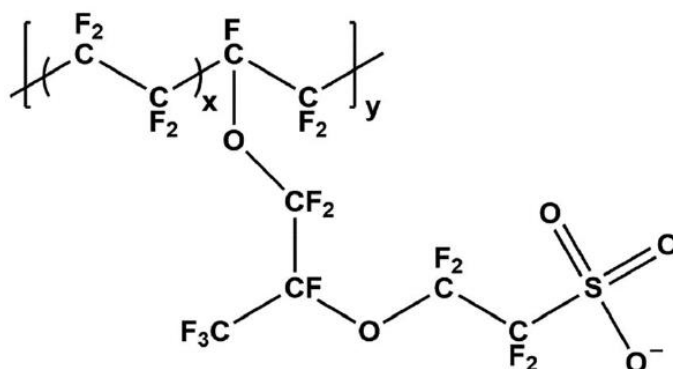


Fig 2.3: Structure of Nafion

In this study, Nafion 112 was used. ‘112’ refers to a film that have 1100 EW (number of dry Nafion per mole of sulfonic acid groups) and a thickness of 0.002 inches [3]. The membrane does not exhibit adequate hydrophilicity for direct spreading of metal solutions by inkjet printing. Studies have proved that layer-by-layer assembly of polyelectrolyte films can improve adhesion of metal lines fabricated by inkjet printing [4]. It causes water to dissociate and produce charged species. Layer-by-layer deposition of polyelectrolyte multilayers was carried out by alternate coating of plasma-treated Nafion membranes with polycations and

polyanions. Polymer chains are adsorbed and surface charge is reversed during each deposition, leading to the formation of electrostatically crossed film. Plasma cleaning of Nafion is performed in order to activate the surface for formation of thin polyelectrolyte layer. It was done with the help of Harrick plasma PDC-32G-2 230 V plasma treatment equipment. The plasma treated Nafion membrane were immediately dipped into the polyelectrolyte solution to form hydrophilic layer. Morphology of polyelectrolyte film changes with pH of polyelectrolyte solution as the ionization is pH dependent. Hence, due to their strong behaviour and no pH dependence, poly diallyl dimethyl ammonium chloride (PDDA) and poly sodium styrene sulfonate (PSS) were chosen as polycation and polyanion respectively to be coated on the plasma treated Nafion membrane.

The polycationic solution was made by adding 1 mL of PDDA into 100 mL 1.5 M NaCl while the polyanionic solution was made by addition of 2 mg of PSS to 100 mL 1.5M NaCl solution. The NaCl increases the porous nature of the electrolytic layers thereby making clear path for the travel of reactants and increases annealing process in the films [4]. When PDDA is absorbed, contact angle in air increases while the same decreases when PSS is absorbed. But the PSS layer penetrates into the under layers, making the surface composed of mixture of two layers. In this form, reorganisation of charges takes place making the surface more hydrophobic [4]. Hence, polyelectrolyte coating should always end with PDDA coating. The excess of either of the polycation or polyanion causes swelling of the structure. So intermediary washing is necessary in layer-by-layer deposition of polyelectrolytes. After polyelectrolyte coating the membrane is ready to be printed with AgNO_3 and KX for the development of nanostructures. As nanowires were required, instead of using 4 M KCl, 4 M 95:5 weight percent of 5 mL KBr:KI solution was used. The procedure for developing nanowires is the same as that given in section 2.1. Additional care should be taken while handling Nafion membrane which would be discussed further sections.

2.3 Electrodeposition of Platinum

An atomic monolayer of platinum is formed on a gold coated silicon wafer by stepping the potential across -0.8 V vs V_{SSCE} and 0.4 V vs V_{SSCE} . This process is self-terminating by the action of hydrogen atom getting adsorbed on top of deposited platinum atom, leading to a Pt/H layer shielding the deposited platinum layer from further deposition. Since gold is non-reactive in nature, leaching of platinum back into the solution does not occur when the polarity of

applied voltage stepped to positive potential. Each cycle deposits a layer of platinum and deposition of n such layers of platinum can be achieved by repeating the process

The process of electrodeposition of platinum over gold substrates can be taken to silver thin films. For reacting substrates like silver, while stepping the potential to positive values, the silver substrate starts to leach into the solution and this is unfavourable. Literature suggests, to terminate platinum deposition on reacting substrates like silver, by emersion in hydrogen saturated DI water and then dry it with nitrogen gas.

