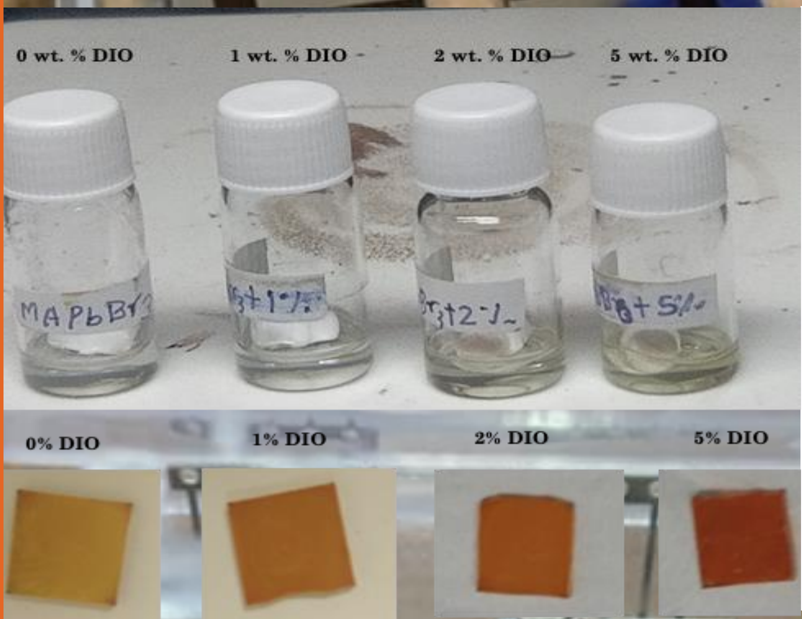
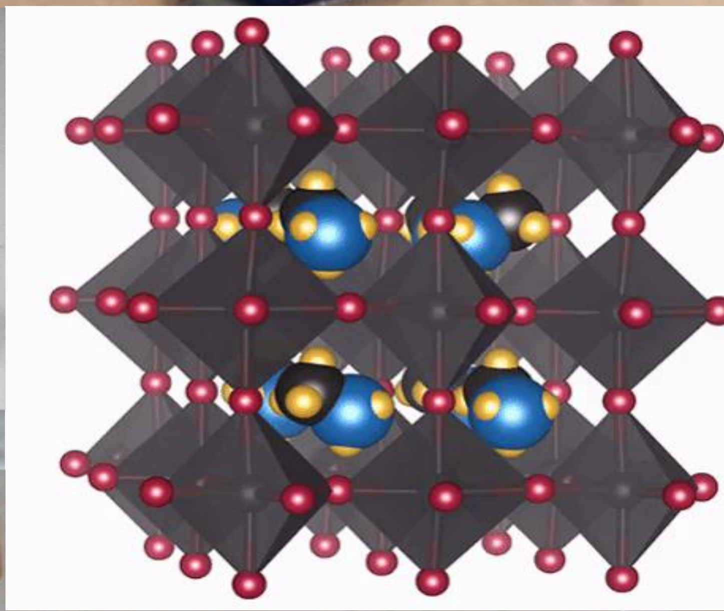
10 YEARS
Making a Difference
NCPRE

NewsLetter

January 2021 Edition »





NCPRE *Profile*

The National Centre for Photovoltaic Research and Education (NCPRE) at IIT Bombay is one of the leading PV research center in the country. It was launched in 2010 with funding from the Ministry of New & Renewable Energy (MNRE) of the Government of India, soon after the launch of India's National Solar Mission. The broad objectives of NCPRE are to provide R&D and education support for India's ambitious 10 GW solar mission. NCPRE has 29 faculty members and over 120 research staff and students across 9 Departments at IIT Bombay. State-of-the-art laboratory facilities, with over 200 equipment spread across 12 laboratories, have been set up which are accessible to all researchers and Industries. The Centre is involved in both basic and applied research activities.

These research activities include silicon solar cell fabrication and characterization, new materials for PV devices, energy storage and batteries for PV, development of power electronic interfaces for solar PV systems, and module characterization and reliability. NCPRE has a strong programme of industry outreach. It undertakes projects and consultancy in its areas of experience. It also provides services for characterization and measurements. NCPRE periodically conducts workshops and hands-on training in the field of photovoltaics for industry as well as academia.

