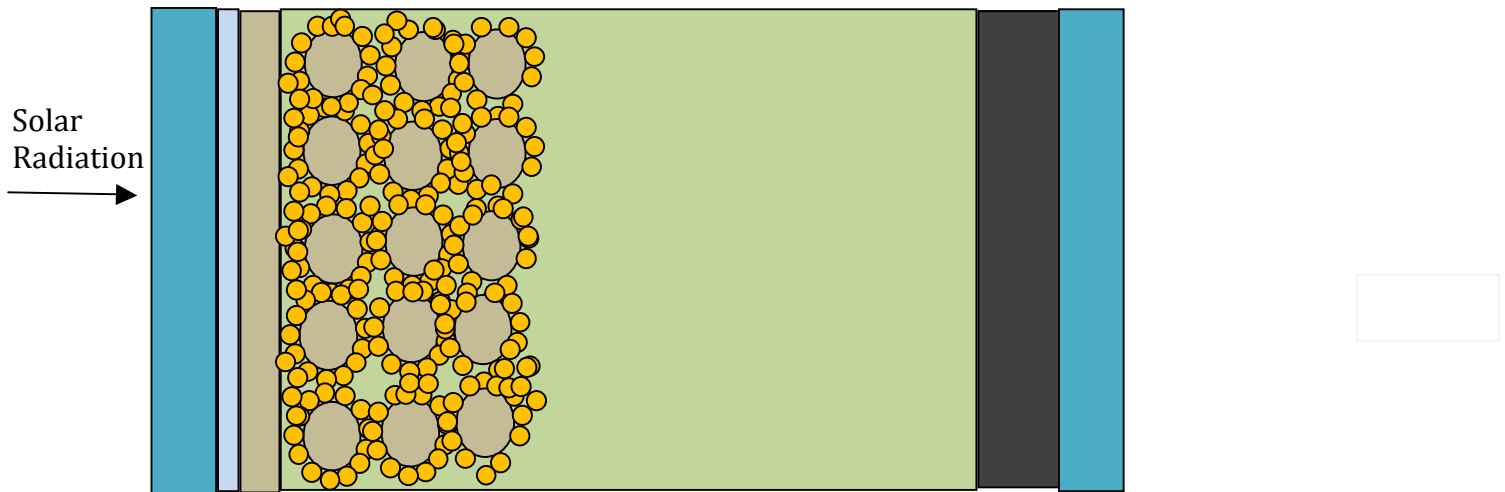


## CdS quantum dots based solar cell

The need for an infinite source of energy has been one of mankind's primary objective all throughout human history. Early man found timber as most abundant source of energy as it can be found all around him. Then in a more recent past he switched to fossil fuels and it gave the energy to drive the machines he invented. In 2007 it was estimated that 86.4% of mankind's primary energy came from fossil fuels which included coal, petrol and natural gases. The depletion and ever increasing price of fossil fuels has forced man to turn to the Sun for a more renewable source of energy.

The Solar Era started with the discovery of Photovoltaic effect by French physicist A.E.Becquerel . Later Albert Einstein's photoelectric effect in 1905 also marked a milestone in the path of Solar energy usage. In Bell's lab 1954 Gerald Pearson, Daryl Chapin and Calvin Fuller developed a photovoltaic cell able to develop energy that powers basic machines. Silicon based solar cells hit the market since the giving an efficiency of 6% initially and later it can be said to be approaching the theoretical limiting efficiency known as the Shockley-Queisser limit which is 33.7%.The high cost of manufacturing Si based monocrystalline solar cells led to the development of Quantum-dots-sensitized solar cells(QDSSC).



- CdS quantum dots
- Fluorine doped tin oxide
- Glass
- TiO<sub>2</sub> compact layer(blocking layer)
- TiO<sub>2</sub> (on which quantum dots are grown)
- RGO Cu<sub>2</sub>S
- Polysulphide Electrolyte

In a CdS quantum dots solar cell quantum dot CdS acts as a sensitizer on the surface of TiO<sub>2</sub> surface. Exciting the quantum dots with solar radiation, leads to the excitation of electrons from valence band to conduction band. The smaller the energy gap  $E_g$  known as the forbidden energy gap, more easily would it get excited to higher states. This excitation of electron in the quantum dots leads to the formation of an electron-hole pair formation. The electron being in a higher conduction band and the hole formed in valence band of CdS.

