

IDEA-2019-CH-01

“Solar Water Splitting by Using
the Concept of Artificial Leaf”

Submitted By

Dhananjay Dileep (16BCH013)

Deep Patel(16BCH043)

CHEMICAL ENGINEERING
INSTITUTE OF TECHNOLOGY
NIRMA UNIVERSITY
AHMEDABAD-382481

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"Solar Water Splitting by Using the Concept of Artificial Leaf"

Idea Lab Project

Submitted By

Dhananjay Dileep (16bch013)

Deep Patel (16bch043)

Under the mentorship of

Dr. Sanjay Patel

Dr. Leena Bora

DEPARTMENT NAME INSTITUTE
OF TECHNOLOGY NIRMA
UNIVERSITY AHMEDABAD-382481

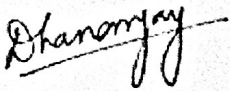
Declaration

We do hereby declare that the technical project report submitted is original, and is the outcome of the independent investigations/research carried out by us and contains no plagiarism. The research is leading to the discovery of new facts/techniques/correlation of scientific facts already known. This work has not been submitted to or supported by any other University or funding agency.

We do hereby further declare that the text, diagrams or any other material taken from other sources (including but not limited to books, journals and web) have been acknowledged, referred and cited to the best of our knowledge and understanding.

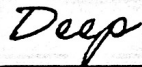
Date:22/06/20

Place:Ahmedabad



Signature of Student1

16bch013



Signature of Student2

16ch043


(Mrs S Patel)

Signature of Mentor1

Mentor Name1



Signature of Mentor2

Mentor Name2

NIRMA UNIVERSITY INSTITUTE
OF TECHNOLOGY IDEA LAB
CHEMICAL ENGINEERING

Annual/Final Report of the work done on the Idea Lab Project. (Report to be submitted within 3 weeks after completion of the project)

1. Idea Lab Project ID: IDEA-2019-CH-01
2. Project Title: Solar Water Splitting by Using the Concept of Artificial Leaf
3. Period of Project: 15/07/2019 to 04/03/2020
4. (a) Name of Student (Roll No.): Dhananjay Dileep 16bch013
Department: Chemical Engineering
- (b) Name of Student (Roll No.): Deep Patel 16bch043
Department: Chemical Engineering
- (c) Name of Mentor: Dr. Sanjay Patel
Dr. Leena Bora
5. Project Start Date: 15/07/2019
6. (a) Total Amount Approved: Rs. 100,000/-
- (b) Total Expenditure: Rs. Amount/-
- (c) Report of the work done:
 - i. Brief objective of the project: Harnessing Solar Energy into Electrical and Chemical Energy
 - ii. Synthesis of Catalyst
 - iii. Results achieved from the work
Not published yet
Results achieved
 - iv. Has all the objectives been achieved as per plan. If not, state reasons.
1)Some characterizations of catalysts have not been performed
2)Scalability has not been demonstrated

v. Please indicate the technical difficulties, if any, experienced in implementing the project

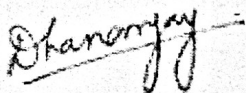
We were out of country for the 8th Semester internship and communication and implementation was slow, only to be delayed by COVID-19

vi. If the project has been completed, please enclose a summary of the findings of the study

From this study, we conclude that the list of potential candidate for solar water splitting in natural sunlight at industrial scale are:

1. V₂O₅/TiO₂-SiO₂
2. CuO-TiO₂/Graphene

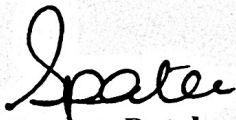
However, detailed study is still required to further investigate physico-chemical properties of these two potential candidates, along with determination of its performance at large scale before providing a final verdict.



Signature of Student1

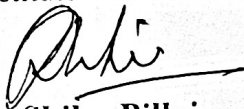
Dhananjay Dileep

16BCH013



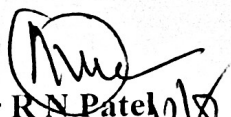
Dr Sanjay Patel

Mentor,
Professor & Head, Chemical Engg. Dept.
Institute of Technology, Nirma University

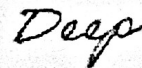


Dr Shibu Pillai

Idea Lab Co-ordinator,
Chemical Engg. Dept., Nirma University



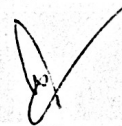
Dr R N Patel
Director, Institute of Technology,
Nirma University



Signature of Student2

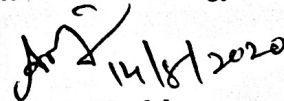
Deep Patel

16BCH043



Dr Leena Bora

Mentor,
Asst. Professor, Chemical Engg. Dept.
Institute of Technology, Nirma University



Dr Ankit Thakkar

Idea Lab Co-ordinator,
Institute of Technology, Nirma University

1.1 Introduction

The concept of 'artificial leaf' employs the photocatalytic splitting of water. The idea is to utilize energy from the solar spectrum and use it to oxidize water to oxygen and hydrogen. If this is connected to a fuel cell it reverts chemical energy to electrical energy, and a closed-loop energy circuit can be designed. Conventional approaches have used the solar spectrum to generate electricity and then use it for other applications. Still, one must bear in mind that each conversion of energy is entailed with a lot of losses. The aim of this project is to successfully create a solar cell capable of splitting water into clean fuel and combustion supporters (hydrogen and oxygen). This provides an alternative to fossil fuels and other non-renewable sources of energy.

The cells that have been designed to harness energy from the sun comprise of DSSCs (Dye Synthesized Solar Cells), catalysts with a perovskite structure, and by far the most abundant, Silicon-based solar cells. DSSCs have achieved little success in commercialization because of low efficiency, poor stability of the cell, photodegradation of the dye, and leakage of electrolyte. The payback period for DSSCs exceeds their lifetime over ten times, making it absolutely impossible to compete with fossil fuels.

