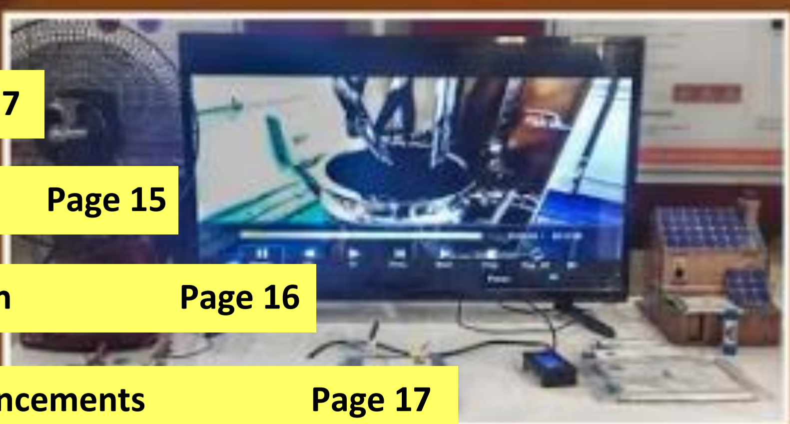
NCPRE

10 YEARS
Making a Difference
NCPRE

NewsLetter

October 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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Inkjet printing as a thin film fabrication technique for Li-ion battery and perovskite solar cell applications

Prof. Dipti Gupta, Ashok Kushwaha (PhD student, NCPRE-Energy storage group), Anu Teresa Peter (PhD student, NCPRE- Thin film materials & Devices group).

Inkjet printing is a versatile fabrication technique that can fabricate electronic devices in a digital non-contact mode that allows for printing on large areas and a variety of substrates with low wastage of materials, rendering it cost-effective, facile and scalable. Our group has developed inkjet printed micro porous thin film graphene electrode for high-performance lithium-ion battery, where printed electrode can retain 87% of initial reversible capacity after 100 cycles at high current density and reversible capacity of 942 mAh/g at 0.1C low current density. In this context, a thin-film Li-ion battery (LIB) system is being considered as a more suitable power supply since it has favorable features, such as being flexible, light weight, and thin, together with unparalleled high energy and power densities. More importantly, the reduced thickness of the electrodes helps with faster kinetics, leading to enhanced rate capability. However, fabrication of thin-film electrodes for LIBs is challenging and mostly relies on traditional thin-film deposition techniques, such as chemical vapor deposition (CVD), sputtering and pulsed laser deposition (PLD), and Sol–gel methods such as Dip/tape Casting and the Doctor Blade technique.

Unfortunately, many of these methods require expensive and sophisticated equipment(s), with necessities concerning attainment of a high vacuum and high temperature, which limit the development of thin-film batteries.

