Facilitation Centre for Industrial Plasma Technologies
Institute for Plasma Research

Plasma Processing Update

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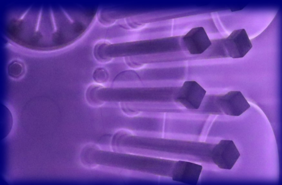
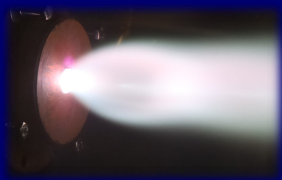
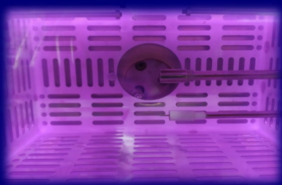
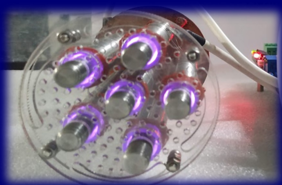


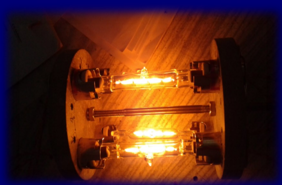

Inside this Issue

FCIPT Newsletter Team

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ARTICLES

Development of CZTS absorber based thin film solar cell at FCIPT

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Highlights

- **Indigenous Technology for Solar Cell.**
- **Magnetron Sputtering: Industry Friendly technique suitable for large area deposition.**
- **No disposal issues: Toxic Free constituents.**
- **Low production cost.**
- **Stability: No performance degradation with time.**
- **Longer production sustainability due to earth abundant constituents.**
- **Variable substrate: Rigid to flexible**
- **Compound semiconductor absorber CZTS (Cu_2ZnSnS_4) : Easy to vary elemental ratio makes it easy to control film properties.**
- **Multilayer Thin Film Structure**

While looking for a solar photovoltaic technology there are few things to be considered:

a. Indigenous technology
b. User friendly industrial technology (easy to make & scale up for large area)
c. Toxic free material (no disposal issues)
d. Abundantly available material (for future sustainability)
e. Low production cost

There are many photovoltaic technologies available in the market, but each of them have their own advantages and disadvantages as discussed below:

a. Crystalline Si based solar cell: To the best of our knowledge, Si-wafers required for this type of solar cell are not manufactured in India, resulting in imports which is an expensive affair.
b. Thin film Si based Solar Cell: Process of making this type of solar cell requires the use of Silane gas which is toxic and flammable.
c. CdTe based thin film Solar Cell: Cd is a toxic element and Te is scarcely available. This type of solar cell is not cost efficient in long run.
d. $CuInGaS_xSe_{2-x}$ based thin film Solar Cell: The lack of availability of rare earth elements like Indium (In) makes it difficult to fulfill large scale production requirements in future.
e. Perovskite thin film solar cell: this type of solar cell is a recent development and shows higher efficiency; however suffers from stability issues

Kesterite (CZTS) is a suitable candidate for absorber material in thin film solar cell from all perspectives because of its reasonable performance and earth abundant constituents. There are three types of Kesterite that are being used as absorbers:

a. Pure Sulfide: Cu_2ZnSnS_4 (Record Efficiency ~11%)
b. Pure Selenide: $Cu_2ZnSnSe_4$ (Record Efficiency ~ 12%)
c. Sulfo-Selenide: $Cu_2ZnSnSe_{4-x}S_x$ (Record Efficiency ~ 13%)

Selenium (Se) is a rare, toxic and costly material compared to sulfur (S). Among pure sulfide, mixed sulfo-selenide and pure selenide absorbers, pure sulfide has a higher band gap, uses only abundant elements and has completely non-toxic constitution. Therefore it is preferable both from the desire of a higher band gap absorber for the technical benefits of single junction solar cell and an environmental compatibility perspective to retain a selenium free CZTS (Cu_2ZnSnS_4) absorber. Compared to Selenium, handling of sulfur is safe making it suitable for large production in industry.

Typical qualities of the pure Sulfide based Kesterite material can be summarized as follows:

a. Made up of abundant elements

b. No disposal issues due to nontoxicity

c. Optimum band gap ~ 1.5 eV (direct band gap)

d. High absorption coefficient ~ 10^4 cm^{-1}

e. Low cost and less material thickness

f. Stable with time

Magnetron Sputtering is a well proven technology in Industry for large area coatings for different applications including solar cell applications (for CdTe and CIGS). Combination of sputtering technique and CZTS material is suitable for low cost sustainable solar cell technology. Development of high efficiency CZTS absorber based solar cell using sputtering method is our main focus at FCIPT.