The approach adopted here is to overcome the problems associated with dye synthesized solar cells. The catalyst synthesized in this method should operate effectively in the visible region. A large portion of the solar spectrum belongs to the IR region which means that the energy from this portion is low and diffused. Any attempt to utilize this for water splitting would be ineffective. For water splitting, the bandgap energy equivalent must match the redox potential of water. The best attempt to do that is to synthesize a catalyst that has a bandgap in the visible region. TiO_2 is commonly used as a photocatalyst; however, its energy corresponds to $>3\text{eV}$, which indicates it lies in the UV region. A hybrid system would tune the bandgap in a manner that allows maximum utilization of the visible region, which constitutes 46% of the solar spectrum.

Hence CuO , Cu_2O , and TiO_2 systems are developed for this project. Also, it indicates that a dye wouldn't be required for the catalyst; consequently, the stability and lifetime of the cell is vastly improved. The added advantage of this system is this system displays less ecotoxicity as compared against silicon-based solar cells. The scope of this project is to effectively create a solar cell that is able to generate electricity, which can be used to split water. A small cell might not generate enough potential to achieve water splitting, but solar cells such as these could be stacked in tandem, and it could work like a battery to increase current and potential drop. The only bottleneck is to achieve maximum surface area for solar radiation absorption and transparency of the glass being used as a substrate.

1.2 Literature Survey

1.2.1 Concept of Artificial leaf

1. Mimicking the function of leaf, i.e conversion of sunlight into chemical energy by splitting water to produce Oxygen and water equivalents.
2. Four electron-hole process [1].

Downfalls of previous attempts with Wired configuration [2-40]

1. Highly expensive light absorbing materials [(Al)GaAs; GaInP] and other fuel-forming catalysts [Pt;RuO₂;IrO₂].
2. Requirement of strongly acidic/basic medium which ultimately leads to corrosion/caustic embrittlement.
3. High Ohmic and hydraulic loss.
4. Very low overall efficiency (max. reported: 5% in acidic/basic medium and wireless config.; 2.5% in neutral medium and wireless config.)

Transition metal oxides as catalysts for artificial water splitting [41-46]

1. The oxidation of water to Oxygen and hydrogen involves 4 electrons and 4 protons.
2. Major barrier is to avoid high energy species formation like OH•
3. Transition metals provide a multi electron pathway which overcomes the formation of hydroxyl radicals.

Parameters of proposed process

1. pH conditions: neutral
2. Working Temperature: 298.15K
3. Pressure: 1 atm
4. Type of cell as an artificial leaf: Perforated Triple junction with amorphous silicon photovoltaic interface
5. Top side: Hydrogen evolving layer
6. Bottom side: Oxygen evolving layer

Structure of the previous best cell for water splitting

1. O₂ evolving complex (OEC) of previous best cell
2. Co complex is used as an OEC. (Co-cubane(extended from corners))
3. It self-assembles upon oxidation of Co²⁺.
4. It self-heals and can operate in buffered electrolyte.
5. Pure or natural water at room temperature can be used. (Similar to photosynthetic organisms)
6. It is directly deposited on ITO .

More electronegative than Mn .H₂ evolving layer of previous best cell Ternary alloy (NiMoZn).

Interfaced directly with commercial triple-junction amorphous silicon (3jn-a-Si) solar cell.

Interface of previous best cell

Stacked amorphous Silicon junctions deposited on Stainless Steel (SS) substrate and coated with Indium Tin Oxide (ITO). A commercial grade silicon wafer can be purchased to be used as the interface.

Various electrolytes used in previous best cell

1. 1M K_3BO_3
2. 0.1M KBr

1.3 Major Objectives Proposed

1. Mimicking the photosynthesis to generate Oxygen and Hydrogen with inorganic/organic materials as a fuel-forming catalysts interfaced with light-harvesting semiconductors.
2. Role of a catalyst:
3. To capture the wireless current that actually drives the water-splitting.
4. To overcome the water oxidation barrier (1.23V) and overpotentials (if any).
5. To reduce the ohmic resistance, hydraulic path resistance by used perforated 3-junction catalysts.
6. To increase the overall efficiency of existing technology .
7. To reduce the cost of the overall process.
8. To make this process commercially available.

1.4 Objectives Achieved

1. Developed a solar cell with maximum current efficiency than that of conventional solar cells for solar water splitting.
2. Selection of best suitable catalyst for solar water splitting from four potential candidates.

1.5 Objectives Not Achieved

1. Characterization of few catalysts are not done.
2. Quantification for the amount of hydrogen produced is not done.

1.6 Technical Difficulties Faced

1. Highly expensive light absorbing materials [(Al)GaAs; GaInP] and other fuel-forming catalysts [Pt;RuO₂;IrO₂].
2. Requirement of strongly acidic/basic medium which ultimately leads to corrosion/caustic embrittlement.
3. High Ohmic and hydraulic loss.

4. Very low overall efficiency (max. reported: 5% in acidic/basic medium and wireless config.; 2.5% in neutral medium and wireless config.)

1.7 Experimental Setup and Results

1.7.1 Catalyst Preparation Techniques

CuO/Cu₂O/TiO₂ system was prepared by the conventional sol-gel approach. The methodology has been adapted from [1]. Titanium butoxide was added to isopropanol in the ratio 1:5 (40ml:200ml). The mixture was vigorously stirred for over 30 minutes and labeled as solution A. Copper sulfate was solubilized in deionized water, maintaining stoichiometric equivalents with titanium. The mixture is stirred for 30 minutes to ensure complete dissolution. This solution was labeled as stock solution B. This is followed by a controlled dropwise addition of copper sulfate solution to titanium isopropoxide(B to A) with the help of a burette, maintaining vigorous stirring. The reaction mass was allowed to sit at room temperature for ~3h. After a gel-like consistency was achieved it was oven-dried overnight at 100°C. This resulted in the stripping of excess solvent from the reaction mixture, and a powdery mass was obtained. For conversion into oxide particles, calcination was carried out at 500°C for at a ramp of 10°C/min for 6 hours. These were used as the active catalytic agent in the production of energy from sunlight.