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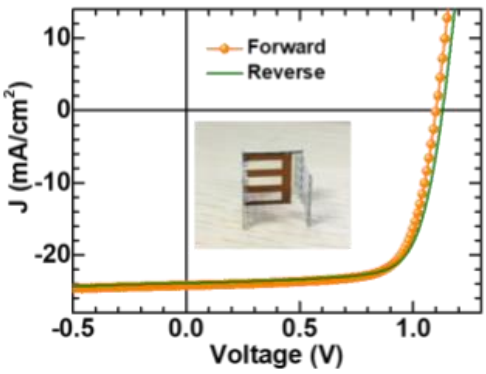
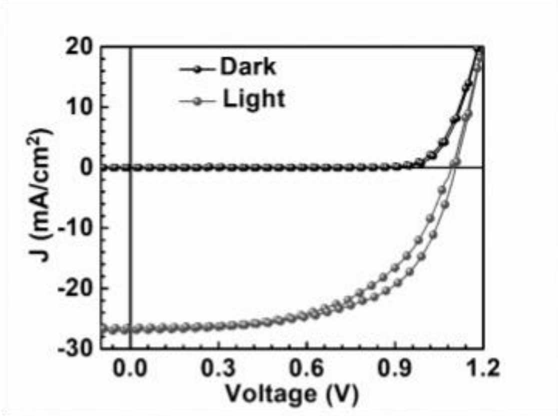
Efficient Perovskite Solar Cells in two different configurations

In NCPRE, Thin Film Group aimed to fabricate high efficiency Perovskite Solar Cell (PSC) in regular (*n-i-p*) and inverted (*p-i-n*) device configurations. We have successfully made the state-of-art solar cells with power conversion efficiency ~20% for *p-i-n* and ~17% for *n-i-p* configurations for devices over an active area of 0.18cm^2. Typically active area for high efficiency numbers are reported for device active area of 0.1 cm^2 or less in PSC community. The photovoltaic parameters are shown in the table below. Next, we plan to make transparent PSCs using top transparent electrode for either kind of device configurations. This will facilitate NCPRE to demonstrate the tandem solar cell structures with Silicon as bottom low bandgap cell.

Device Structure 1. [*p-i-n*]: ITO/PTAA/MAPI/PCBM/BCP/Ag
Device Structure 2. [*n-i-p*]: FTO/SnO_2/$MAFAPb(IBr)_3$/Spiro-OMeTAD/MoO_3/Ag



Device (1)



Device (2)

Device Structure	Current Density (J_{SC})	Open-circuit Voltage (V_{OC})	Fill Factor (%)	Efficiency (%)
1.	24.19	1.10	74	19.69
2.	25.01	1.09	60.7	16.54

Table: Photovoltaic Parameters of Device (1) and Device (2)

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Large area carbon-based perovskite solar cells

Perovskite Solar Cell (PSC) technology has shown remarkable improvement in efficiency, increasing from 3.8% in 2009 to its present-day level > 25%. However, short lifetime and vacuum processed deposition of gold/silver counter electrodes are the significant obstacles for their commercialization, limiting this technology to lab-scale fabrication. Carbon, with the −5 eV work function comparable to gold and its properties like superior electrical conductivity, chemical stability and low-cost in particular, make it an appropriate choice as the alternative and economical perovskite counter electrode. Above all, the facile printability of carbon paste on the various substrates provides the opportunity for large area and roll-to-roll fabrication of PSC. We have prepared highly conductive (sheet resistance 8.43 $\Omega\ \square^{-1}$) and hydrophobic (contact angle 148.5°) perovskite compatible low-temperature curable carbon paste. The perovskite solar cell without an expensive organic hole collection layer fabricated with the carbon layer. The prepared device with 11.43% efficiency has shown remarkable ambient stability, retaining more than 53% of their initial efficiency after one month.

Large area screen printed carbon-based perovskite solar cells and mini-modules were also prepared. Single-cell with an active area of 2 cm^2 has an efficiency of 6.20%. The cell with the same configuration having the small active area of 0.13 cm^2 shows 13.36% efficiency. Perovskite mini-modules were fabricated by connecting cells in the series. 4 cm^2 mini-module with two 2 cm^2 active area cells connected in the series gives 4.81% efficiency. We have also fabricated the five-cell mini-module with a 10 cm^2 active area (5 cells of 2 cm^2 active area connected in series) as shown in the figure. These mini-modules show the Voc of 4.1 V. All the devices show significant stability under continuous illumination. These results are encouraging and can contribute towards the realization of low-cost, large-scale, and stable perovskite solar cells, which will be a positive leap towards its mass production and make this technology commercially viable.