The excited electron is then transferred to the TiO<sub>2</sub> conduction which is lower in energy. This electron is further transferred to conduction band of the Fluorine doped tin oxide layer coated on glass surface. FTO conduction band has a lower energy than TiO<sub>2</sub> conduction band. This electron can thus be transferred into an electronic circuit carrying a load and finally it reaches the counter electrode and recombines with the hole generated.

The idea of solar paint is to develop an efficient and cheap method to generate energy using solar cells made of CdS, CdSe or CdS/CdSe quantum dots which can be painted literally onto any surface and then making a solar cell from it. Solar paint could be coated onto any surface using brush or even a basic spray paint approach.

The project began with the synthesis of quantum dot CdS based solar paint by 'growing' CdS on TiO<sub>2</sub> surface and then making a paste with it. A binder was used to bind the CdS properly onto FTO coated glass surface which had a layer of compact TiO<sub>2</sub> layer already on it. The main idea of the project was to study how spray painting the CdS onto a glass surface would affect its photovoltaic behavior.

## **Experiment**

The preparation of CdS on TiO<sub>2</sub> surface was done by using 0.1M CdNO<sub>3</sub> solution 0.1M Na<sub>2</sub>S stock solution and TiO<sub>2</sub> powder. 0.7985g of TiO<sub>2</sub> was weighed and stirred with 100ml ethanol in a round bottom flask for 15 minutes. To the solution, 1ml CdNO<sub>3</sub> was added drop wise followed by drop wise addition of 1ml Na<sub>2</sub>S. This serves as a method to grow insitu CdS quantum dots on TiO<sub>2</sub> surface. 50ml CdNO<sub>3</sub> and 50ml Na<sub>2</sub>S was added by the successive drop wise addition.

The CdS coated TiO<sub>2</sub> now needs to be coated on a compact layer TiO<sub>2</sub> that had already been generated on FTO coated glass surface. The FTO coated glass which needs to act as working electrode was purchased from Pilkington. FTO coated glass was cut in 0.9cmx6cm dimensions. The glass was washed with water and sonicated for 30mins in a prepared soap water solution. The glass was washed with distilled water and again sonicated for 15mins in ethanol. The FTO coated glass now dried by blowing air and was marked to differentiate them. A compact layer of TiO<sub>2</sub> can be generated on the FTO side on the coated glass by either treating with TiCl<sub>4</sub> or spraying with 0.2M TiAA (Titanium bis(isopropylacetate)). In the TiCl<sub>4</sub> method the FTO coated side was kept facing upward in a petridish and heated with 0.4M TiCl<sub>4</sub> solution at 70 degree Celsius in an oven for 30mins. A thin TiO<sub>2</sub> layer

was thus developed on FTO surface. The TiO<sub>2</sub> layer was then annealed by placing the electrode in an oven at 500 degree Celsius in an oven for another 30mins.

In the TiAA method, 0.2M TiAA was coated onto the FTO surface by spraying a definite no of layers of TiAA on the FTO surface at a temperature of 500 degree Celsius maintained on a hot plate surface. A time gap of 20s was maintained between each successive spraying to ensure the oxidation of TiAA and thus a compact layer of TiO<sub>2</sub>.

In our initial approach we tried to Dr blade the CdS quantum dot paste onto surface of FTO which had a layer of TiO<sub>2</sub> compact layer on it. The paste seemed to leave cracks on the CdS film. This problem was tried to be tackled by using a ethyl cellulose as a binder .A solution was made with 3% by weight ethyl cellulose in ethanol which was used to bind the CdS onto the working electrode surface. This was done by making a paste of 0.2g CdS, 1ml ethyl cellulose solution and 1ml ethanol. This was coated on the surface but the cracks couldn't be avoided but the CdS binded much more strongly onto TiO<sub>2</sub> compact layer. The film couldn't be removed even with normal scratching. This gave rise to the idea of spraying CdS, ethyl cellulose, ethanol onto the glass surface which could be a solution to avoid the cracks developed on CdS film developed in Dr blading technique.