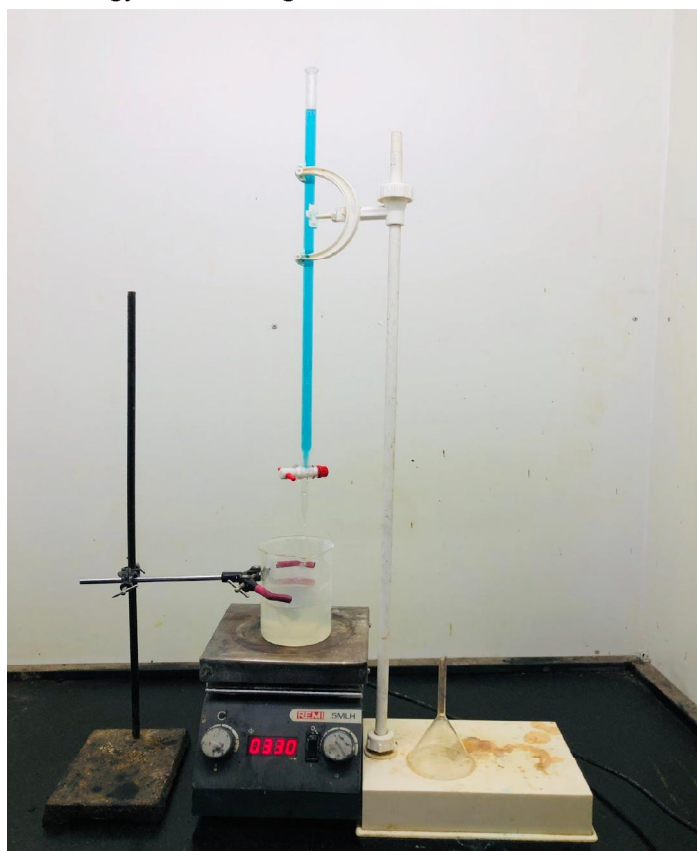


Figure 1. Experimental apparatus for synthesis of CuO-TiO₂ catalyst

The synthesis of V₂O₅ was done by the co-precipitation method. Sodium metavanadate solution was mixed with concentrated HCl solution at 343K with constant stirring for 2 hours. Urea

was added as a precipitating agent. The final orange-red slurry was heated overnight at 393K, followed by calcination at 773K for 2 hours. Hence, the brownish-black powder of vanadium pentoxide obtained was characterized by FTIR, SEM, EDX, and XRD. The support matrix of $\text{TiO}_2\text{-SiO}_2$ (equimolar composition) was prepared by adding a TiCl_4 solution to NaOH solution (conc.), followed by constant stirring at 334K for 3 hours. Finally, Sodium silicate with conc. HCl solution was added in the slurry, and isothermal stirring at 334K for 4 hours was carried out. Then the slurry was heated overnight at 393K and calcined at 773K for 2 hours. Further, to remove sodium ions impurity, vacuum filtration for 5 hours was carried out. Final moisture content was removed from the powder by heating the powder at 393K for 6 hours, after vacuum filtration. Finally, the catalyst material was impregnated on the catalyst matrix by the conventional wet impregnation method. The final catalyst was prepared with 5% (w/w) Vanadium Pentoxide on $\text{TiO}_2\text{-SiO}_2$ support to maintain the best possible thermal and mechanical stability of Vanadium Pentoxide, as justified in literature [2-20].

1.7.2 Construction of Solar Cell

The anode and cathode of a solar cell are prepared by using ITO (Indium Tin Oxide) sheet, with graphite coating. The graphite layer was coated on the ITO by mechanical dispersion of pencil lead. Further, both the anode and cathode are coated with the catalyst layer by the dip-coating technique. It is important to note that the catalysts are prepared such that it possesses electron-withdrawing layers, and hence no extra need coating of additional electron or proton transfer layers are required. Finally, such double-coated electrodes are held together with the help of a crocodile pin, with a dilute NaOH solution inserted between the double-coated electrode, which acts as an electrolyte. It is important to note that no harmful electrolytes are used during solar cell construction, which enhances the viability of such a sustainable design of our solar cells. Figure 2 shows our finally developed solar cell, which was used with the different catalysts for water splitting in the presence of sunlight.