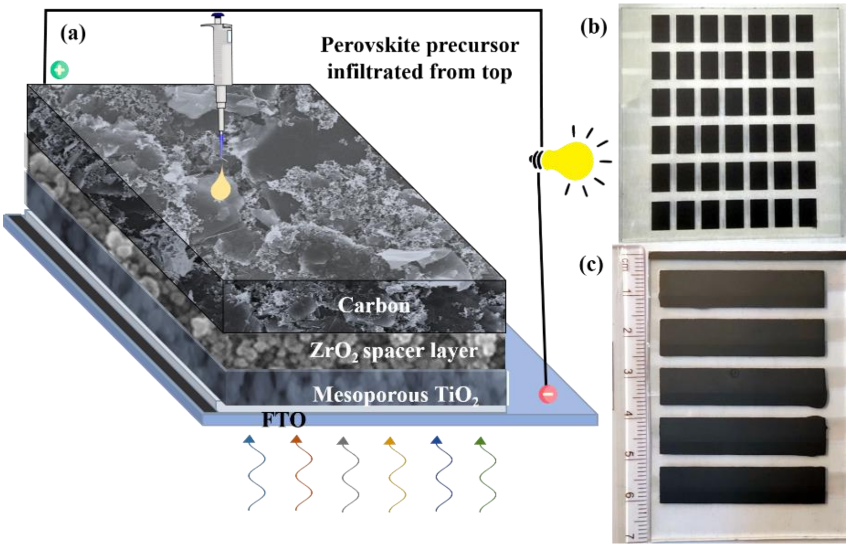


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Figure: (a) Carbon-based perovskite solar cell device structure

(b) Screen printed device before perovskite infiltration

(c) Mini-module

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Additive engineering of CBP molecules for defects passivation and moisture stability of hybrid perovskite layer

Additive engineering is the way to handle grain boundary defects in solution processed halides perovskites semiconductor thin-films. Most of the moieties used for this role are known to be n-type small organic molecules like PCBM, BCP, amine-based compounds or insulating large Eg molecules PEO, PMMA, PS, etc. However, this is the first report we demonstrate that a commonly known p-type organic small molecule (CBP) can also passivate the defects at grain boundaries to reduce optical losses and overall improved performance of the perovskite solar cells (PSCs) in terms of efficiency and moisture/thermal stability. This work is carried out in collaboration with Physics Department (Prof. Kabra) and MEMS (Prof. Bhargava and Prof. Mallick) as a part of deliverable of NCPRE- IIT Bombay funded by MNRE-India.

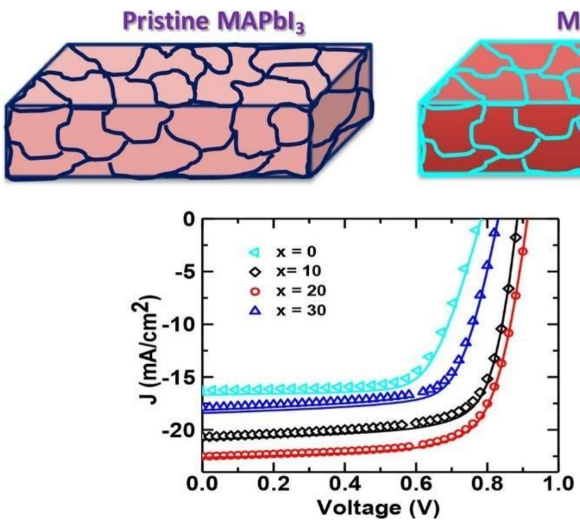

Figure: Schematic diagram of Pristine $MAPbI_3$ and $MAPbI_3$+CBP and JV curve of p-i-n devices where x is CBP concentration

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Let the 'Machine' do your Electroluminescence image analysis

Does anyone accept the solar module with cracked cells? No! The cracks on the solar cells may cause a gradual reduction in power output. These cracks are usually invisible to the naked eye.

Here Electroluminescence (EL) imaging comes to the rescue, where one can see the cracks present in the cells. Unfortunately, the problem doesn't end here. An expert eye is required to detect and report these cracks in the cells. In addition to that, as the solar modules are produced and installed in bulk, the manual observation of such a large number of EL images is a tedious and time-consuming process. Due to the wide variety of visual features in EL images, reporting the presence of cracks may include human bias as well. So why not automate this process!