The Spraying technique was tried with CdS for first time so we needed to know how the layer thickness or No of spray coats affected the photovoltaic performance of the cell. In spraying technique the solution of CdS was prepared by mixing 0.2g of CdS in a solution containing 1ml ethyl cellulose and 9ml ethanol solution by sonication and stirring it overnight. **The spray coat thickness dependent on the pressure of air flow through sprayer and speed or rate of spraying so, a much qualitative study was done to see the variation in photovoltaic performance.**

In the first experiment, the Spray technique was used to coat different layer prepared CdS solution keeping the TiO<sub>2</sub> compact layer constant. The TiO<sub>2</sub> compact blocking layer was sprayed using the TiAA method at 500 degree Celsius. The pressure of spraying was kept constant throughout the experiment. A constant 14 spray coats of TiAA was kept throughout the 1<sup>st</sup> experiment. The compact layer thickness was thus kept constant. A 'sweep over' spraying technique was done to make sure all the working electrodes have same constant layer of TiO<sub>2</sub> thickness and the initial burst of spray was avoided on the electrodes. The 'sweep over' spraying was manually done at almost uniform velocity. The CdS solution was sprayed with an interval of around 5s. The CdS spray coating was with 6, 15, 50 and 75 spray coats.

In the second experiment, the blocking layer of compact TiO<sub>2</sub> was varied keeping the CdS layer constant. The 'sweep over' spraying was done with 5,10, 20 and 30 coatings of TiAA and a constant layer of 6 spray coats CdS was maintained coated second experiment.

The electrolyte 1M Na<sub>2</sub>S, S was prepared by dissolving 6.0045g of Na<sub>2</sub>S and 0.8016g of Sulfur in 25ml ethanol is used for both the two experiments . The polysulphide electrolyte which is a redox couple S<sup>2-</sup>, S<sub>n</sub><sup>2-</sup> helps as a hole scavenger.

### **To prepare the counter electrode :**

Counter electrode is made by Dr blading Cu<sub>2</sub>S RGO (Graphene Oxide)paste onto the FTO surface coated on glass.

**Instruments used:**Absorbance of the CdS samples where calculated using a Shimadzu UV-3101PC UV-VIS-NIR Scanning spectrophotometer.

Photovoltaic data was collected using PARASTAT 2263 with a xenon source capable of shining 1Sun on an area of 0.28cm<sup>2</sup>

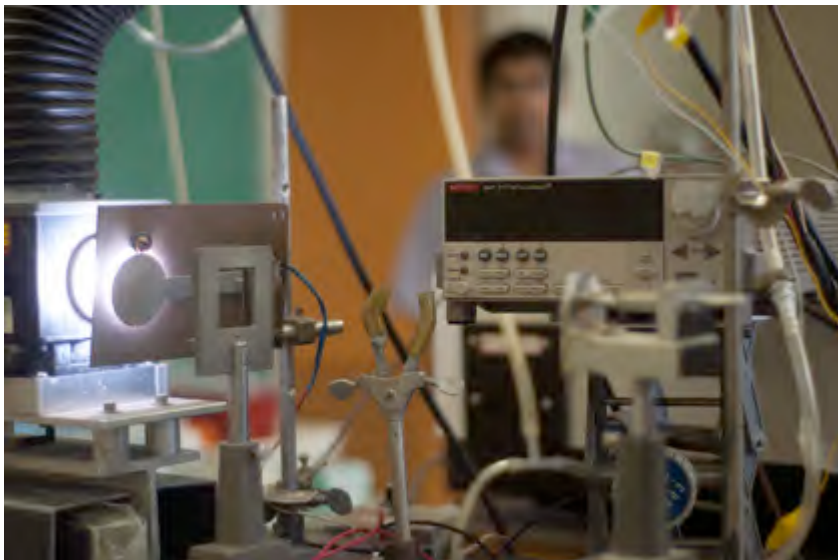


Image 1: The Xenon lamp used to shine 1Sun on sample kept on a holder

### **Cell Setup**

1 Sun was lighted onto an open cell sample through the circle of area 0.28cm<sup>2</sup>. The excited electrons are transferred from the conduction band of CdS to conduction band of TiO<sub>2</sub> and then it is transferred to the compact TiO<sub>2</sub> and finally to the FTO where it finds its way to the load.