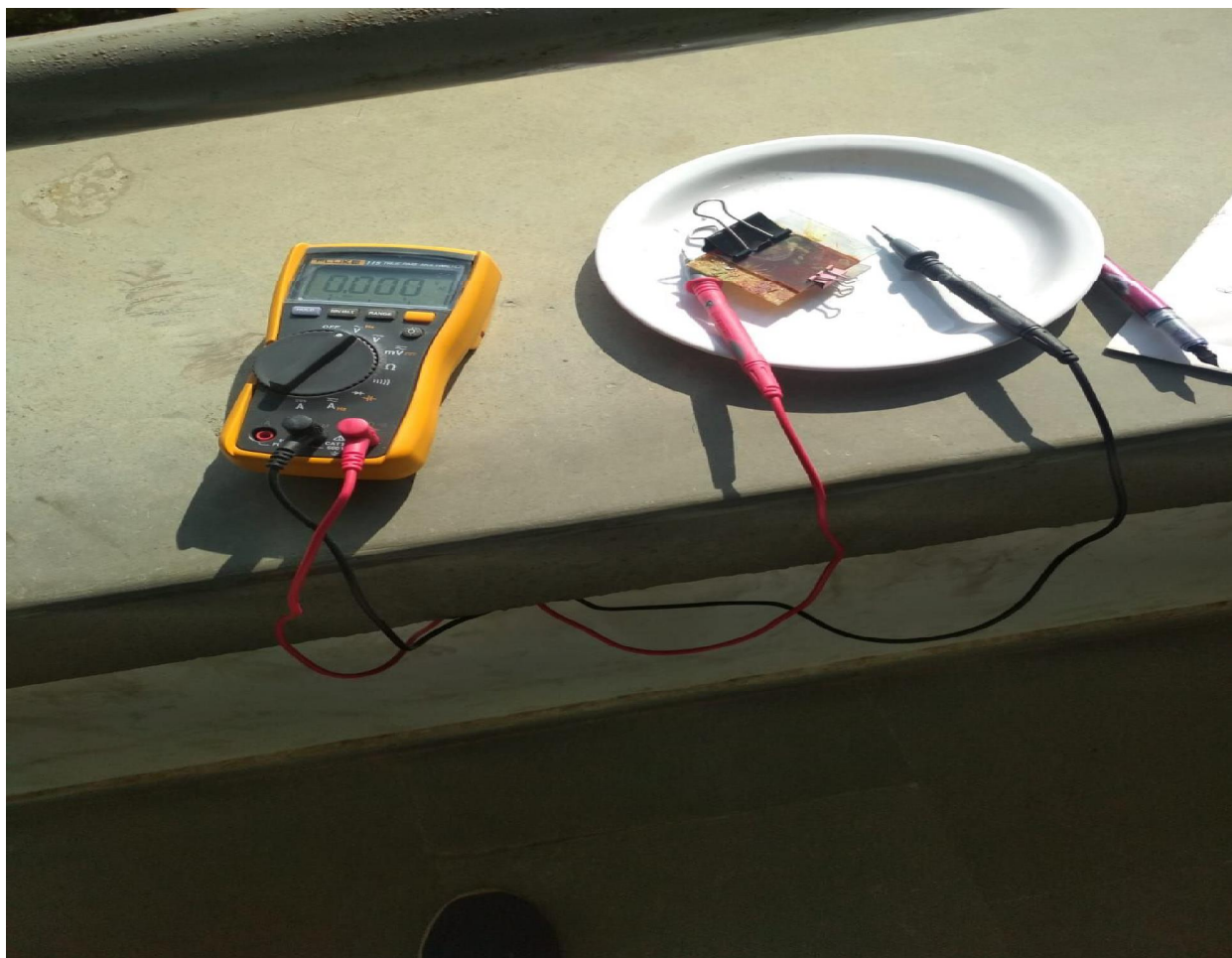


Figure 2. Final Construction of Actual Solar Cell

The voltage and current of the solar cell were measured using a multimeter (as shown in figure 1), with an error of ± 0.01 V or A. The current and the voltage measured was tip-to-tip, i.e. the corresponding quantities are measured between two tips of the anode and the cathode; not between the surfaces of anode and cathode. It is because the tip-to-tip current and voltage are the actual quantities that we will be getting after all direct and indirect losses from the electrodes.

1.7.3 Graphene Oxide Synthesis

Graphene incorporation into the catalyst was expected to enhance the conductivity of the solar cell and cause a more bathochromic shift in the bandgap [21-30], enabling enhanced utilization of the solar spectra for energy harvesting. Graphene was synthesized using an electro-exfoliation approach, and the chemical route using coal as a starting material. Electro-exfoliation of graphite consists of a water/electrolyte mixture, a sulfate salt, and sodium lauryl sulfate as a surfactant to avoid aggregation. For this purpose, pencil leads (2B) were collected and dipped into the electrolyte while being connected to a power source. This led to the consumption of the electrodes and the generation of graphene nano-sol. The black precipitate was added given water washes followed by ethanol washes to aid filtration and removal of ion leachates. Electrolytes used for this purpose were nitric acid (1M) and sulfuric acid (1M). Sodium nitrate could also be substituted for nitric acid for this purpose.

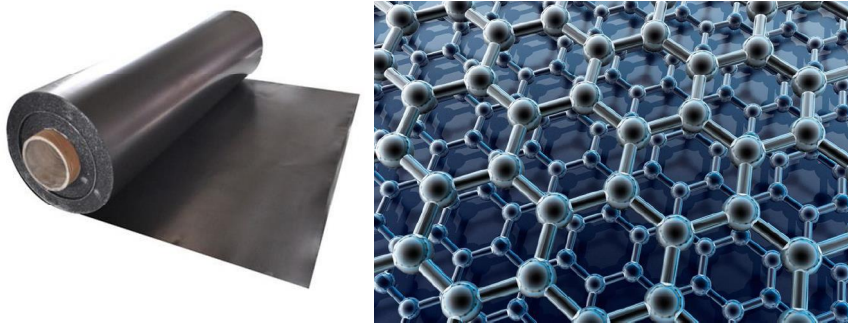


Figure 3. Actual Sheet of Graphene and its molecular arrangement [31]

The second approach dealt with chemical exfoliation of coal as an alternate substrate to graphite. About 2.5 g of coal was used as the starting substrate and 120 ml of concentrated sulfuric acid was added to the coal under vigorous stirring for a prolonged time interval of 24 hrs. The temperature was maintained at 80°C. The resulting precipitate was washed in dilute nitric acid and centrifuged at ~8000rpm for 15 minutes. The process was given 5 repetitions to remove dissolved ions from the precipitate or other adsorbed impurities. Following the washes, it was ball milled along with the CuO/TiO₂ catalyst for uniform dispersion. Finally, the composite catalyst was allowed to calcine in a muffle furnace for 6 hours at 500°C.

1.7.4 Working of the Solar Cell

As shown in figure 4, when the natural sunlight falls on the catalyst surface, an electron-hole pair is generated. Since our catalysts already have an electron-transporting layer, it reduces the probability of electron-hole pair recombination by removed electrons from the catalysts and thereby transferring it to Cathode, where electrons recombine with H⁺ to generate H₂, and the holes created are transferred to Anode, where OH⁻ ions lose its electron to generate O₂. It is important to note that no dyes or other chemicals [32-45] are required in our designed solar for filtering the solar spectrum, the credit of which must be attributed to in-built electron transporting layers, which reduces the further excitation of electrons due to IR to higher vibrational levels and thereby reducing the kinetic energy loss of electron associated with such excitation and de-excitation process. The absence of such losses is confirmed by comparing our output current and voltage with conventional solar cells in literature, which were initially designed with dyes to filter the solar spectrum.