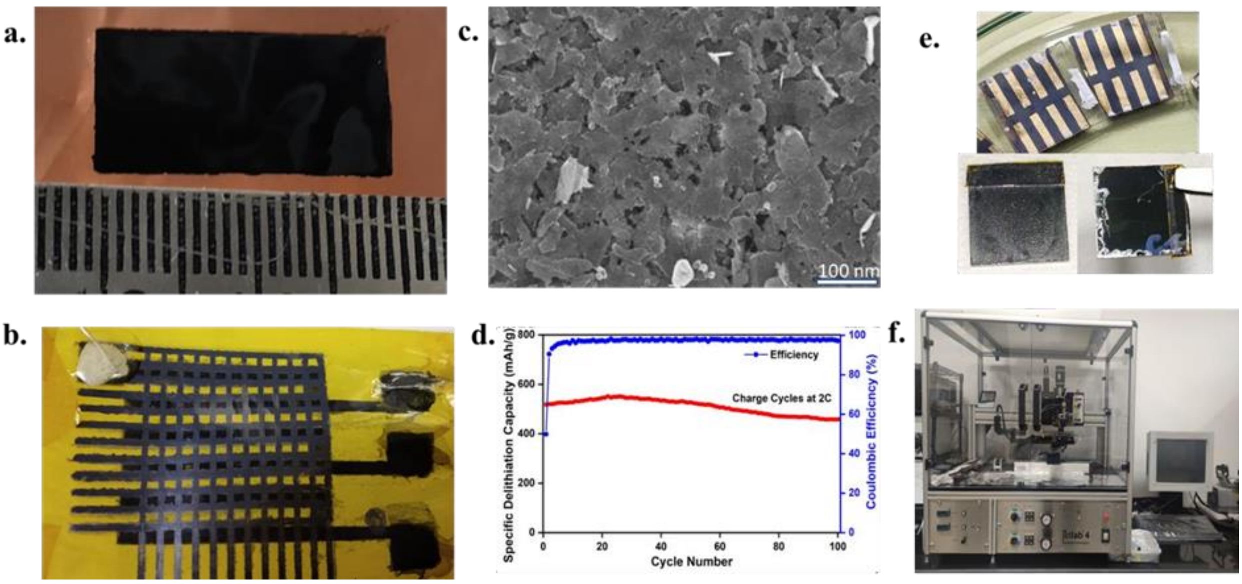

Figure: (a,b) Inkjet-printed graphene thin films (c) FESEM image of printed graphene thin film (d) Variations of the reversible capacity and coulombic efficiency with cycle number for 100 cycles conducted at 2C current density. (e) Inkjet-printed triple cation perovskite thin films and the perovskite solar cells fabricated using inkjet-printed thin films. (f) Microfab Technologies, INC. Jetlab4 model Inkjet printer used for the thin film fabrications.

Perovskite solar cells (PSCs) rose to their current fame due to their rapid performance growth in a short period of one decade, as compared to silicon solar cells. Though they have achieved high performance using lab-scale techniques, their stability and scalability still remain a roadblock towards commercialization. Inkjet printing, an efficient and scalable method, can be applied to fabricate different functional layers of perovskite solar cells. As a benchmark for comparing inkjet-printed perovskite solar cells, the primary step was to develop PSCs using spin-coating techniques. We have achieved 14% and 8.35% efficiency with triple cation perovskite in n-i-p mesoscopic and planar architectures in nitrogen atmosphere, respectively. The inkjet-printed PSCs with triple cation perovskite fabricated in ambient condition with humidity greater than 80% reached efficiencies of 2.4% and 1.24% in n-i-p mesoscopic and planar architectures, respectively; which is under further optimization with respect to various parameters pertaining to inkjet printing.

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Towards achieving high voltage electrochemical stability and water-stability of transition metal oxide-based cathode materials for the next-generation alkali metal- ion batteries

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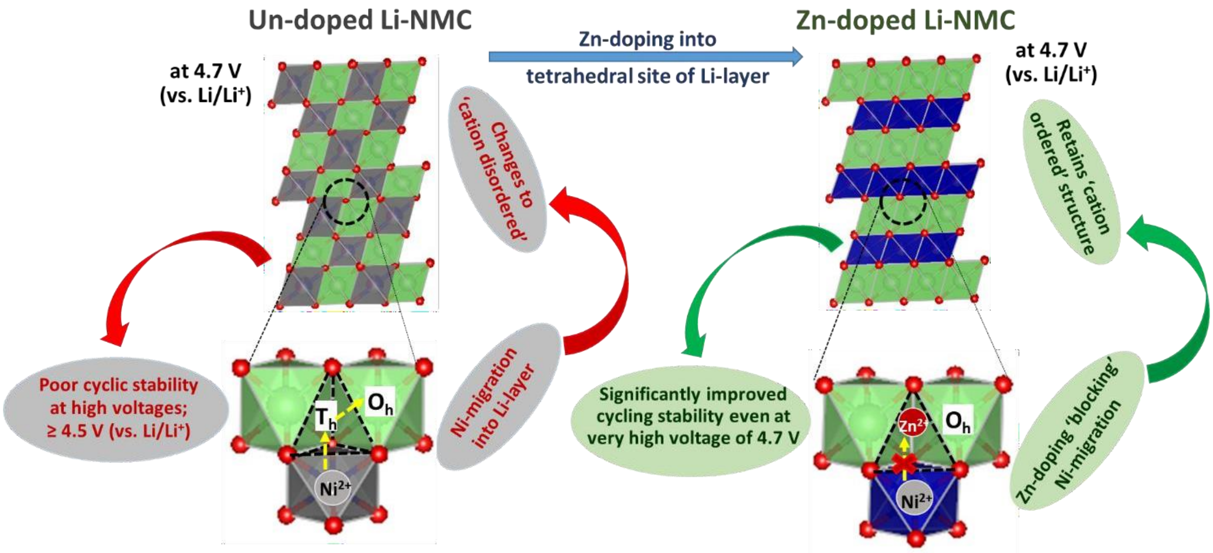
Transition metal (T_M) oxides are a fascinating class of materials, whose properties can be suitably tuned in a variety of ways; such as by selecting T_M-ions/dopants having preferred electronic configurations, engineering the crystallographic site occupancy by dopants, controlling/modifying the degree of covalence of T_M-O bonds, modifying lattice spacing(s), tuning phase assemblage etc. Such modifications done from the fundamental perspectives influence the performances of T_M-oxides for a variety of applications, including their widespread usage as cathode-active materials in alkali metal-ion batteries (*i.e.*, the Li-ion and Na-ion battery systems).