The compact layer of TiO<sub>2</sub> acts as a blocking layer which prevents short circuiting when electrolyte comes in contact with the working electrode FTO. The electrolyte which is a redox couple S<sup>2-</sup>, S<sub>n</sub><sup>2-</sup> helps as a hole scavenger which transfers the hole to the counter electrode where it recombines with the electron coming from the load to counter electrode RGO, Cu<sub>2</sub>S.

The performance of the cell depends on lots of parameters and kinetics of electron transfer from each layer to the next. The TiO<sub>2</sub> takes away the electron from CdS and prevents its recombination as soon as excitation to conduction band.

## Results and Discussion

### Experiment 1: Varying CdS coats keeping TiO<sub>2</sub> constant at 14 spray coats.

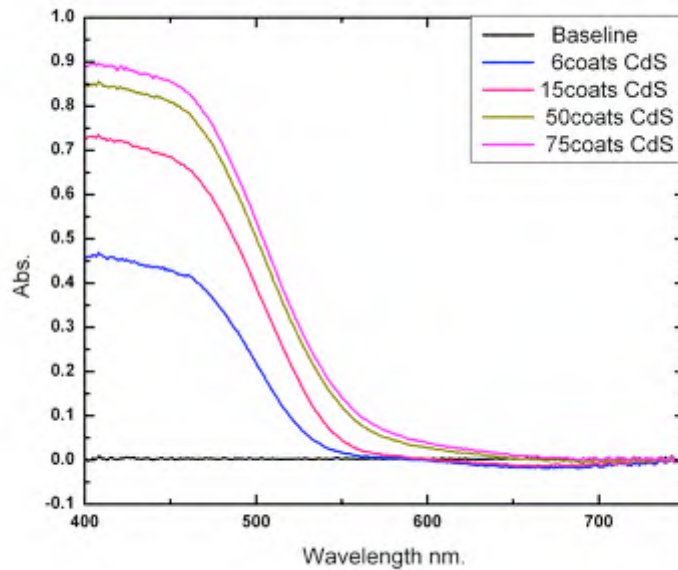


Fig1: Absorbance at different wavelengths gave maximum absorbtion around 400nm. The absorbance value increased as the no of spray coats where increased.

### The Current (mA/cm<sup>2</sup>) was plotted with time

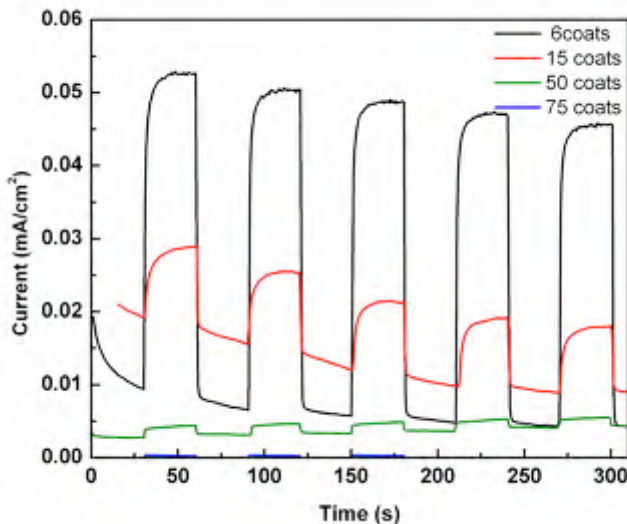


Fig2: The current increased as the no of coats decreased. The maximum current per unit area was observed for 6coats.