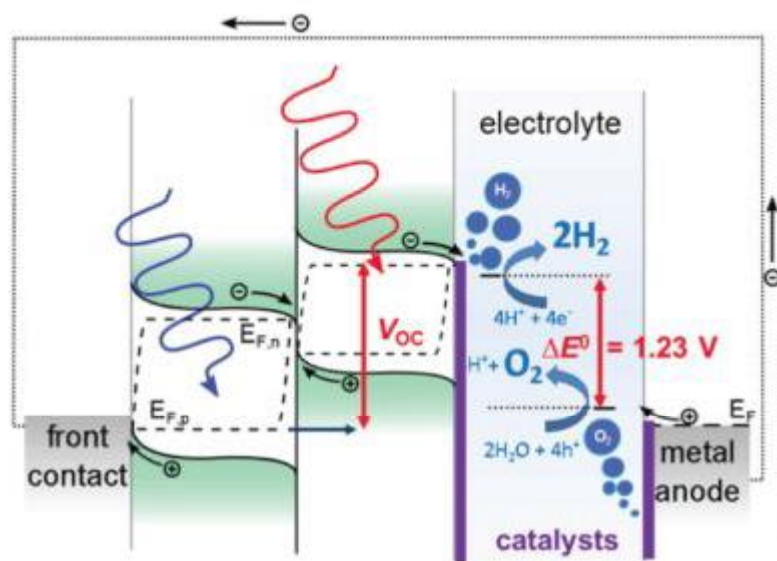


Figure 4. Detailed working mechanism of designed solar cell [46]

1.7.5 Characterization of Catalysts

The Physico-chemical properties of Vanadium Pentoxide catalyst were determined by SEM, EDX, XRD, and FTIR techniques. The band-gap of the catalysts were determined using UV-Vis spectroscopy.

SEM image of $\text{TiO}_2\text{-SiO}_2$ matrix support (not attached hereby) was observed to have a shape of nanoflower with average diameter of around 15 nm. When V_2O_5 is impregnated on the support, the clusters of V_2O_5 dispersed on the support to yield nanorods of 0.1 micron diameter as seen from figure 5. Such dispersion of catalyst on the support was observed due to higher catalyst-support interaction as compared to catalyst-catalyst interaction. Exact quantification of interaction may be done by TPD studies, but is not provided hereby since it is not within the scope of current study.

FTIR data (not attached hereby) were observed to show O-V-O, Si-O-Si, Si-O-Ti and Si-O-V bonds, which further enhances our claim of V_2O_5 synthesized on $\text{TiO}_2\text{-SiO}_2$ support. Also VO_5^- repeating units were observed to be present from FTIR plots, which further corroborate our claim. It is important to determine the phase of the catalyst along with its structure, and XRD characterization was carried out.

XRD data (not attached hereby) showed that TiO_2 and SiO_2 were present in anatase phase. Further no clear crystal structure of V_2O_5 was observed, which helps us to conclude that it has an amorphous phase. Finally, the composition of the catalyst was determined by EDX spectroscopy. Corresponding results can be seen in figure 6, which shows the presence of 5% (w/w) Vanadium Pentoxide, and 47.5% (w/w) of Silica and Titania, each.