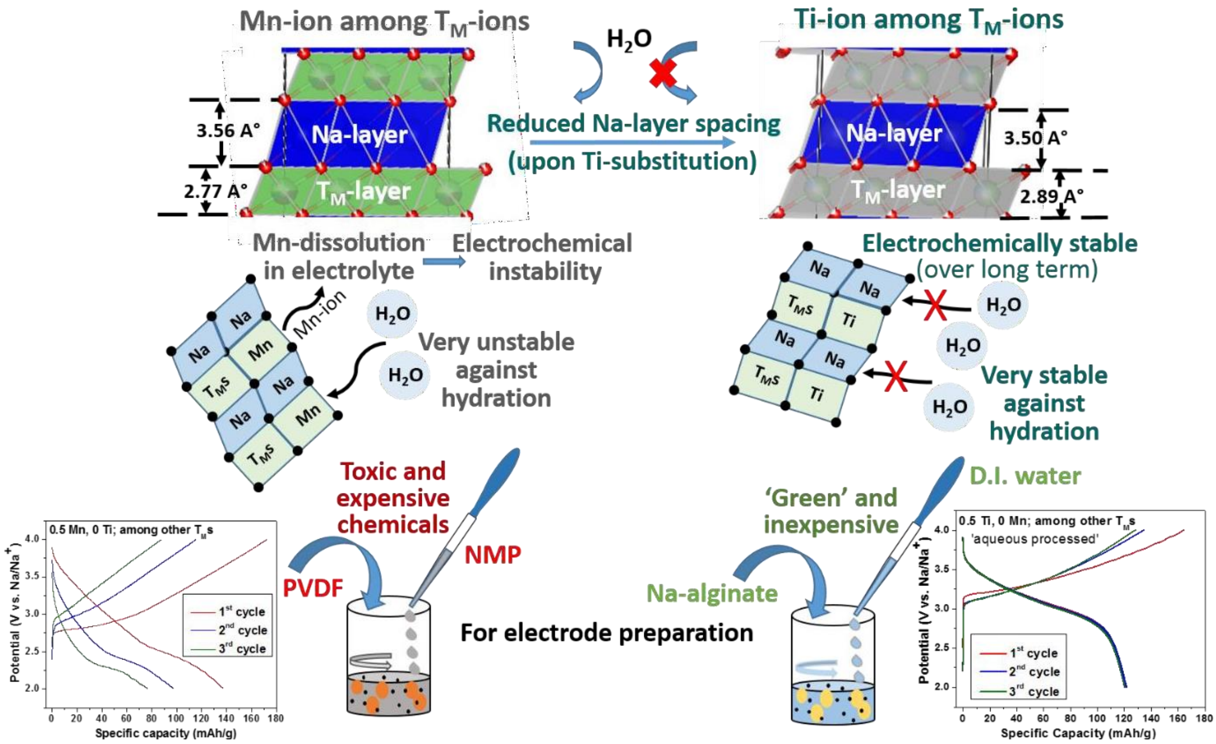
In the context of Li-ion batteries, 'cation disordering' that takes place at deep states of delithiation of Ni-containing 'layered' Li-T_M-oxides leads to structural-cum-electrochemical instability during charging of Li-ion cells at potentials beyond 4.3 V (vs. Li/Li^+). This forms a major bottleneck towards raising the operating voltage of Li-ion batteries and thus, leads to a compromise over the energy density. Nevertheless, our recent research results have indicated that optimal doping of such 'layered' Li-T_M-oxides with ion(s) having d^{10} electronic configuration (and, thus, no OSPE) suppresses Ni-migration from T_M-layer to Li-layer (*viz.*, 'cation disordering') and, thus, preserves the structural integrity even upon deep states of delithiation (*i.e.*, at high cell voltages) [recently, published as; Sharma *et al.*, *ACS Appl. Mater. Interfaces* **13**[22] (2021) 25836].



Sharma et al., ACS Appl. Mater. Interfaces **13**[22] (2021) 25836

Figure: Effect of Tetrahedral site Zn-doping on the migration passage of Ni-containing Layered Transition Metal (T_M) oxide on High Voltage Structural and Electrochemical Stability.

In the context of the upcoming Na-ion battery system, O3-type 'layered' Na-T_M-oxides are promising as cathode-active materials due to their inherently high initial Na-content (as compared to the P2 counterparts); but suffer from instabilities caused due to multiple phase transformations during Na-removal/insertion and sensitivity to air/moisture. We have been able to tune the composition and structural features to suppress the phase transitions upon Na-removal/insertion and also improve the air/water-stability in significant terms; so much so that long-term cyclic stability has been achieved with health/environment-friendly 'aqueous processed' electrodes (sans, usage of toxic/hazardous/expensive chemicals like NMP and PVDF). The changes in structural features, which have led to such outstanding water-stability, include differential contraction/dilation of the Na-'inter-slab'/T_M-'slab' spacing and partial occupancy of the dopant at tetrahedral sites of the structure [recently, published as; Kumar *et al.*; *J. Mater. Chem. A* **8** (2020) 18064].