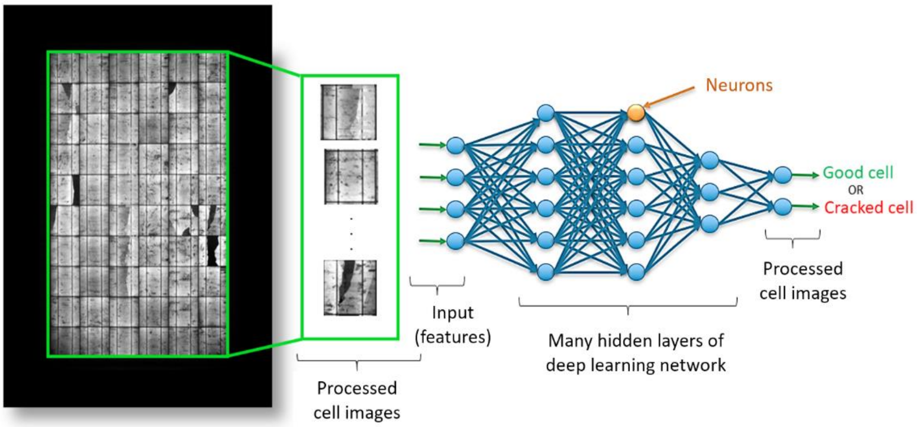

Figure: Process flow for binary classification of cells

Advanced Image Processing and Artificial Intelligence (AI) techniques are becoming popular as a solution to such problems. Manual observation of cracks in EL images requires a person to be trained with a variety of EL images having different kinds of cracked and non-cracked features on the cells. Similarly, here in NCPRE, we have developed a deep learning model that is trained with large amounts of EL image data consisting of different features of cracked and non-cracked cells for automated classification of cells. The EL images were collected from installed PV plants from different climatic zones of India during the 'All India Survey 2018'. Unlike most of the published works in this area that have used the lab simulated data with artificially generated cracks, our data consists of the images of the fielded PV modules having cracks mainly due to environmental causes, poor installation practices, and transportation. Also, the camera used for capturing EL images was developed by NCPRE at a relatively low cost and is robust for field applications.

For cell wise analysis of EL images, it is important to crop out the background of the PV module and separate each individual cell. Various image processing algorithms were implemented in a sequence to prepare our cell EL images from the module EL images. The cracked and non-cracked cells were manually labeled, just like a textbook is prepared for our model to read and get 'trained' for the 'test'! ResNet50 is the deep network architecture used for the training. The parameters of the model are tuned in such a way that it will learn better to classify the cells with higher accuracy. The trained model is now prepared for the test on the image data which is not part of the training data set. The accuracy of the model in the test was found to be 98.6%! Similar experiments are performed with EL images from another source to study the performance of models on a cross dataset and it is found that active learning of models over new labeled data is the way towards a generic classification model.

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Consultancy Programme on Secondary Cell & Module Calibration

Technical and Quality Enrichment Solution for Lab Accreditation

Uncertainty in determination of power generation is one of the critical factors contributing to the cost of solar photovoltaic (PV) installations. Precise measurement of cell and module characteristics are indispensable in reducing the financial risk associated with the investments in PV industry. Since, it is not economical to measure all cells and modules in the production line with the required precision and certainty; calibration becomes a key step in PV performance analysis value chain. As the PV reference cells are difficult to obtain and maintain, many PV measurement labs use secondary cells/modules calibrated against the primary reference devices. Thus, there is a need for accredited secondary characterization laboratories, which can serve the purpose by maintaining the ISO 17025 quality standards. Besides, Indian solar photovoltaic (PV) industry spends considerable revenue and spends considerable time in getting calibration certificates from international certifying centers.

However, the process of establishing secondary cell calibration facility setup requires clear understanding of legal, technical, and accreditation related aspects. In connection to this a consultancy programme on **Secondary Cell & Module Calibration** has been initiated under the scope of the project "Strengthening Quality Infrastructure for the Solar Industry" This activity is the combined efforts of PTB, Germany & MNRE, India with technical expertise from Fraunhofer, Germany. NCPRE, IIT, Bombay is leading the activity as national coordinator and will be the participant as well during these consultancy workshops. The aim of these workshops is to support the Indian labs in improving their measurement procedures, and quality infrastructure to get the accreditation level based on ISO 17025 quality standards. This programme consists of nine modules encompassing all the major related topics including standards and traceability, quality assurance & quality management procedures, and equipment upgradation. At the end of this consultancy workshop a round-robin intercomparison exercise will be performed for technical evaluation of the participant labs. Based on this exercise specific feedback and guidance will be provided for overall improvement of individual laboratory. Recently Kick-off workshop session was successfully commenced with general introduction of participant labs i.e. IIT (Bombay), NISE (Gurugram), NPL (Delhi), and CPRI (Bangalore). Therefore, in essence these consultancy workshops with NCPRE, IIT, Bombay as the national coordinator will assist the Indian participant labs on secondary calibration facility setup establishment up to the accreditation level.