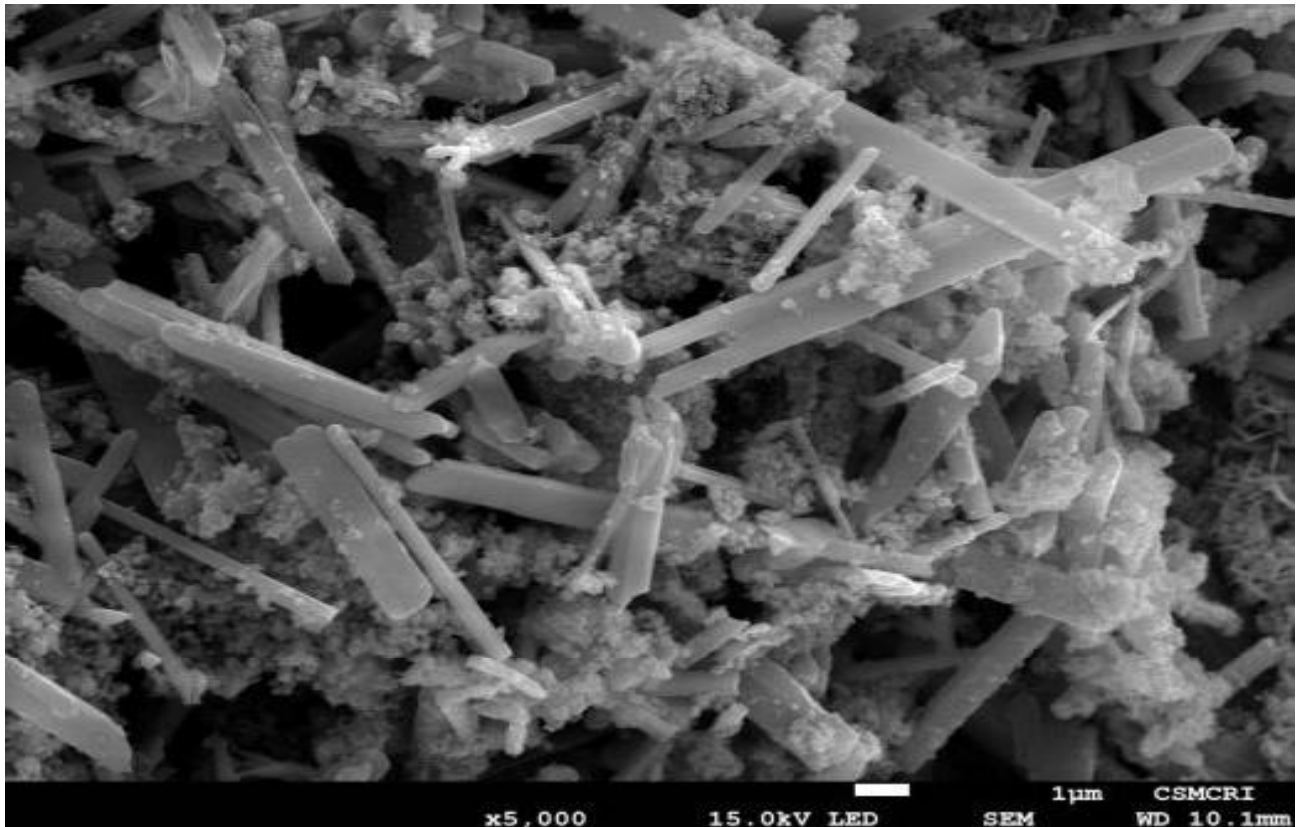


Figure 5. SEM image of Vanadium Pentoxide doped on Silica and Titania support

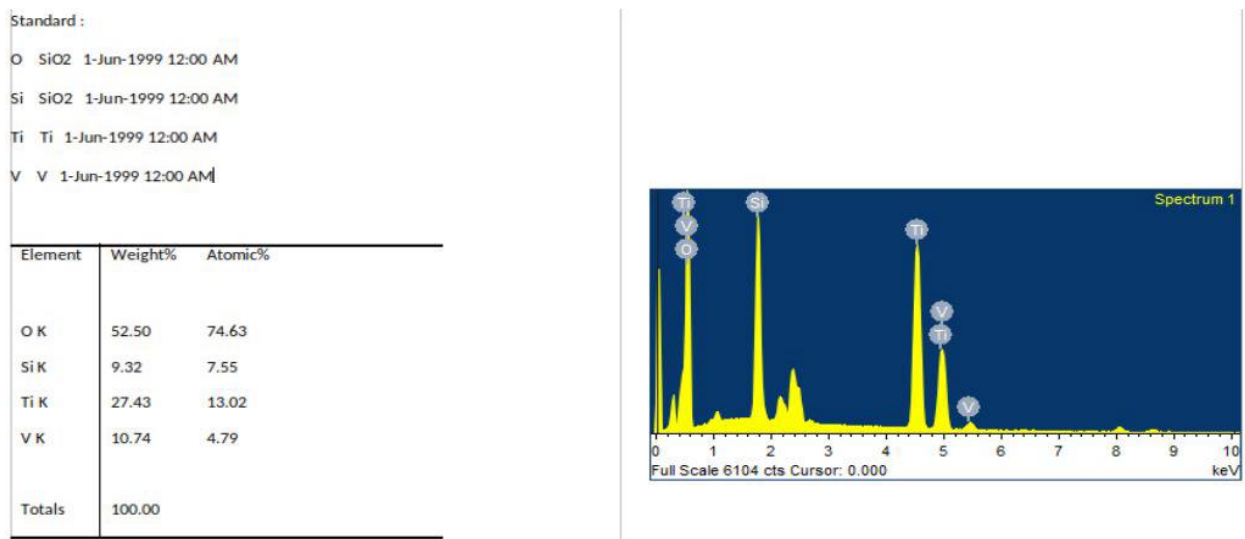


Figure 6. EDX data of Vanadium Pentoxide doped on Silica and Titania support

1.7.6 Estimation of bandgap from the UV

The band gaps of all the catalysts were determined by determining the wavelength of absorption in the UV-Visible region of the spectrum by UV-Visible spectroscopy. Corresponding results can be seen in figure 9. Prior to determination of absorption wavelength, calibration of UV-Visible spectrophotometer was performed by determining the absorption spectrum of KMnO_4 solution, and comparing the same with literature (refer figure 7). After determining the absorption wavelength of all three catalysts, the corresponding band gap is determined by tauc method. (refer figure 10)

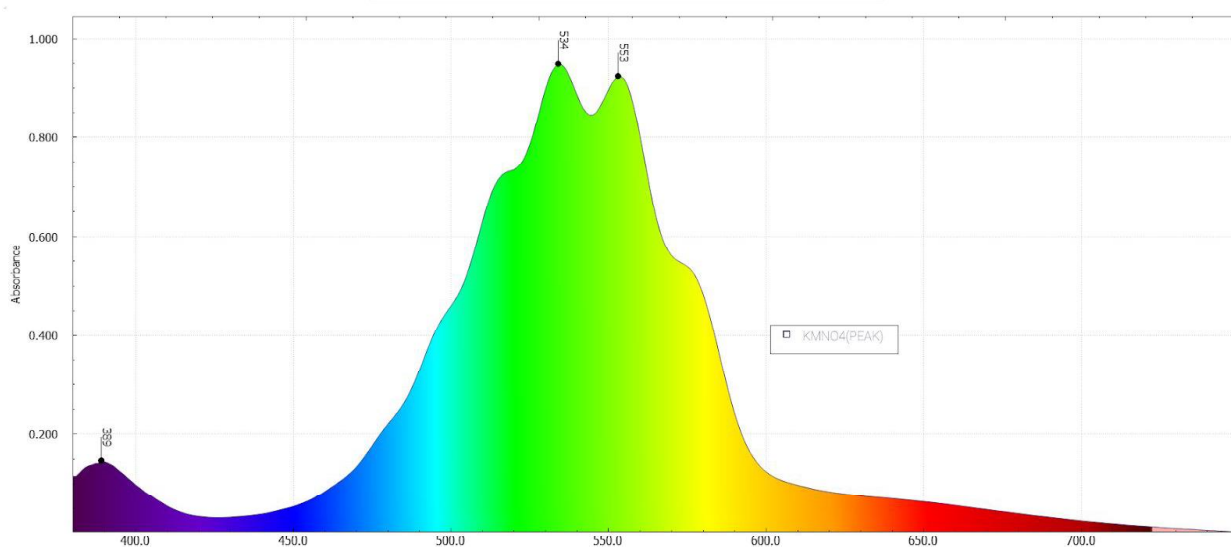


Figure 7. Calibration curve for UV-Visible spectrophotometer with KMnO_4 solution