Kumar *et al.*; *J. Mater. Chem. A* **8** (2020) 18064

Figure: Tuning T_M-ion 'slab thickness' and alkali metal-ion 'inter-slab spacing' of Na-T_M-oxides in opposite terms (and also suppressing T_M-dissolution in electrolyte) leads to outstanding air/water-stability and long-term electrochemical stability.

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Vanadium Redox Flow Battery:
A Promising Large-Scale Energy Storage Device

Large-scale energy storage systems based on vanadium redox flow batteries (VRFBs) are developed for the deployment of renewable energy technologies. VRFB is easy to scale and the energy and power can be decoupled. The materials used for the electrode have a crucial role on the performance of VRFB. It is reported that the pre-treatment of the electrode increases the hydrophilicity and creates functional groups (carbonyl, carboxyl and hydroxyl) on the electrode surface, thereby influencing the kinetics. The figure below presents the performance of VRFB with untreated and electrochemically treated Toray carbon papers (CPs). The electrochemically generated functional groups on CP can be confirmed by XPS. It is found that the asymmetrically configured cell with CP_2.0 V_15 min_-1.0 V_10 min at the positive electrode and CP_2.0 V_15 min at the negative electrode offers maximum power density of ~325 mW cm^{-2}, and it is much higher than that of symmetric cell using untreated CP electrodes (~85 mW cm^{-2}).

[Note: CP_2.0 V_15 min_-1.0 V_10 min indicates CP electrode after the initial treatment at +2.0 V for 15 min treated subsequently at -1.0 V for 10 min].

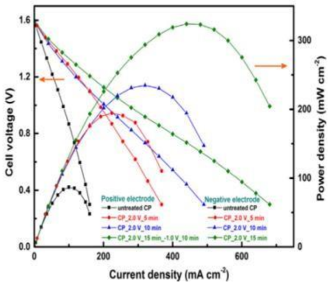


Figure: Polarization and power density curves recorded with a 5 cm^2 VRFB with electrochemically treated and untreated CP electrodes at a flow rate of 20 mL min^{-1}.

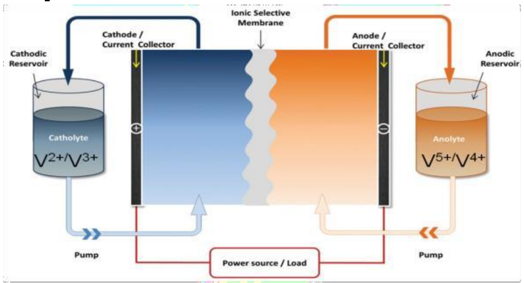
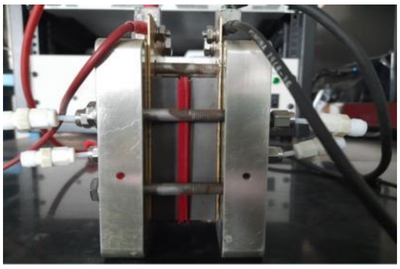
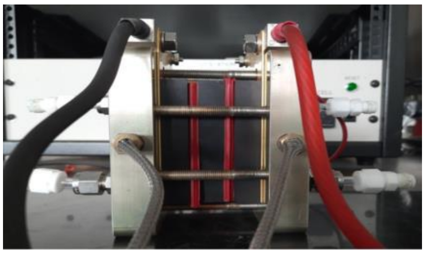


Figure: Schematic of Vanadium redox flow battery.

Redox flow battery test station (Fuel Cell Technologies Inc., USA) with single cell of 25 cm² area



Single cell of 5 cm² area



Two cell stack (2*25 cm² area)

People involved –

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Universal USB Charger

In this information-rich world, information is getting increasingly portable nowadays. With the huge demand to deliver global information in a timely and efficient manner, information sharing needs a portable platform for real-time response. Portable Electronic Devices (PEDs) including mobile phones, laptops, tablets and wearable electronic devices are the most promising ways that have facilitated the rapid growth of information sharing and processing.

The heart of these PEDs is their battery chargers, these battery chargers are simply AC to DC power converters also known as AC to DC adapters. Since, different PEDs require different voltage and power levels to charge their batteries, each PED needs a battery charger of its own kind. Also, various electronic devices like digital cameras, speakers, monitors, etc. need dedicated AC to DC adapters, which can meet their voltage and power specifications. In summary, the increasing numbers of PEDs and other electronic devices result in the manufacturing of a large number of AC to DC adapters and when discarded, flooding the earth with an enormous amount of electronic waste (e-waste).