Being a multilayer device following steps are used for the fabrication of such devices:

i. Cleaning of glass substrate using RCA cleaning method for better adhesion.

ii. Plasma cleaning of glass and deposition of thin Cr layer using magnetron sputtering on glass for better adhesion.

iii. Deposition of Mo layer on top of Cr layer which works as back contact of the device. (i.e., positive terminal of the device)

iv. Deposition of Cu, Zn, Sn mixture by magnetron co-sputtering with a optimized elemental ratio.

v. Sulfurization of the above mixture for the formation of CZTS compound layer which will work as a p-type absorber.

vi. Deposition of n-type thin layer of CdS using chemical bath deposition (CBD) process to form a p-n junction and work as buffer layer.

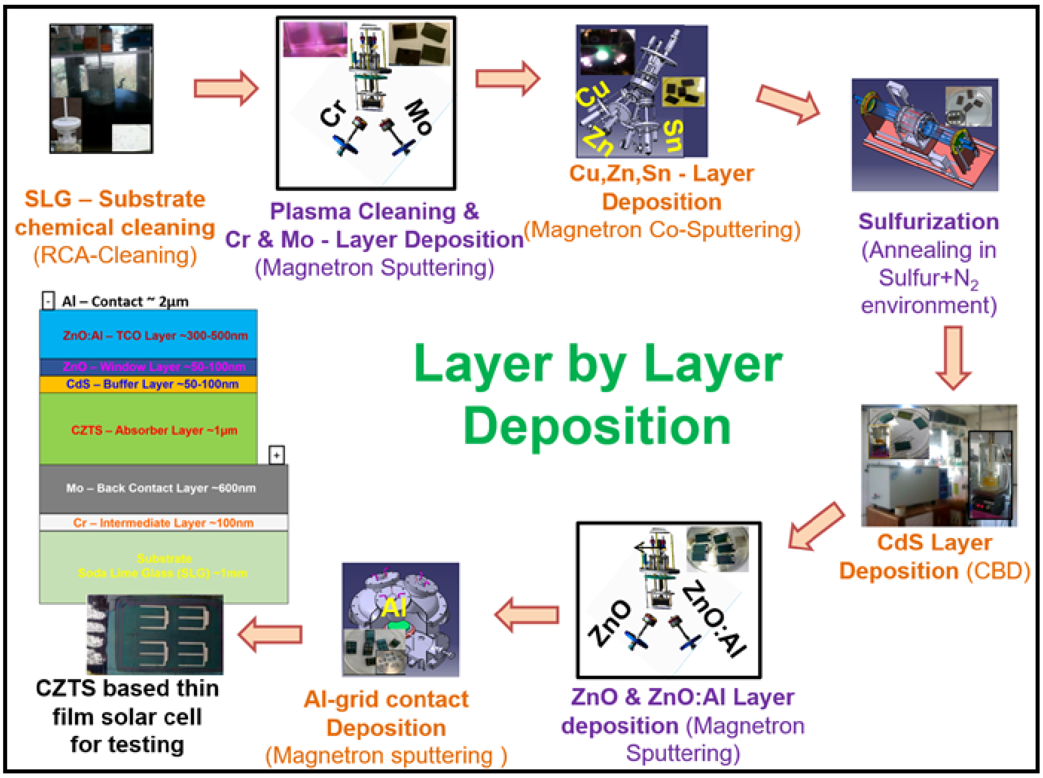

Figure 1: Deposition process of CZTS thin film solar cell

ARTICLES

vii. Deposition of thin intrinsic zinc oxide (i-ZnO) to act as barrier layer and aluminium doped zinc oxide (ZnO:Al) known as transparent conducting oxide layer to collect the generated charge particle using magnetron sputtering.

viii. At the end a comb shape Al contact is deposited using the magnetron sputtering which works as the negative terminal of the device.

The step wise layer by layer deposition of the device is shown in the figure 1. This multilayer thin film structure SLG/Cr/Mo/CZTS/CdS/i-ZnO/ZnO:Al work as a complete solar cell device.

Typical optimized properties of all the layers are summarized in the following table:

Sr. No.	Layer	Properties
1	ZnO:Al Layer	Low Resistivity ~<$5x10^{-3}$Ω-cm, High Transparency ~>85%, E_g ~3.3eV
2	ZnO Layer	High Resistivity, High Transparency ~>90%, E_g ~3.3eV
3	CdS Layer	High Resistivity, High Transparency ~>80%, E_g ~2.3eV
4	CZTS Layer	High Absorption Coefficient ~>$10^4$$cm^{-1}$, E_g ~1.5eV
5	Mo Layer	Very Low Resistivity ~<$5x10^{-5}$Ω-cm, Stable during device fabrication
6	Cr Layer	For Adhesion Improvement, Stable during device fabrication

After optimization, CZTS absorber based solar photovoltaic device was developed with 5% efficiency. The scanning electron microscopic (SEM) cross section image and I-V characteristics of the device are shown in figure 2. Further research work is in progress at FCIPT to increase the device efficiency.