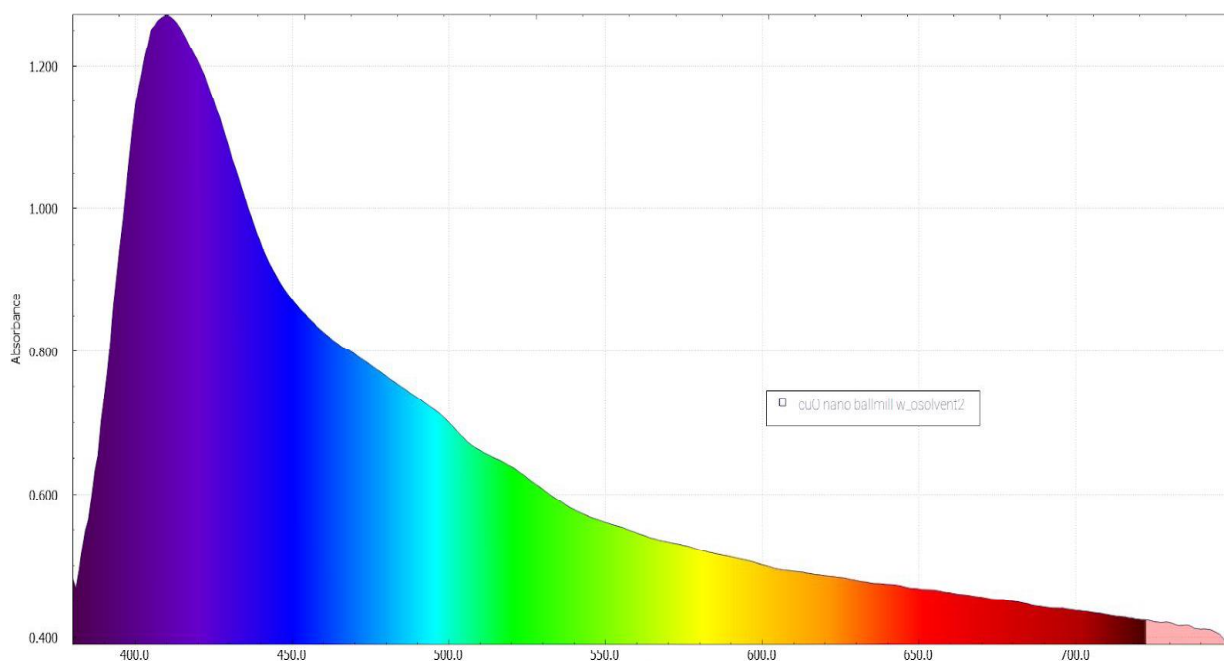


Figure 8. UV-Visible absorption characteristic curve for CuO-TiO_2 catalyst

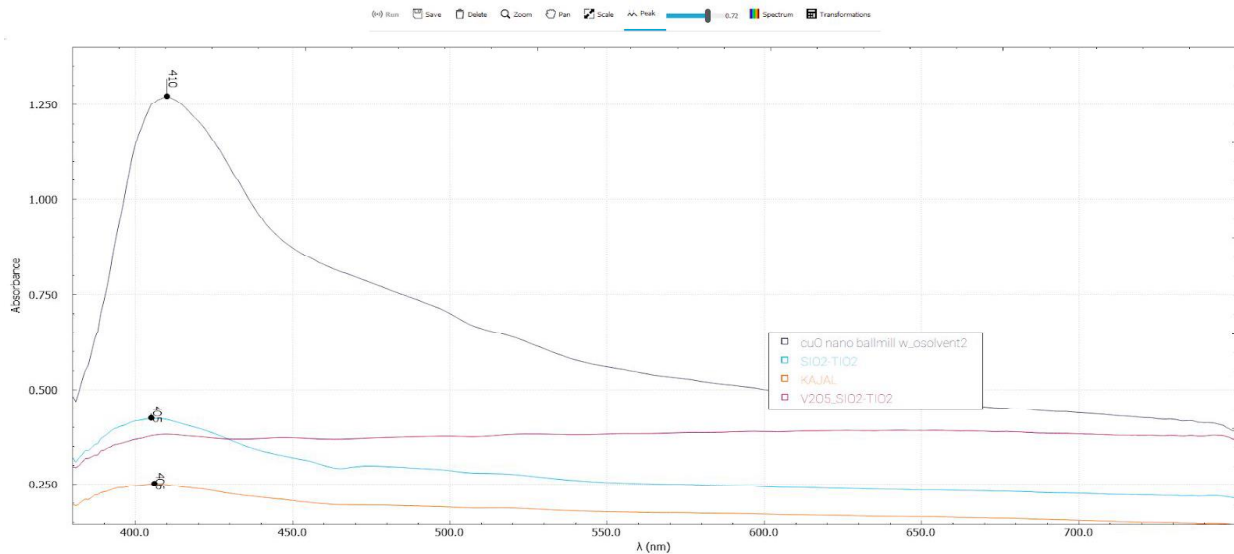


Figure 9. UV-Visible absorption characteristic curve for all the catalysts

As seen from figure 10, the lowest band was observed for Vanadium Pentoxide Catalyst, owing to its smaller particle size, higher contact surface area, more dispersion of catalyst on support, and hence lesser resistance. Hence, Vanadium Pentoxide catalyst synthesized hereby is a best suitable catalyst due to appreciable lower band-gap. However, an interesting part is that CuO/TiO₂ catalyst was observed to have a higher band gap, contrary to our intuition based on its physical and chemical properties. So, we determined the output current and voltage of the solar cell having CuO/TiO₂ as a catalyst (refer section 3 for details on its construction). Albeit its higher band gap, it was surprisingly observed to produce 1mA current, and an output voltage of 0.15 V. The current observed hereby was observed to be the largest than that reported in literature till date (0.8 mA MoS₂/Au), and hence one should not overlook CuO/TiO₂ from the list of potential candidates of catalysts. However, there is still some scope of improvement, since the resistance of 21 ohm was observed for this catalyst, which can be reduced significantly by doping it with a superconductor (having zero band-gap) like graphene.



Figure 10. Band-gaps of all the catalysts

1.8 Budget Analysis

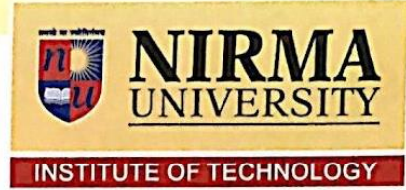
1. Budget Sanctioned: Rs. 1,00,000/-
2. Budget Utilized: Rs. 68,115.65/-
(Personal Fund Utilized: Rs. 40,000/-
Department Fund Utilized: Rs. 10,000/-)

| Budget Utilization | | | |
|---|-------------------|---------|------------|
| S.no. | Component | Qty | Price(Rs.) |
| 1 | Cu(II) Nitrate | 1 | 1818 |
| 2 | Titanium butoxide | 1(100g) | 1620 |
| 3 | acetyl acetone | 100ml | 1548 |
| 4 | MWCNT | 5g | 8227 |
| 5 | ITO sheet | 1 pack | 3500 |
| Total utilization from allotted budget | | | 18,115.65 |
| Total utilization from personal funds | | | 40,000 |
| Total utilization from department funds | | | 10,000 |
| Total utilization | | | 68,115.65 |

| Serial No. | Name of Product | Amount | Bill No. | Date | Consumable/ Nonconsumable | Dead Stock Number (if any) |
|------------|-----------------|--------|----------|------|------------------------------|----------------------------------|
|------------|-----------------|--------|----------|------|------------------------------|----------------------------------|