**The Current Vs Voltage curve was plotted for the following data**

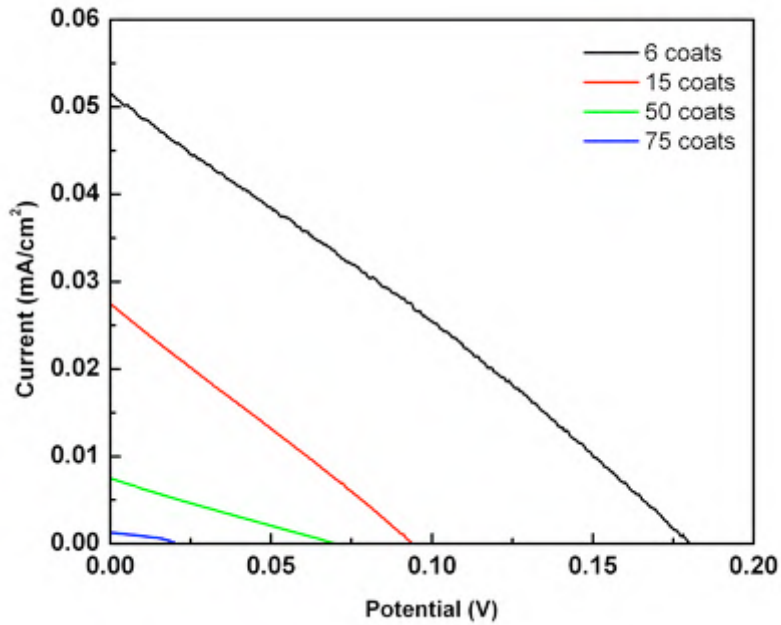
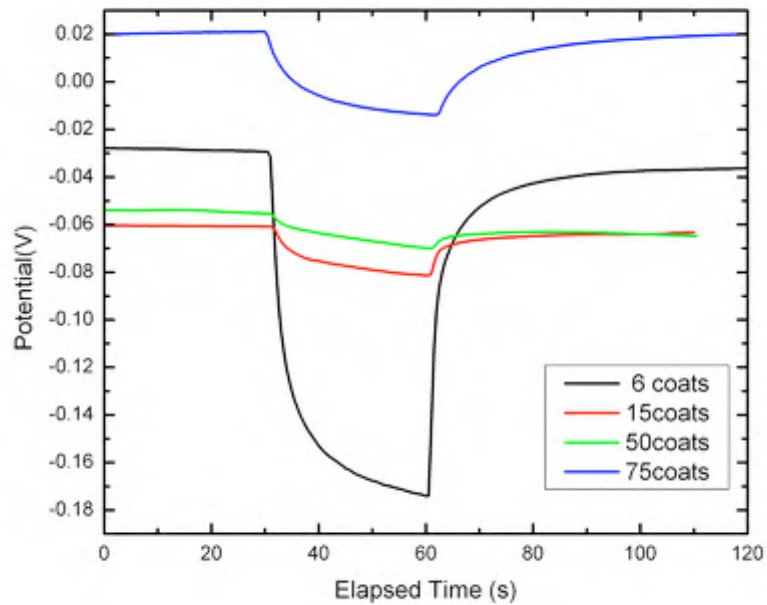


Fig 3: The Current Vs Voltage curve gave the maximum fill factor for the least no of coatings.

**Voltage Vs Time curve was plotted for the experiment**



It was evident from the curve that 6 coats gave the maximum voltage .

Experiment 2: The TiO<sub>2</sub> spray coats were varied keeping the CdS layers constant at 6 spray coatings.

Spray coats of 5, 10, 20 and 30 coats of TiAA was coated.