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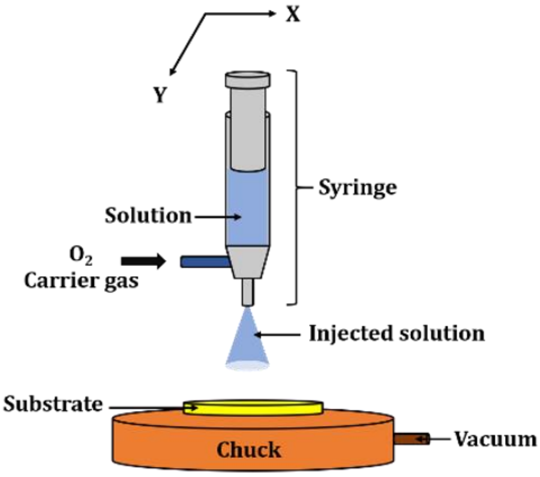
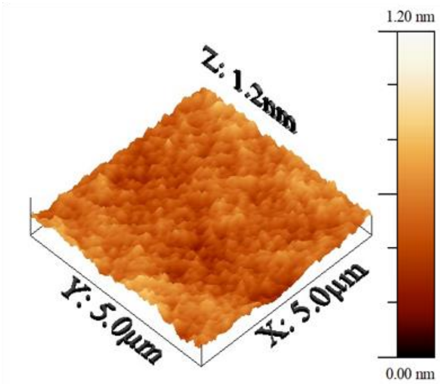
Spray-coating for Silicon Dioxide Thin Film Deposition



2-D schematic of spray coater tool



Surface morphology of spray coated uniform SiO_2 film

Cost is the most important parameter that a solar industry focusses on. Efforts are being made to improve the solar cell efficiency. However, the performance enhancement is targeted without increasing the cost of solar cell fabrication. Looking at the global PV market, advanced solar cell designs are set to dominate over conventional Al-BSF cells. Dielectric film at the rear of these cells plays a very important role in terms of both electrical as well as optical aspect. We, here at NCPRE have custom-designed a spray-coater tool for the deposition of thin silicon dioxide (SiO_2) films. The spray-coating deposition is simple, cost-effective, and industrially viable. In addition, it has an advantage over other the solution processed techniques, such as spin- and dip-coating in terms of deposition uniformity over industrial scale size samples with high throughput. Spray coater is different from the spray-pyrolysis system in a way that in the spray-coating process, the solution is sprayed over a cold substrate, which is further subjected to a thermal treatment for drying and densification. Using this custom-designed spray-coater tool, we have demonstrated ~10 nm thin uniform and stoichiometric SiO_2 film with excellent interface and passivation properties.

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Jayshree Bhajipale

Jayshree Bhajipale and Anil Kottantharayil, "Passivation of n- and p-type Silicon Surfaces with Spray-coated Sol-gel Silicon Oxide Thin Film", IEEE Transactions on Electron Devices, 67 (2020) 5045 -5052, DOI: *10.1109/TED.2020.3025981*.

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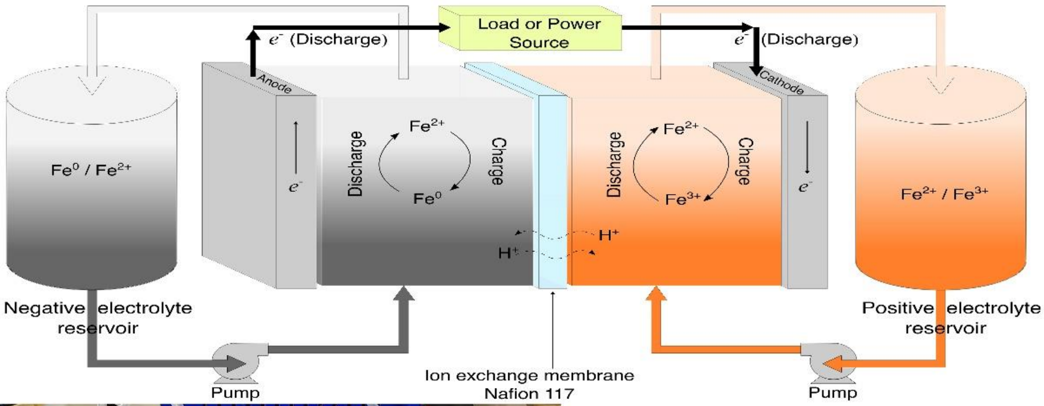
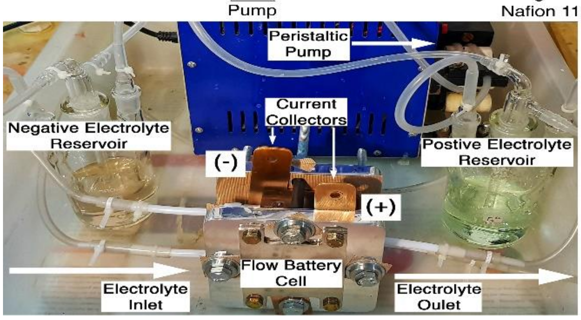
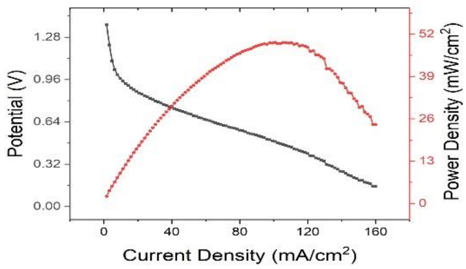
Iron-based Redox Flow Battery: An inexpensive environment-friendly large-scale energy storage device

A subset of immense battery field technology is the Redox Flow Batteries (RFB). Unlike normal batteries where the reactants are usually solid, a redox flow battery uses liquid reactants, which can be stored in large tanks. This decouples energy and power, and allows a modular design with flexible operation. A rather benign and cheaper type is the all iron Redox Flow Battery.