E-waste is one of the fastest-growing waste streams, and its disposal is a challenge for the whole world. It is estimated that 50 million tons of e-waste have been generated globally in 2018, and half of this comprises of personal devices such as computers, laptops, smart phones, tablets and TVs. The discarded AC to DC adapters of these devices are also contributing to the global e-waste generation significantly. So, it is worthwhile to explore the concept of a universal USB charger (single USB charger for all PEDs), as it could be a step towards significant reduction of global e-waste generation.

USB STANDARDS AND SPECIFICATIONS

A USB specification is a set of protocols that defines both the data transfer rate and power transfer capability through a USB connector and port. Table below illustrates the evolution of USB specification in terms of their power handling capacity. The first version of USB specification, called USB 1.1, was brought into existence in the 1990s. USB 1.1 specification had a maximum transfer rate of 12 megabits per second (12Mbps) and maximum bus power transfer capability of 2.5 W (5 V, 500 mA).

USB Specification	Nominal Voltage	Maximum Current
USB 1.1	5V	500mA
USB 2.0	5V	500mA
USB 3.1	5V	900mA
USB BC 1.2	5V	Up to 1.5A
USB Type-C @ 1.5A	5V	1.5A
USB Type-C @ 3A	5V	3A
USB PD	Up to 20V	Up to 5A

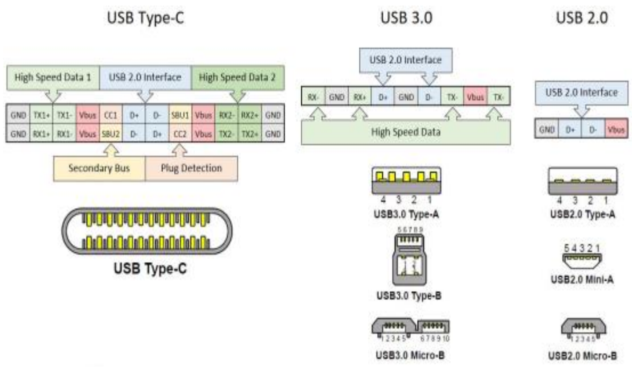

Table: Evolution of USB Specifications

The next revision was USB 2.0, with a maximum transfer rate of 480 Mbps. The further revision (USB 3.1) has ramped up the data transfer rate to a greater extent, 5.0 gigabits per second (USB 3.1 Gen 1), 10.0 gigabits per second (USB 3.1 Gen 2) and 20.0 gigabits per second (USB 3.2). In addition to higher speeds, this specification has also increased bus power, offering 4.5W, compared to 2.5W that was available in USB 1.1 and USB 2.0.

USB BC 1.2 is a special USB specification, introduced for a USB charger, a device with a dedicated charging port, such as a wall adapter or car power adapter, with a maximum power delivery of 7.5 W. USB Type-C is simply a new connector type for USB 3.1, which can carry a maximum current of 3 A, hence it can deliver maximum power up to 15 W. Since, the evolution of the first USB 1.1 till the USB Type-C specification, a nominal voltage of 5 V has been maintained and only the current has been incremented from 500 mA to 3 A, restricting the maximum power delivery up to 15 W. Hence, to increase the power delivery, recently a new USB specification has been introduced known as USB PD (power delivery). With USB PD, a huge jump in power can be achieved i.e. up to 100 W, because now the voltage can be increased to a level of 20 V and current can be increased up to 5 A. So, with the USB PD specification, high power consuming devices like monitors, tablets, and laptops can be powered through a USB charger. Therefore, with the arrival of USB Type-C and PD specification, the concept of a universal USB charger seems to be a legitimate possibility.

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Is Ion dynamics in perovskite devices same under large and small signal switching?

Perovskite based devices are being explored not only for Photovoltaics but also for various opto-electronic applications like light emitting diode (LED) and solid-state memories. In all these applications, device electrostatics is influenced by ion migration, which have long term implications regarding stability and performance degradation.