### Absorbance data

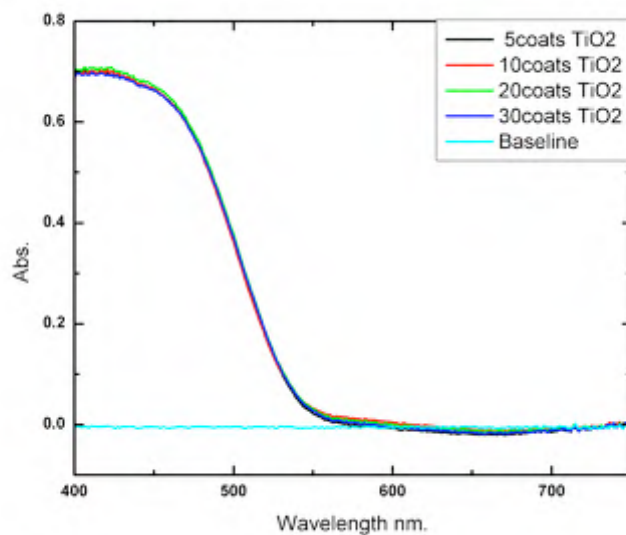


Fig 4: As expected they gave the same absorbance for all the different TiO<sub>2</sub> coats as the CdS coats where kept constant .This ensured that CdS coatings for all the samples where the same thickness as there absorbance peaks overlapped.

**Variation of Current (mA/cm<sup>2</sup>)with time(s) was studied for the experiment**

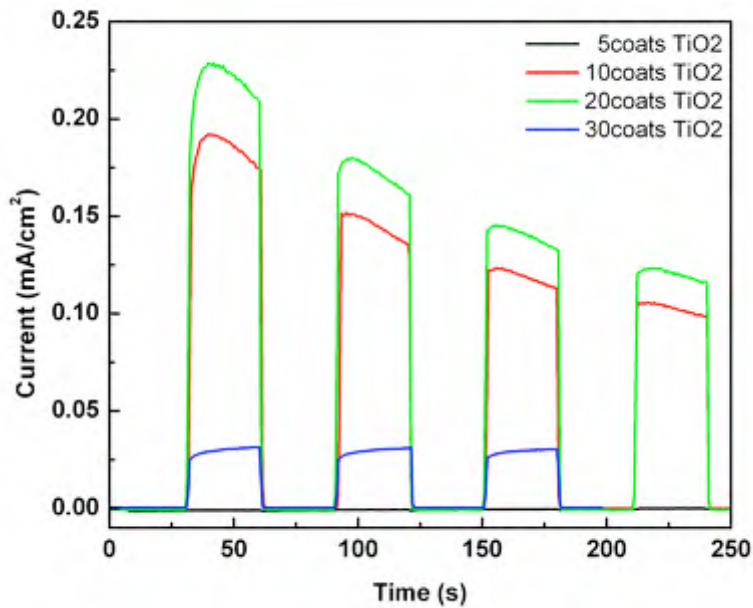


Fig 5: The cell gave a maximum current for 20coats of TiO<sub>2</sub> and least for 5 coats of TiO<sub>2</sub>. It increased from 5spray coats to 10 spray coats and gave a maximum around 20spray coats .Then it decreased from 20 to 30 coats .



**Current Vs Voltage was plotted for the experiment**

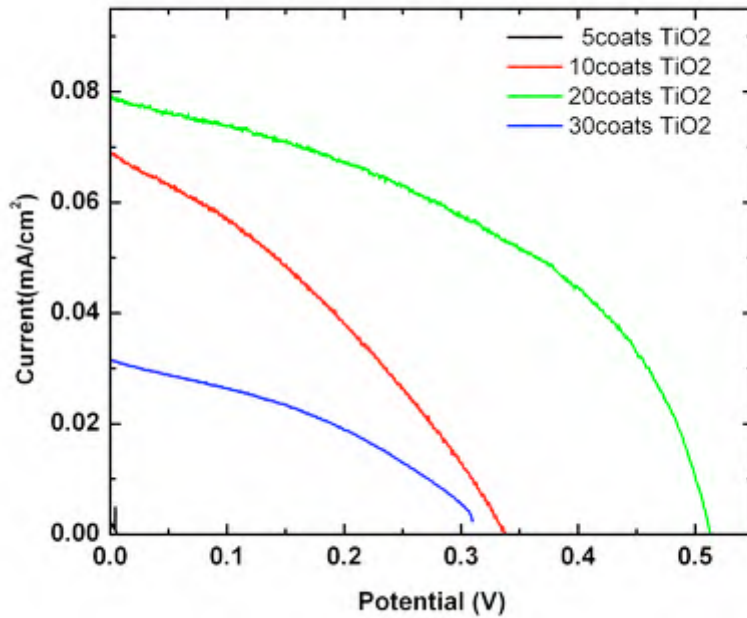


Fig 6: The Current Vs Voltage data gave a maximum fill factor for 20 coats. The fill factor (product of open circuit voltage and short circuit current-area under the curve) was increased from 5 coats to 10 coats to 20 coats where it showed a maximum. It then decreased from 20 to 10.