An all-iron Redox Flow Battery utilizes reaction among iron metal and two other soluble iron compounds in two different oxidation states to store and discharge electricity. Of course, the compounds are separated by a membrane to prevent spontaneous reactions. Whenever electric power is required, the reactants flow, and a chemical reaction is started at the electrodes. The exhausted chemicals then can be regenerated when power is in excess by reversing the reaction as well as the flow. A typical module generates a voltage of ~1.0 V and the current is proportional to the size of the electrode. One such device is made by one of the NCPRE teams (M. Shariq Anwar under the guidance of Prof. Arindam Sarkar) in Energy Storage Group along with its power output characteristics. Of course, the power generated by each module is low compared to other RFBs, the great advantage of using iron is its availability in our country and low toxicity. One can, thus, envision a giant battery made by assembling several thousand modules capable of storing and discharging several 100 MWh of energy.







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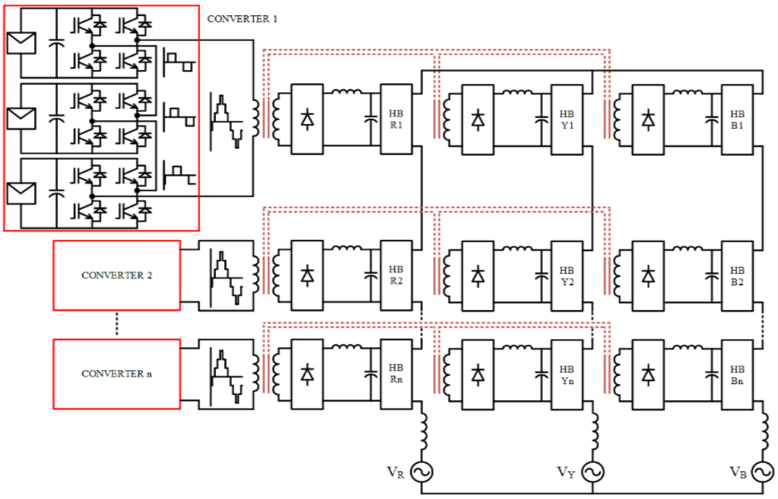
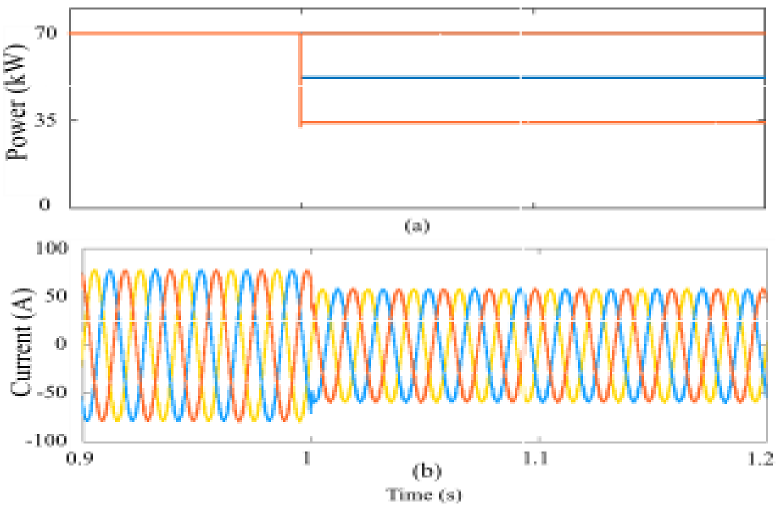
Elimination of Phase Imbalance in Cascaded Multilevel Converters for large-scale Photovoltaic Integration

Cascaded H-bridge Converters (CHB) are ideal candidates for large-scale photovoltaic (PV) integration because of their modular structure, and the absence of a bulky line frequency power transformer. To eliminate the leakage current, isolated dc-dc converters are needed to connect the PV arrays to the H-bridges of CHB. These dc-dc converters extract maximum power from each PV array independently. Under partial shading conditions, the power generated in the three phases of CHB are different thereby leading to an unbalance in the grid currents. The existing methods to balance the grid currents require the converter to be overrated or to operate at reduced PV power. Hence, a new topology is proposed to distribute the power equally among the three phases of CHB without over-rating the converter or reducing the power being drawn from the PV array. This is achieved by using high-frequency transformers each having one primary and three secondaries as shown in the figure below. The lower figure shows the power generated in the three PV arrays of one module of the proposed converter, and the grid currents. From this figure, it can be inferred that the grid currents are balanced even though the power generated in the PV arrays is different.