2.4 PEM Fuel Cell and Electrolyzer

Proton-Exchange Membrane or Polymer-Electrolyte Membrane (PEM) is semipermeable membrane made from a class of polymers called ionomers which conducts proton and act as electronic insulator and reactant barrier. They are the most important part in the membrane electrode assembly (MEA) of PEMFC and PEM electrolyser. Primary characterization of PEM is based on proton conductivity, methanol permeability and thermal stability.

PEM electrolysis is electrolysis of water in a cell containing PEM which is responsible for the conduction of protons, separation of product gases and electrical insulation of electrodes. It was first developed in the 1960s to overcome the bottle necks of alkaline hydrolysis. Electrolyser converts electrical energy into chemical energy by splitting of water into hydrogen and oxygen. General uses of PEM electrolyser include electrical grid stabilization from dynamic electrical sources like wind turbines, localized hydrogen production as a fuel for fuel cell vehicles, etc.

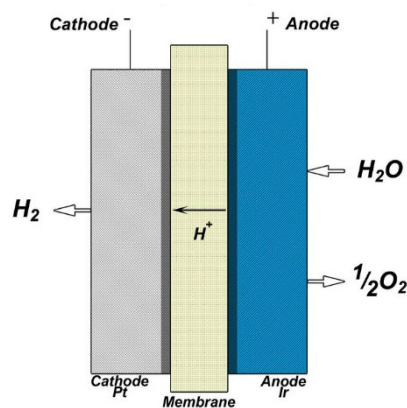
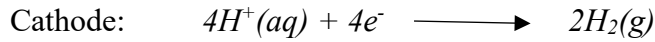


Fig 2.4: Schematic diagram of PEM electrolyser



Oxygen Evolution Reaction (OER) occurs at the anode of the electrolyser where liquid water is fed into the catalyst on which water is oxidised to oxygen, protons and electrons. At the cathode, Hydrogen Evolution Reaction (HER) takes place where supplied electrons and protons that have conducted through the membrane are combined to produce hydrogen gas. Ability of PEM electrolyzers to operate at higher current densities result in reduced operational costs. It also exhibits low gas crossover rate resulting in high product gas purity (approximately 99.5%). These advantages prompt us to carry out analytical studies to enhance the efficiency of the MEA.

Proton-Exchange Membrane Fuel Cells (PEMFC) is the leading contender to replace the alkaline fuel cell technology used in the space shuttle which as all fuel cells converts chemical energy into electrical energy [7]. Invented in the early 1960s by the General Electric, it addressed the issues posed by the existing fuel cell technologies on which initially used sulfonated polystyrene membranes were replaced by Nafion ionomer owing to its superior performance and durability. The MEA consists of electrodes, electrolyte (membrane), catalysts and gas diffusion layers. The most important part of the cell is the triple phase boundary where electrolyte, catalyst and reactants mix for the cell reactions to occur.

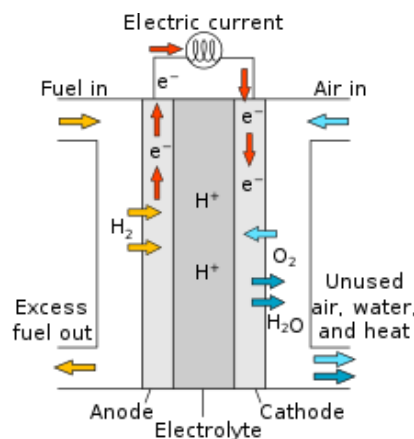
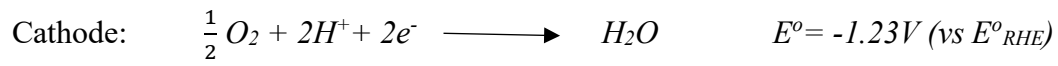
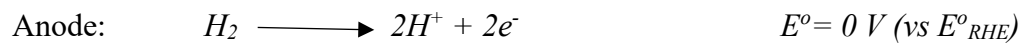