The behaviour of mobile ions in perovskite devices is often complex and surprising. In this article, we show that for small signal switching, the time delay in current response scales inversely with the ion mobility whereas for large signal switching the time delay is independent of ion mobility and entirely dependent on electronic dipoles. These results and the corresponding theory are backed by numerical simulations (in-house developed code) and experimental observations from Prof. Dinesh Kabra's group and data from various labs. If you are curious to know more, please refer to the paper

Saketh Chandra, T.; Singareddy, A.; Hossain, K.; Sivadas, D.; Bhatia, S.; Singh, S.; Kabra, D.; Nair, P. R. Ion Mobility Independent Large Signal Switching of Perovskite Devices. Appl. Phys. Lett. 2021, 119 (2). https://doi.org/10.1063/5.0051342

Scilight article: https://doi.org/10.1063/10.0005670

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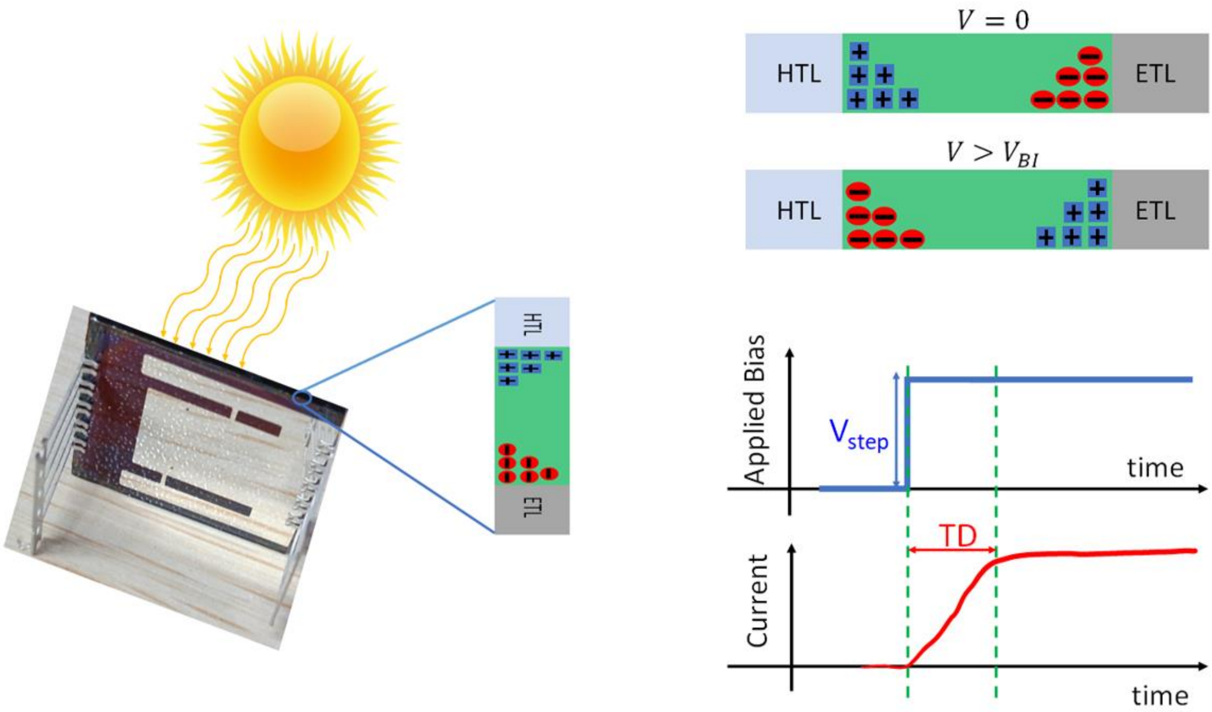

Figure: (Left) Large signal switching of perovskite PIN device. (Top right figure) Schematic of the device with ion migration at V=0 and V > V_{BI} (built-in voltage). (Bottom right figure) Schematic of the applied bias and resultant current through the device depicting the time delay (TD).