Proposed configuration of CHB for PV integration



(a) Power generated by the three PV arrays
(b) Grid currents

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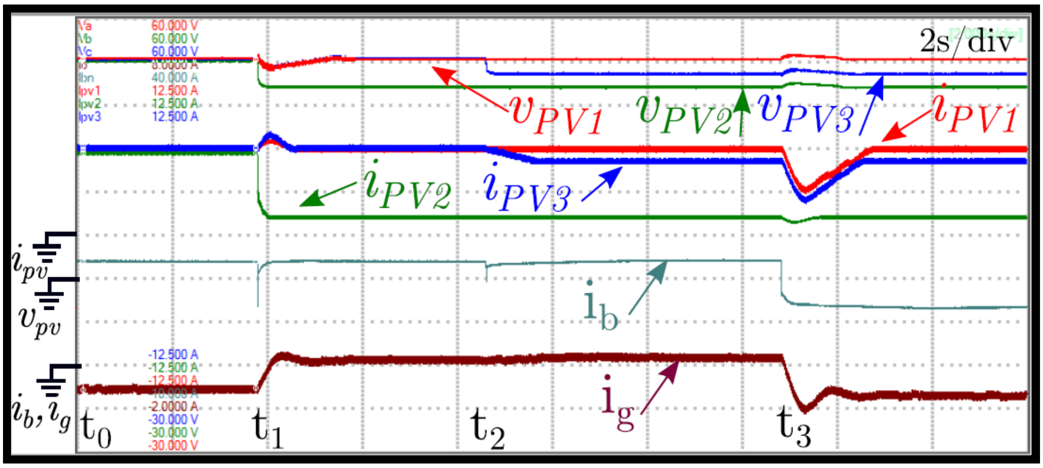
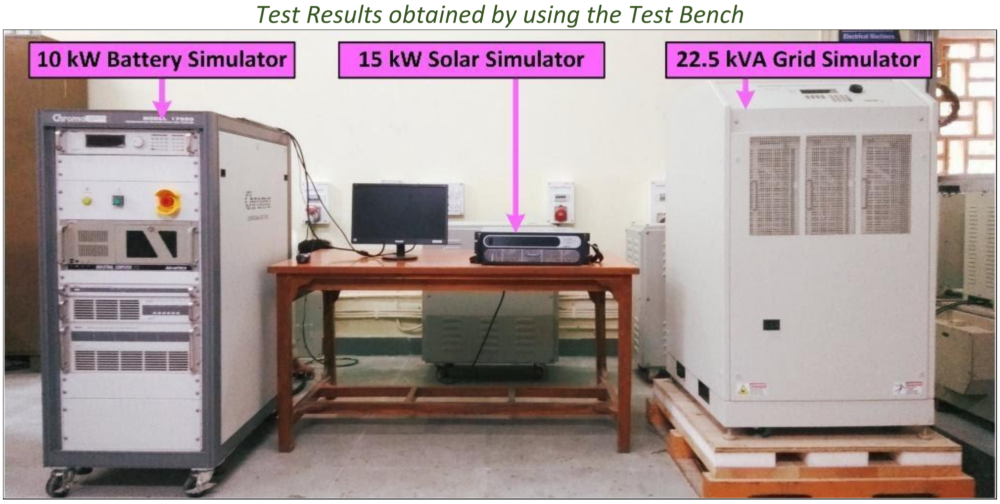
One Test Bench to Comprehensively Test all Power Electronic Interfaces of Solar PV System under Balanced & Unbalanced Grid Conditions

A test bench has been designed which can test all the power electronic interfaces of solar PV with all the possible combinations of inverter, battery, grid and transformer according to the need. The test bench consists of a 22.5kVA grid simulator, a 15 kW solar array simulator and a 10 kW battery simulator. All the instruments are controlled through PCs. Certain provisions made with this test bench are as follows:

- Isolation transformers are installed at the input supply side of the instruments whenever required
- Can connect the inverter output to the grid with and without transformer.
- Can connect other testing and measuring instruments, e.g. electronic loads, DSO, etc.
- Various experiments pertaining to Solar PV system, electric vehicle charging-discharging, and emulation of grid side disturbance, unbalanced grid, etc. can be performed from low to high power level.