Fig 2.5: Schematic representation of PEMFC

Fig 2.5 shows the schematic representation of the working of a PEMFC. A stream of hydrogen is fed into the anode side of the MEA where it is catalytically split into protons and electrons, Hydrogen Oxidation Reaction (HOR). The newly formed protons permeate through the membrane to the cathode side at which oxygen molecules (fed into cathode side) protons

and electrons (arriving through external circuit) react to form water, called Oxygen Reduction Reaction (ORR).



Chapter 3

Results and Discussions

3.1 Inkjet Printing of Silver on Chromatographic Paper

Printing salts using cartridges needed meticulous monitoring of the procedures at each step. First of all, it has to be assured that black ink is completely removed. Then loading calculations are done to know the amount of solution dispensed on each print. The calculations were done by printing DI water on chromatographic paper following the standard procedures for calculating the loading. Four samples of 1 mg, 2mg and 3mg loadings were developed, in which 2 samples had 3 mg loading, each of the four having 2x2 square inch area. Two cartridges were made ready for printing the already prepared AgNO_3 and KCl solutions. 300 μL of the solutions were filled using pipette and the layers were printed as per the format shown below.

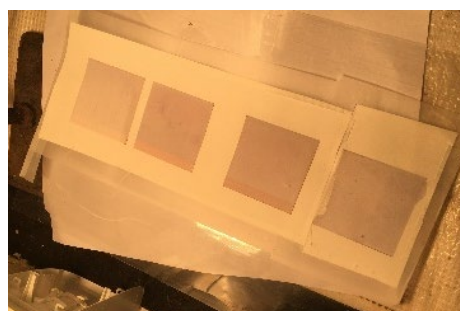
1 mg: *KAAAKK (3 prints of each solution)*

2 mg: *KKKAAAAAKK (5 prints of each solution)*

3 mg: *KKKKKAAAAAAKK (7 prints of each solution)*



(a)



(b)



(c)



(d)

Fig 3.1: (a) Printing of salts on substrate, (b) exposing the printed substrate to halogen lamp, (c) immersing exposed substrate in ID78 solution, (d) substrate after development

Carefully, all the layers were printed on the chromatographic paper. AgNO_3 is not printed first so that all the silver molecules could be developed into nanostructures. If it was printed as the first layer, we may lose some of them due to their absorption on the paper. The sample should be dried thoroughly after each layer of the salt solution is printed. Once all the layers are printed, they are exposed under the halogen lamp for 15 minutes for the formation of latent images. A latent image is a small cluster of metallic silver atoms formed in a silver halide crystal due to the reduction of interstitial silver ions by photoelectrons. A slight yellowish thin film of the substrate confirms the formation of latent images. the exposed substrate is then immersed in ID 78 (developer solution) that electrochemically reduces silver halide crystals into metallic silver grains, where the latent image centres act as catalyst. As KCl solution (small lattice size of chloride ions) was used and due to the fact that ID 78 supplies electrons at a faster rate spherical structure of nanostructures formed might get ruptured and fryums like structures might be formed.

Conductivity of each of the samples were measured using multimeter the values across the entire length of the substrate is reported here. It is observed that the resistance of the nanostructures decreases with increase in silver loading.