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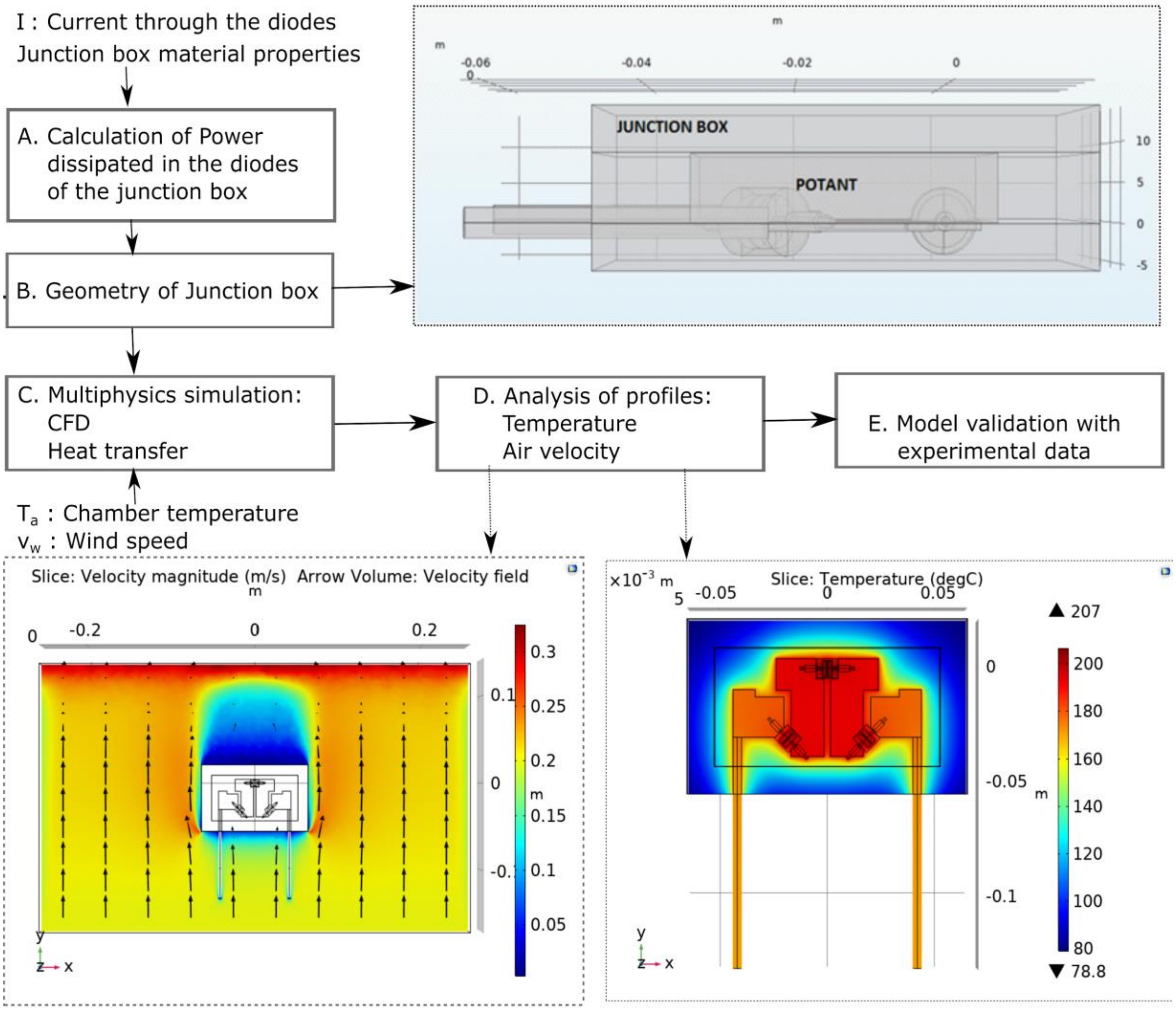
How cool is the junction box design

A Junction box is a part of a photovoltaic (PV) module that houses the conductors that carry currents from the substrings in the module, and the bypass diodes. Under un-shaded conditions, the bypass diodes in the junction box operate in reverse bias. In this case, the heat generated in the diodes is negligible. When the current in any of the substrings in the PV module is limited, then the bypass diode in parallel with that substring becomes forward biased. The power generated in the junction of the diode can reach 4.5 W. It is required that the junction box dissipates this heat to the surroundings to keep the junction temperature below the maximum rating.



The standards that junction boxes must qualify, govern its geometry and materials. A Finite Element Analysis (FEA) model that calculates temperature distribution for a given 3-D design of the junction box, its material properties and the information about the physical conditions around the junction box (air speed and ambient temperature) can save a significant amount of time and cost for manufacturing, experimentation and testing. The simulations of such models help in computing the sensitivity of diode junction temperature with respect to power dissipations in the diodes and the material properties of the junction box, placed in an environment chamber. We have described the methodology for these simulations and are working on the validation of the model.

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Silicon Solar Cell Contacting Scheme Selection

Empowering the reliable Indigenous manufacturing through scientific know-how

Traceable and reliable solar cell measurements are essential for the PV industry as every 1% increase in measurement uncertainty will translate to increased cost and credibility concerns. In collaboration with IIT Bombay spin-off, Silicon Solar Solutions promoted by NCPRE Alumnus Dr Dharmendra Kumar Rai, our scientists at the NCPRE Characterization team led by Dr Ashok Sharma are rigorously working to meet the reliability standards. Our team has successfully developed the in-house shadow-free probes that avoid the shadow of fixed probe bar width by probing the test cell at both ends of all busbars (BB) to empower measurement reliability. However, the non-availability of contact grid standardization based on the number and placement of contact pins for IV measurement is still a concern among testing laboratories.