Test Results obtained by using the Test Bench



Test bench

Please refer below link for list of NCPRE Facilities:
http://www.ncpre.iitb.ac.in/ncpre/pages/equipment_status.html

NCPRE facilities are open for all on a chargeable basis. Please refer below link for details of charges:
http://www.ncpre.iitb.ac.in/ncpre/uploads/eqp_usage_charges_NCPRE_tools.pdf

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NCPRE collaborates with RenewSys India Pvt. Ltd. (India) company and are working towards the optimization of ethylene vinyl acetate (EVA) lamination process, especially the effect of curing temperature on properties of EVA encapsulant used for crystalline silicon solar module encapsulation.

NCPRE SERVICES

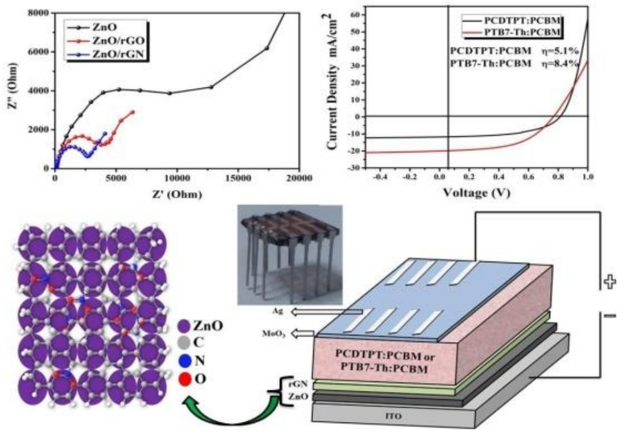
NCPRE has very well-equipped characterization labs with several scientists, engineers and students working on different projects which have been used by industry as well as academia.

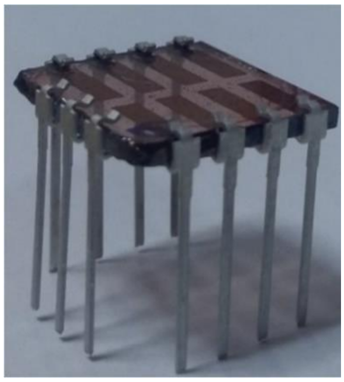
	Examples from the industry	Services availed
1	Kusumgar Corporates Pvt Ltd, Gujrat	Quality check of garnish fabric.
2	Viraj Syntex Pvt Ltd, Uttar Pradesh	UV-Vis measurement of industrial fabric.
3	Entremonde Polycoaters, Maharashtra	Quality inspection of garnish fabric.

Simultaneous Passivation of Surface Vacancies and enhancement in Charge Transfer Property of ZnO Electron Transport Layer for Inverted Organic Solar Cells

-A project carried out at NCPRE under PUMP

The design and development of a charge carrier transport material are decisive parameters for controlling the organic solar cell's power conversion efficiency (PCE). ZnO is one of the most suitable electron transport materials used in inverted bulk heterojunction polymer solar cells. However, the solution-processed ZnO has surface defects, which hinders the power conversation efficiency of the device. Herein, it is designed and demonstrated that the 2D NO_2 group functionalized reduced graphene oxide (rGN) sheet coated on top of the 1D ZnO nanoridges not only passivates the surface but also enhances the charge transport property of the electron transport layer (ETL), thereby improving the overall PCE by 31%. The highly transparent bilayer ZnO/rGN ETL has uniform film formation and, thereby, improved ohmic contact between the cathode and the photoactive layer. Due to the improved electron transport from the photoanode (PTB7-Th:$PC_{71}BM$) to the buffer layer, a photoinduced current density of 20.05 mA cm^{-2} is achieved. This interface modification by rGN can be an effective strategy to passivate the surface and retards the recombination rate to enhance the efficiency of organic photovoltaic cells.





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Publications

- Boskey Sharma, Shivam Singh, Kashimul Hossain, Sudhanshu Mallick, Parag Bhargava, and Dinesh Kabra. "Additive engineering of 4, 4′-Bis (N-carbazolyl)-1, 1′-biphenyl (CBP) molecules for defects passivation and moisture stability of hybrid perovskite layer." *Solar Energy* 211 (2020): 1084-1091, *DOI: 10.1016/j.solener.2020.10.035*.

- Jayshree Bhajipale and Anil Kottantharayil, "Passivation of n- and p-type Silicon Surfaces with Spray-coated Sol-gel Silicon Oxide Thin Film", *IEEE Transactions on Electron Devices*, 67 (2020) 5045 - 5052, *DOI: 10.1109/TED.2020.3025981*

Achievements

Aakash Ahuja, (2nd year, Ph.D. student) working under the guidance of Prof. Sagar Mitra (Energy Storage Group) has been awarded Prime Minister fellowship for Doctoral Research funded by CII-SERB in collaboration with Waaree Energies Limited, India.

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