Sample No	Ag Loading	Resistance (ohms)
1	1 mg	57.4
2	2 mg	26.7
3	3 mg	17.2

3.2 Inkjet Printing of Nanowires on Nafion

The Nafion membrane was made more hydrophilic by layer-by-layer deposition of polyelectrolytes on the plasma cleaned membrane. Coating of polyanion over the polycation leads to the formation of a bilayer. The layer-by-layer deposition should be carried out carefully. Soon after plasma cleaning, the membrane is dipped into PDDA solution. It is left undisturbed for approximately 10 minutes. The membranes are then carefully taken out and is thoroughly dried using a hair dryer. One shouldn't blow the dryer close to the membrane as the polyelectrolyte layers may spread out. It would be better if the membrane is placed on a flat surface and the dryer is held at a sufficient distance from the membrane to ensure that the polyelectrolyte layer is not disturbed. Drying is followed by immersion of the membrane into DI water, to reduce swelling caused by excess polyelectrolyte. We should wait for 7 minutes before drying the membrane again. Then, the membrane is dipped into polyanion (PSS) solution for 10 minutes. Six samples of Nafion membrane each of size 2x2 sq.inch were treated with polyelectrolytes. Five bilayers of polyelectrolyte were coated on the membranes. Another sample of Nafion membrane was taken, without layer-by-layer coating, to do the loading calculations.

1 mg, 2 mg and 3 mg loadings of silver was to be done on the Nafion samples (2 samples for one loading). The printing pattern for each loading is listed below.

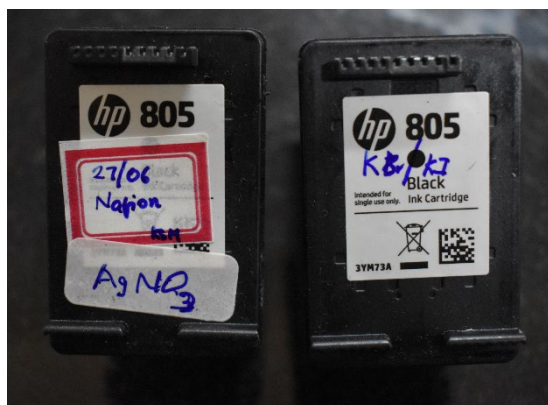
1 mg: *KAAAKK (3 prints of each solution)*

2 mg: *KKKKAAAAAAKK (6 prints of each solution)*

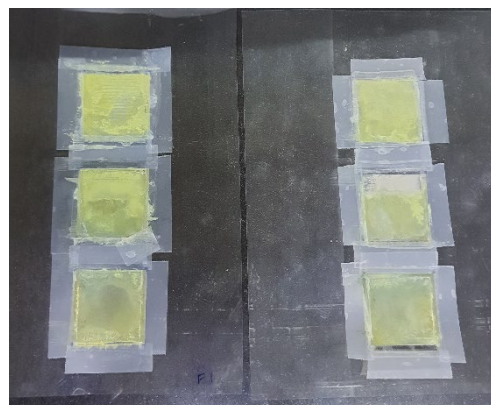
3 mg: *KKKKKKAAAAAAKK (8 prints of each solution)*

As nanowires are required, the precursor salts are AgNO_3 and 95:5 weight percent KBr:KI solution. For the same reason of ensuring complete reaction of silver ions, 2:1 molar mixture of KX: AgNO_3 was prepared. 4 mL each of 2M AgNO_3 and 4M KBr/KI solution were made. Precursor salts were printed according to the pattern shown above. The samples were dried carefully without disturbing the printed salts, succeeded by the next print. Some of the samples got contaminated due to printing (both the samples with 3 mg loadings). It was observed when samples of different loading (especially high loading) all are printed at once. As the loading increases the printer cartridge made impressions on the substrate. When those were printed individually, it was not observed. Additionally, it should be noted that the substrates should be arranged in the OHP sheet in such a manner that lower loaded samples are