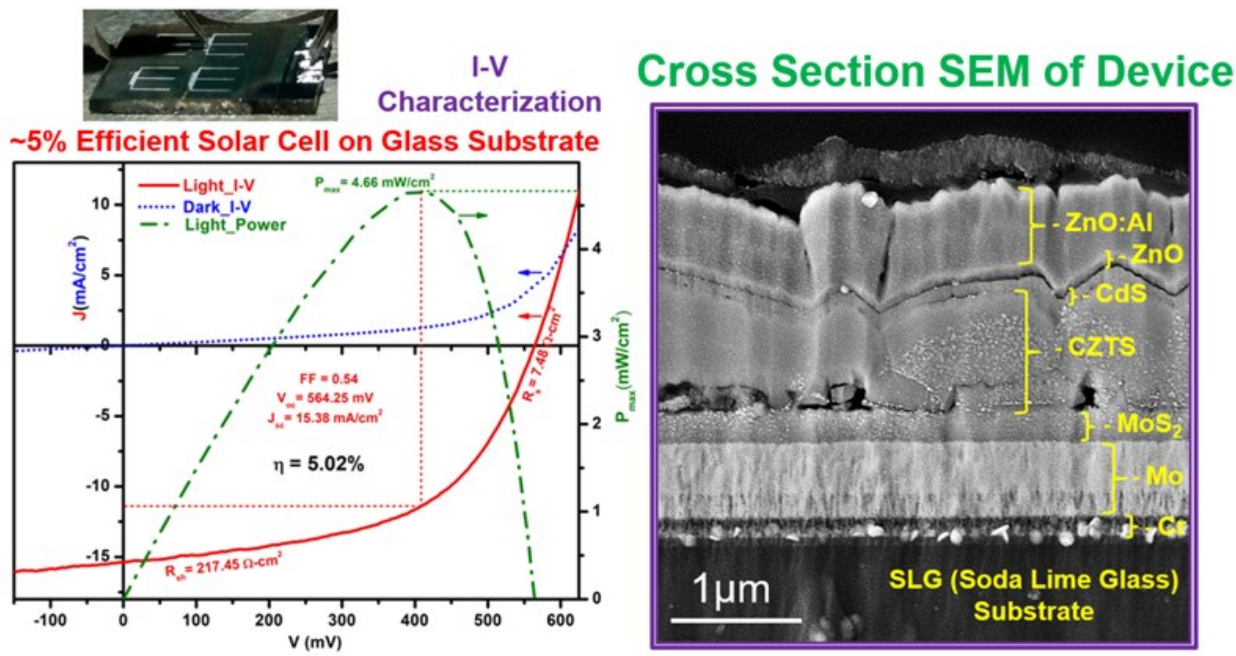

Figure 2: I-V characteristics and cross section SEM image of the device

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Highlights

- **Pulsed DC power supply**
- **Plasma Nitriding**
- **Variable duty cycle**

Team members

- **Naresh Vaghela**
- **Ghanshyam Jhala**
- **Keena Kalaria**
- **Alphonsa Joseph**
- **Suryakant B. Gupta**

ARTICLES

Installation and commissioning of Pulsed DC power supply at IGCAR, Kalpakkam

A 25 kW pulsed high voltage direct current (HVDC) power Supply has been successfully integrated with the existing Plasma Nitriding system at Indira Gandhi Centre of Atomic Research (IGCAR), Kalpakkam, Tamilnadu. The integrated Plasma Nitriding system will be used to nitride the nuclear reactor components. Few test runs of Plasma Nitriding process have been carried out and post Plasma Nitriding parameters were found satisfactorily. Major specifications of the pulsed DC power supply are as follows:

Sr. No.	Parameter	Requirement
1	Voltage	0 to -800 V variable
2	Power	25.6 kW max. (load dependent)
3	Frequency	20 kHz fixed
4	Duty cycle	10% to 80% variable
5	Temperature measurement	0 to 700 ^{o}C
6	Protections	Over current, over voltage and

Figure 3: Picture of pulsed HV DC power supply integrated with Plasma Nitriding system at IGCAR Kalpakkam

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Highlights

- **Image processing based feedback system**
- **Software capable of generating digital signals**

Team members

- **Abhishek Sharma**
- **Manika Sharma**
- **Vishal Jain**
- **Ramesh Bhatiya**
- **Ambati Siva Reddy**

Image processing based gap control in high power plasma torch system

At IPR, a high power plasma torch system has been developed that generates high temperature plasma arc using graphite electrodes. These graphite electrodes are mechanically moved using the stepper motors driven through feedback systems. An additional image processing based system is also developed and tested to automate its movement for adjusting the gap between the electrodes.