To understand the impact of existing ambiguity on contacting strategy selection, our team at NCPRE first simulated and analyzed the two most probable used probing schemes L1: single voltage pin (-V-) at the centre, L2: one voltage pin adjacent to each current pin (-IV-). Careful analysis of simulation results explained the influence of fill factor (FF) and efficiency variations due to non-uniform potential distribution along the bus bar of substantial resistance. Further analytical model strengthens probing the bus bar with one voltage pin at the centre of two current pins (-IVI-) repeated at equidistance (L3). Therefore, based on the experimental and analytical results, NCPRE has developed an in-house L3 configuration to enhance solar cell performance. This further strengthens the government's "Atmanirbhar Bharat" initiative towards traceable solar cell assessment. In future, our investigation will help the testing laboratories for quality assurance of solar cell measurements without much concern on contacting strategy selection.

Figure: Single Sense Pin Configuration (L1)

Figure: Single Sense Pin Configuration (L2)

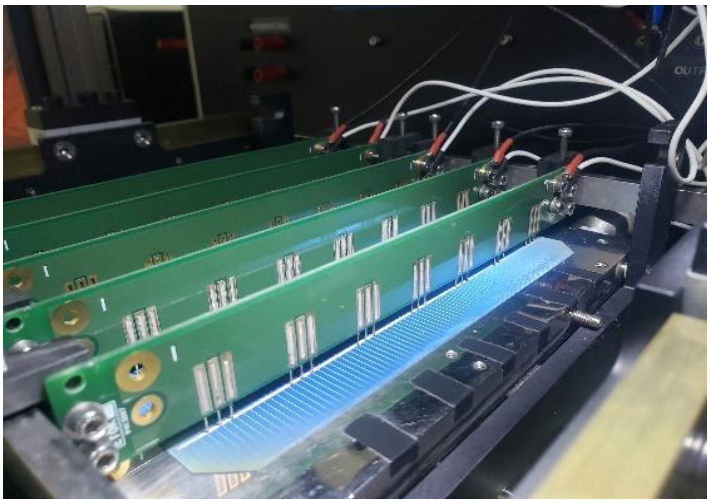

Figure: Single Sense Pin Configuration (L3)

People involved -

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DektakXT Stylus Profiler

The DektakXT® stylus surface profiler is an advanced thin and thick film step height measurement tool. The DektakXT system takes measurements electromechanically by moving a diamond-tipped stylus over the sample surface according to a user-programmed scan length, duration and stylus force. In addition to profiling surface topography and waviness, the DektakXT system measures roughness in the nanometre range.

Salient features and specifications:

Scan Range	1) 6.5 µm	Resolution	1) 0.1 nm
	2) 65.5 µm		2) 1 nm
	3) 524 µm		3) 8 nm
Profile	1) Valleys	Measurement Range	1) 90% below zero
	2) Hills and Valleys		2) 50% below zero and 50% above zero
	3) Hills		3) 90% above zero
Stylus Force		1 mg to 15 mg	
Length		50 µm to 55,000 µm (55 mm)	
Duration		10 sec to 50 sec	

Table - The DektakXT features a single-arch design and smart electronics for improved noise floor performance.

Academic Collaboration

- Thin-film group collaborate with University of Cambridge, UK to provide an insight on dark exciton transport physics to explain photophysics of organic semiconductors. It is readily being used perovskite solar cells as charge transporting layers and in a broader context connects with exciton and charge transport in semi-crystalline solids. There is an industry partner (CDT Pvt. Ltd, UK) too for this work. This joint work gets published in one of the high impact journals Applied Phys. Reviews (IF = 19.2). This article also got featured in SCILIGHT news of American Institute of Physics and featured article of issue.
  https://aip.scitation.org/doi/abs/10.1063/5.0054583

  SCILIGHT News link:
  https://aip.scitation.org/doi/10.1063/10.0006354.

Industrial collaboration

- MoU signed with Corning Research & Development Corporation, USA for the development of flexible solar cells using their flexible glass substrates.

- Cambridge Display Technology Pvt Ltd, UK sends their new class of materials systems under MoU for testing in optoelectronic devices.

Publications

- Sonali Bhaduri, Sudhanshu Mallick, Narendra Shiradkar, and Anil Kottantharayil, “Characterization of reliability of anti-soiling coatings using tapping mode-AFM phase imaging,” Journal of Renewable and Sustainable Energy, Volume 13, 2021, DOI: 10.1063/5.0039255.

- Tirupati Saketh Chandra, Abhimanyu Singareddy, Kashimul Hossain, Dhyana Sivadas, Swasti Bhatia, Shivam Singh Dinesh Kabra and Pradeep R. Nair, “Ion Mobility Independent Large Signal Switching of Perovskite Devices”, Applied Physics Letters, 119, 023506, 2021, DOI:10.1063/5.005134

Achievements & Announcements

- 5th IEEE Workshop on Recent Advances in Photonics (IEEE-WRAP) in 4-6 March 2022

- NCPRE investigator is Technical chair for "Photonics for Renewable Energy"

  https://ieee-wrap.org/

NCPRE

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