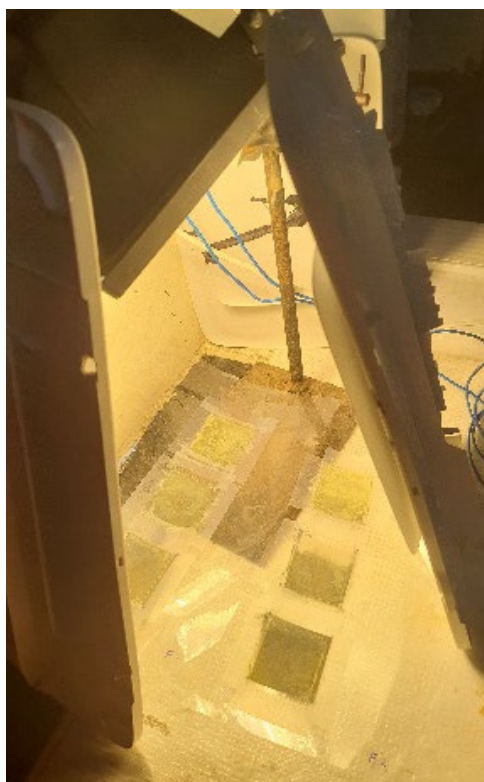
printed first instead of the highly loaded (it also fixed the problem for 2 mg prints). They were exposed to halogen lamp for 15 minutes. Out of six samples, only three were developed further (one for each loading). Then, they were immersed in the developer solution (ID 78) for 20 minutes. Since the salts become wet while in the developer solution, the tray should not be disturbed during that period to eliminate the chances of displacement of the printed salts. Before cleaning the samples in DI water, it was dried.



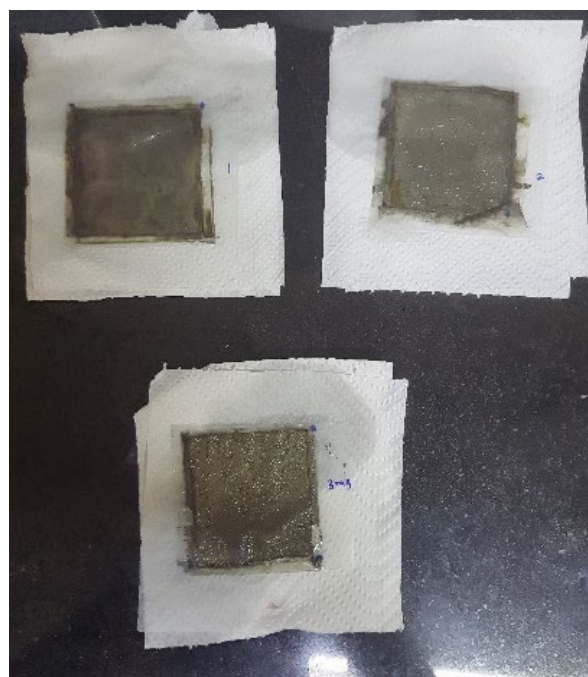
(a)



(b)



(c)



(d)

Fig 3.2: (a) Cleaned cartridges, (b) After printing all the samples with appropriate loading, (c) Exposure to halogen lamp (d) Fully developed substrates

Conductivity values of the developed nanowires were measured using the four-probe method.

Sample ID	Ag Loading	Sheet Resistance (ohms/sq.)
1	1 mg	$(9.33+26.41)/2 = 17.87$
2	1 mg	$(22.91+28.92)/2 = 25.92$
1	2 mg	$(0.31+0.47)/2 = 0.39$
2	2 mg	$(0.35+0.33)/2 = 0.34$
1	3 mg	$(0.43+0.45)/2 = 0.44$
2	3 mg	$(0.59+0.48)/2 = 0.54$

It can be seen that as silver loading increases, the resistance decreases. The trend is not followed in the case of 3 mg samples because, as I have mentioned, of scrapping of cartridge on the sample. The other 3 mg sample degraded a bit more degraded which didn't allow me to check the same on it.

3.3 Deposition of Platinum on Silver Thin Film

The precursor salts used to prepare electrolytes for deposition of platinum (over gold or silver) are 3mM K_2PtCl_4 and 0.5 M KCl. 9.96 mg of K_2PtCl_4 and 2.98 g of KCl was dissolved in 80 mL of DI water. The pH of the solution was adjusted to 4 using $HClO_4$ and NaOH. 20 mL electrolytic cell was taken for deposition. The silver nanofilm was stuck onto the OHP sheet using double sided tape. Reversible Hydrogen Electrode (RHE) is the reference electrode, graphite is the counter electrode and the silver thin film on OHP sheet is the working electrode. The electrolyte was purged with nitrogen to remove dissolved oxygen and a nitrogen blanket was provided inside the cell during the reaction.