3. Budget Unutilized: Rs. 81,884.35 /-

Ref No. IT/Chem/PUR/Idea-LVB/2019-20/
Date: 26/11/2019



To,
TECHINSTRO
Plot No. 463, Row No-17,
Yadav Nagar,
Nagpur, Maharashtra-440026
India
Ph no. 9765849656

Subject: PO for the purchase of ITO Coated Glass Slides TIXZX004 as per Annexure I

Dear Sir,

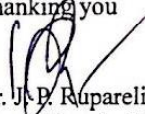
With reference to above, the undersigned is pleased to place an order as per the terms and conditions and with the rates described as per **Annexure – I**.

Total order value is **Rs. 8,208.90** (In words Rs. Eight Thousand Two Hundred Eight and Ninety Paise Only)

Terms and Conditions:

1. The above prices are inclusive of all taxes and tariffs.
2. Payment will be made within 20 days after delivery of the material.
3. Goods delivered should as per specification or as mentioned in the company's latest catalog.
4. Delivery charges to deliver material at Institute of Technology, Nirma University are included in PO.
5. Delivery period- With in 3 to 4 days from the receipt of the purchase order.
6. If items are supplied after the prescribed period of delivery then the penalty will charge 2% per week maximum up to 6%. However in case of delay the undersigned is free to cancel orders also.
7. Receipt should be in the name of the Nirma University, Institute of Technology and our GST Registration No is. 24AAATT6829N1ZY. And also mention HSN Code.

Thanking you


Dr. J. P. Ruparelia
Head, Chemical Engineering Department,
School of Engineering, Institute of Technology,
Nirma University

Encl: Annexure- I

Copy to:

1. Account Section 2. Purchase Department 3. Department Copy

Institute of Technology, Nirma University

Sarkhej-Gandhinagar Highway, Ahmedabad 382 481, INDIA, Ph.: +91-02717-241911/12/13/14/15 Fax: +91-02717-241917 Email: nit@nirmauni.ac.in Website: www.nirmauni.ac.in

Annexure – I

| Sr. No. | Name of Item | Quantity | Unit Price (Approx). | Total Amount Rs. |
|--------------------------|---|----------|----------------------|------------------|
| 1 | ITO Coated Glass Slides TIXZ004 Dimension: L 50mm x W 50 mm x Thickness 0.7 mm HSN Code – 70200019 Transmittance: Greater then 83% Resistivity - 10 ohms/sq. Brand - Techinstro Product Code – TIXZ004 | 6 | 1,303.00 | 7818.00 |
| Total | | | | 7818.00 |
| IGSTS (5%) | | | | 390.90 |
| Total Cost (Approx.) Rs. | | | | 8208.90 |

Ref No. IT/Chem/PUR/Idea-SSP/2019-20/
Date: 26/11/2019



To,
TECHINSTRO
Plot No. 463, Row No-17,
Yadav Nagar,
Nagpur, Maharashtra-440026
India
Ph no. 9765849656

Subject: PO for the purchase of FTO Glass TISX004 as per Annexure I

Dear Sir,

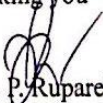
With reference to above, the undersigned is pleased to place an order as per the terms and conditions and with the rates described as per **Annexure – I**.

Total order value is **Rs. 9,906.75** (In words Rs. Nine Thousand Nine Hundred Six and Seventy Five Paisa Only)

Terms and Conditions:

1. The above prices are inclusive of all taxes and tariffs.
2. Payment will be made within 20 days after delivery of the material.
3. Goods delivered should as per specification or as mentioned in the company's latest catalog.
4. Delivery charges to deliver material at Institute of Technology, Nirma University are included in PO.
5. Delivery period- With in 3 to 4 days from the receipt of the purchase order.
6. If items are supplied after the prescribed period of delivery then the penalty will charge 2% per week maximum up to 6%. However in case of delay the undersigned is free to cancel orders also.
7. Receipt should be in the name of the Nirma University, Institute of Technology and our GST Registration No is. 24AAATT6829NIZY. And also mention HSN Code.

Thanking you


Dr. J. P. Ruparelia
Head, Chemical Engineering Department,
School of Engineering, Institute of Technology,
Nirma University

Encl: Annexure- I

Copy to:

1. Account Section 2. Purchase Department 3. Department Copy

Annexure - I

| Sr. No. | Name of Item | Quantity | Unit Price (Approx). | Total Amount Rs. |
|--------------------------|--|----------|----------------------|------------------|
| 1 | FTO Glass TISX004 Dimension: L 50 mm × W 50 mm × T 1.1 mm Resistivity: - 7-10 ohms/sq. Transmittance: - ≥ 83% HSN Code - 70200019 Product Code-TISx004 Brand - TECHINSTRO | 5 | 1,887.00 | 9435.00 |
| Total | | | | 9435.00 |
| IGSTS (5%) | | | | 471.75 |
| Total Cost (Approx.) Rs. | | | | 9906.75 |

1.9 Conclusion and Future Work

From this study, we conclude that the list of potential candidate for solar water splitting in natural sunlight at industrial scale are:

1. V_2O_5/TiO_2-SiO_2
2. $CuO-TiO_2/Graphene$

However, detailed study is still required to further investigate physico-chemical properties of these two potential candidates, along with determination of its performance at large scale before providing a final verdict.

1.9.1 Future Scope and applications

1. Hydrogen can be used to provide heat. Heating – as well as cooling and cooking – are critical applications worldwide.
2. Fuel cells are a modular, scalable technology that can be used for CHP.
3. Hydrogen can be substituted for natural gas in existing gas distribution networks.
4. NERS process

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