**Voltage Vs time was plotted for the experiment**

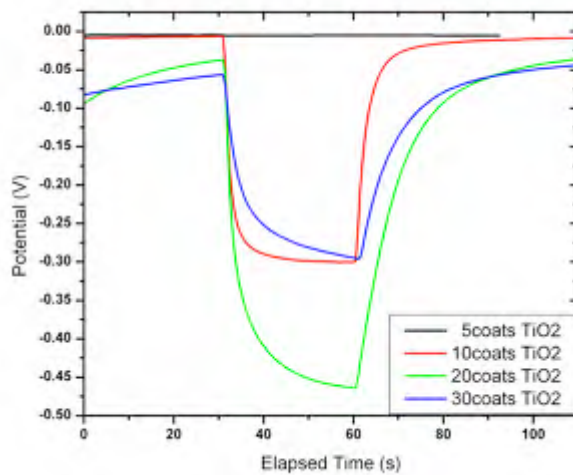


Fig 7: The voltage showed a maximum for the 20coats of TiO<sub>2</sub>

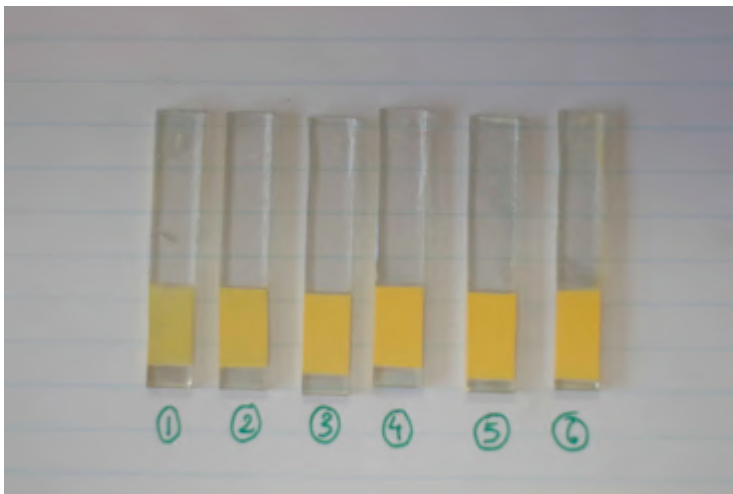


Image 2: Experiment 1 – CdS coating was varied keeping TiO<sub>2</sub> at 14 coat sprays.

## Conclusion

Spraying technique offers a much easier and 'crack-free' coating on the compact layer. Spraying method would be thus a much easier, cheaper and time saving technique when compared to the CdS film prepared using doctor blade on TiO<sub>2</sub> compact layer.

Experiment 1 led to the conclusion that the minimum amount of uniform CdS coatings gave a much efficient and better cell. The increase in no. of spray coatings decrease in current. This may be due to the fact that electrons would take more time to transverse through the CdS layer before reaching the compact layer of TiO<sub>2</sub>. Therefore a lesser no. of layers ensured better cell photovoltaic performance.

Experiment 2 led to the conclusion that TiO<sub>2</sub> coats should be sprayed uniformly around 20 coatings to ensure maximum cell performance. Anything more than 20 coatings would increase the cell resistance and thus decrease the fill factor and the current. The electron would take more time to reach the FTO if it had to transverse through a thicker TiO<sub>2</sub> compact layer. But if the coat was less than 20 coatings, the TiO<sub>2</sub> compact layer wouldn't act as a good blocking layer and more short circuiting would be happening between the contact between FTO of working electrode and electrolyte.

Therefore a minimum of 5 or 6 spray coats of CdS and approximate 20 spray coats  $\text{TiO}_2$  would ensure the a cell which show the best photovoltaic behavior.

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