To calculate the amount of platinum deposited, current v/s time under constant potential was studied using chronoamperometry. Four samples of silver nanofilms were prepared and each of them were subjected to deposition for four cycles. Hence, the silver thin films were rinsed with hydrogen saturated water outside the cell which quenches the substrate from further deposition of platinum. The first run of the experiment didn't go well as the chronoamperometric curves weren't smooth. This became better while it was done for the second time. It was repeated for the third time to check for repeatability of the obtained results, which went successful.

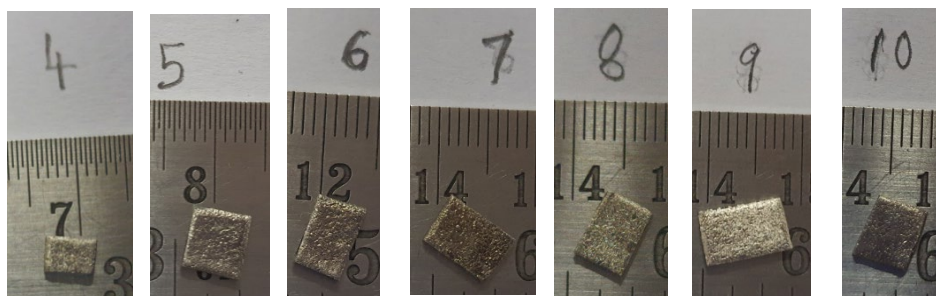


Fig: 3.3 Cross sections of platinum deposited silver wafers

All the samples shown in fig 3.3 were subjected to ICP-OES (inductively coupled plasma – optical emission spectroscopy). The results were not entertaining. This led for checking the equipment and self-evaluation of the possible human errors. It was then found that there was some defect in the RHE which led to wrong deposition as per the comparison of expected results and the results obtained.

3.4 PEM Electrolyser and Fuel Cell

The H TEC Education PEM electrolyser kit consisted of Nafion membrane coated with electrocatalysts, cathode and anode gas diffusion media, electrode plate and acrylic plates to support the entire structure. All the requirements to operate the electrolyser was arranged. The peristaltic pump was set to run at 78 rpm which gave a flow of 72 mL per min of water (in the range of 70-80 mL per min range specified for the product).

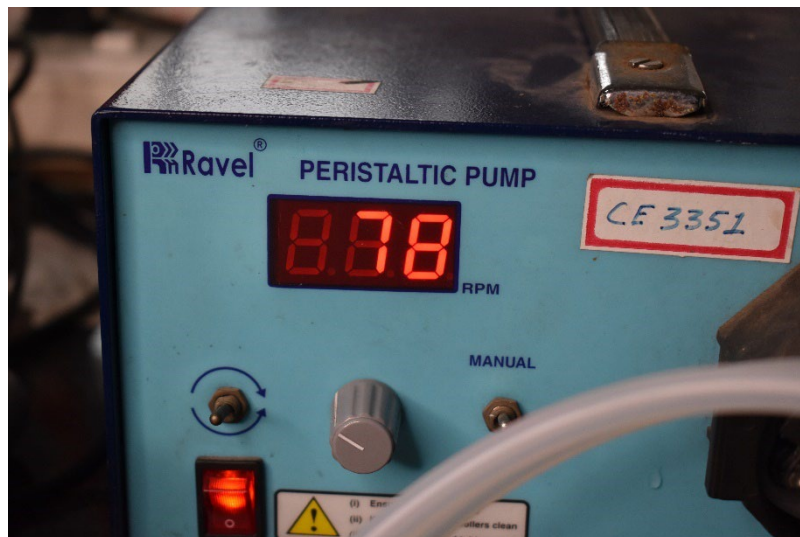


Fig 3.4: Rpm of peristaltic pump

The experimental set up was made and the yield hydrogen was produced at the cathode and oxygen escaped with recycled water from the anode. As per the operation manual, we should be increasing the current (between 0-4 A) till the voltage drawn by the cell is 2 V. Here, the potential across the electrolyser reached when the current was increased up to 1.34 A.