Image processing technique has been implemented to monitor and maintain the prerequisite gap between these electrodes. A camera was used to capture the images of the red hot electrodes. An image processing algorithm was developed to detect the outer edges of the electrodes online. The obtained edges were then used to compute the gaps between the electrodes and based on it, the movement actuation was performed. The computed gaps were translated to physical distance in millimeters (mm). The output of the system controls the distance (mm) by moving the electrodes inward due to its continuous consumption.

The image of the normal and abnormal position stage and thus the control signals generated by the image processing control system is shown in figures below

Figure 4: Online input image : Image of electrode's normal position in image processing software

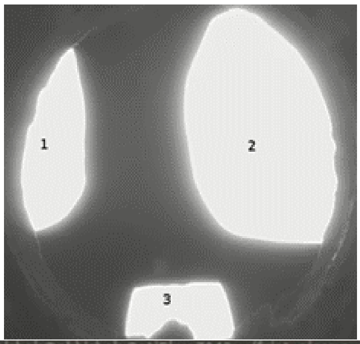


Figure 5: Abnormal position of electrode-1 at some stage

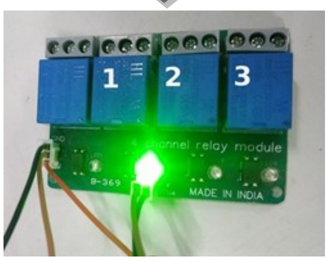


Figure 6: Digital output to relay for electrode 1 movement

PAST EVENTS

Visit of NITI Aayog officials

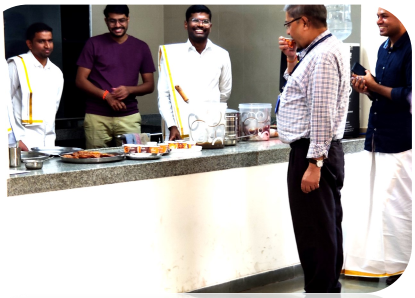
IPR has been selected as one of the Atal Incubation Centres under the Atal Innovation Mission (AIM) under NITI Aayog. As FCIPT is the fulcrum of activities on plasma technology for societal and industrial benefits, a team from Niti Aayog visited this campus on 23rd Jan 2023 to take stock of the activities. The team comprised of Mr. Prithvi Sai and Mr. Rajeev Kumar. After a brief presentation by Dr. Alphonsa Joseph on FCIPT activities, the team introduced themselves and talked about various activities of the Atal Innovation Mission, the main goals of the mission, methodology and so on. This was followed by a visit to different labs at FCIPT campus, viz. plasma torch lab, plasma pyrolysis, plasma activated water lab, plasma textile lab, plasma sterilization, plasma nitriding, plasma based coatings lab, SPIX lab. etc.

Photos taken during NITI Aayog officials' visit

PAST EVENTS

Ugadi / Gudi Padwa / Cheti Chand Celebrations

A surprise celebration was organized on 22.03.2023, at FCIPT campus, on the occasion of UGADI / GUDI PADWA / CHETI CHAND. These festivals are celebrated as a New-year day by TELUGU, MARATHI, and SINDHI people respectively. A few colleagues, lead by Mr. Paramesh, took the initiative of these short celebrations. They appeared in traditional attire and distributed 'Ugadi Pachchadi', a mixture having a combination of six different tastes viz. sweet, sour, salty, pungent, spicy, and bitter. Ingredients include neem flowers, mango, jaggery, sugarcane, tamarind, banana, coconut etc. It symbolically indicates that life is a mixture of good & bad, hardships & pleasures; and one should accept all of them with restraint. Colleagues at FCIPT have enthusiastically took part in this small gathering and savoured the traditional dishes served.






Glimpses of Ugadi celebrations at FCIPT

PUBLICATIONS

Talks Delivered

1. **Dr. Vishal Jain** gave a special guest lecture on "Plasma Pyrolysis Technology at IPR" organized by AEES, BARC, Mumbai, 28th February 2023

Patents Applied/Granted

1. "An apparatus for treating matter using inductively coupled plasma"; Patent No.: 426773 (Granted); **Vishal Jain,** Anand Visani, B.K. Patel, Chirayu Patil, S.K. Nema, P.B. Jhala

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For more details visit us at

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