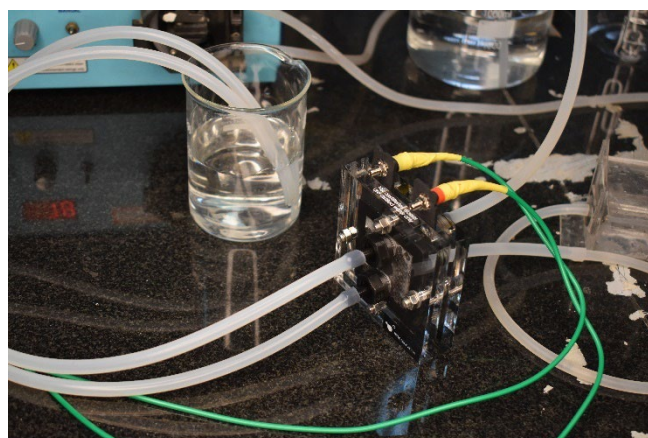
The rated flow rate of the electrolyser was 35 mL/min. The 30-300 mL/min rotameter didn't give any reading, suggesting that flow rate of hydrogen was less than 30 mL/min. To compare the change in the hydrogen produced with increase in inlet temperature of water, count of the number of bubbles of hydrogen produced per minute was taken.

Temp of Water (°C)	Number of H ₂ Bubbles	Number of O ₂ Bubbles	Current Drawn (A)	Potential Difference (V)
35	107	44	1.16	2.1
40	115	46	1.21	2.1
45	121	48	1.25	2.1

The increase in number of bubbles with temperature suggests that as temperature increases, electrolysis occurs at a faster rate. This can also be seen in increase in current drawn by the cell at constant potential.



(a)



(b)

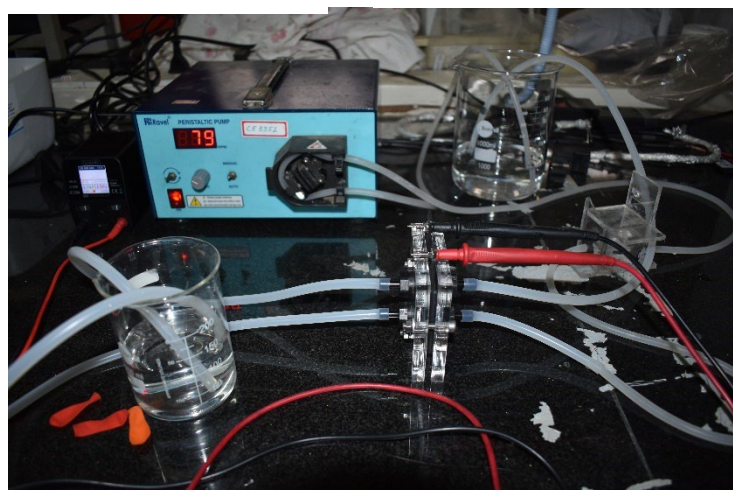


Figure 3.5: (a) bubbling of hydrogen, (b) bubbles of O₂ passing through recycle water

The input of the fuel cell was connected to the output of the electrolyser. Due to leakage encountered in the electrolyser, the system couldn't be operated for sufficient time for analysing the performance of the system (output current, voltage v/s temperature of water).

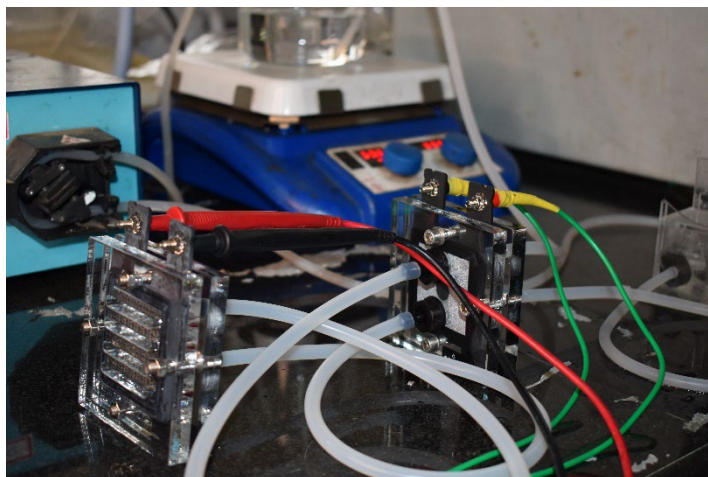


Fig 3.6: Fuel cell (with air plate) added to the electrolyser

The data obtained for the fuel cell was operated at the best operating conditions, we got an output current of 0.928 V and 0.957 A (power = 0.89 W). since the leaking of electrolyser was observed, the current drawn by it reduced up to 0.5 A while the voltage remained the same. At this configuration, the output current was 0.49 A and 0.928 V

Videos of the experiments conducted could be found at the given link: "C:\Users\naiika\Indian Institute of Science\LabFuN - Documents\FuelCells\Videos\Karthik Intern_Toy"

Chapter 4

Conclusion

In-situ synthesis of conductive silver nanostructure network was developed on chromatographic paper. The conductivity of the samples increased as the loading of silver increased. In an attempt to develop silver nanowire network on Nafion membrane, layer-by-layer deposition of polyelectrolyte layers of PDDA (polycation) and PSS (polyanion) was conducted. Five bilayers of polyelectrolytes were coated on the Nafion before developing silver nanowire network to increase the hydrophilicity of the membrane. The conductivity of the network developed showed an increase in conductivity with respect to loading of silver. Less than 1 ohms/sq. could be attained. The PEM electrolyser and fuel cells of H TEC Education were also operated. A database of production of hydrogen vs inlet of temperature of water was prepared. The outlet of the electrolyser was supplied into the fuel cell in which power output of 0.89W was obtained. Further studies regarding the performance of fuel cell with increase in input of hydrogen couldn't be obtained as a leak in the electrolyser degraded its performance.

Appendix A: Loading Calculations on Nafion

First of all, loading of water (amount of water dispensed) per print on the membrane is calculated. ‘*n*’ layers of water (1 to 5) are printed on the membrane. For each set of prints, the initial weight and final weight of the cartridge is noted.

No of Layers (<i>n</i>)	Initial Weight of Cartridge (g), <i>m1</i>	Final Weight of Cartridge (g), <i>m2</i>	Mass Dispensed per Print (g), <i>m1-m2/n</i>	Loading per Unit Area ($\mu\text{L}/\text{cm}^2$), (<i>m1-m2</i>)/25
1	23.4	23.3	0.04	1.7
2	23.6	23.5	0.04	1.7
3	23.5	23.4	0.04	1.7
4	23.5	23.4	0.04	1.6
5	23.4	23.2	0.04	1.6

As the density of water is almost 1g/cc, mg can be approximated as μL .

From the data collected, average loading per print of the cartridge is taken as the average value of ‘*Loading per Unit Area*’.

$$(1.7 + 1.7 + 1.7 + 1.6 + 1.6)/5 = 1.7 \mu\text{L}/\text{cm}^2$$

Weight of silver per μL of silver nitrate is calculated.

169.87 g AgNO_3 contains 107.8682g Ag (molecular weights)

Therefore, 1.35896g AgNO_3 (used to make standard solution) contains 0.8629g Ag (4 mL)

Hence, 1 μL contains 0.215725mg Ag.

Amount of silver deposited per print per unit area is 1.7 μL x 0.215725 g = 0.3 mg Ag

From this value, no of prints are calculated as follows;

$$1 \text{ mg} = 1/0.3 \approx 3 \text{ prints}$$

$$2 \text{ mg} = 2/0.3 \approx 6 \text{ prints}$$

$$3 \text{ mg} = 3/0.3 = 8 \text{ prints}$$

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