PVSAT 2024

10–12 April 2024
Technology and Innovation Centre (TIC),
University of Strathclyde, Glasgow, UK

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Programme

Wednesday 10 April 2024

10:30am	Registration and Welcome Refreshments			
Time	**Talk**	**Speaker**	**Title**	**Affiliation**
11am	**Welcome**	Tasmiat Rahman	Conference Chair	University of Southampton
		George Koutsourakis	Programme Chair	NPL
		Strathclyde host	Strathclyde Intro	University of Strathclyde
Session 1 Chair: Tasmiat Rahman				
11:15am	**Invited Speaker**	Aruna Ivaturi	TBC	University of Strathclyde
11:45am	**Contributed**	David Keeble	Detection of vacancy-related point defects in antimony selenide	University Of Dundee
12:00pm	**Contributed**	Dan Lamb	CdTe-based PV on ultrathin glass for emerging large area space applications	Swansea University
12:15pm	**Flash Poster Presentations A**			
12:30pm	**Lunch**			
1:30pm	**Poster Session**			
2:45pm	**Afternoon Break**			
Session 2 Chair: Elizabeth Gibson				
3pm	**Invited Speaker**	Satoshi Uchida	Nanoscopic observation of organometal halide perovskite solar cells with superlattice	University of Tokyo
3:30pm	**Contributed**	Oliver Hutter	Hysteresis and Transient Behaviour in Current Voltage Measurements of Antimony Selenide Solar Cells	Northumbria University
3:45pm	**Contributed**	Matthew Wright	Impact of Surface Electric Fields on Light Soaking Enhancements in SHJ Solar Cells	University Of Oxford
4pm	**Contributed**	Mr Yazan J.K. Musleh	Irradiance Estimation for Vertical Bifacial AgriPV Systems: Integrating Regression Analysis and Decomposition-Transposition Matrix in the UK Context	University of Southampton
4:15pm	**Afternoon Break**			

Session 3 Chair: Nigel Mason				
Time	**Talk**	**Speaker**	**Title**	**Affiliation**
4:30pm	**Contributed**	Daniel Parsons	A Novel System for Performance measurements of Indoor Photovoltaic Devices under Indoor Standard Testing Conditions (ISTC)	National Physical Laboratory
4:45pm	**Contributed**	James McQueen	Multiphysics Modelling for the Design of >35% Efficient Perovskite-on-Silicon Tandem Solar Cells	University Of Oxford
5pm	**Contributed**	Prabeesh Punathil	Zn(x)Mg(1-x)O buffer layer for CZTSSe solar cells using co-sputtering technique.	Northumbria University
5:15pm	**Contributed**	Lewis Osikibo Tamuno-Ibuomi	Indoor Characterisation and Performance Analysis of Static Hexagonal Concentrators for Building Integrated Low Concentrating Photovoltaic Applications	Glasgow Caledonian University
5:30pm-6:30pm	**Welcome Reception**			

Thursday 11 April 2024

Session 4 Chair: Stuart Boden				
Time	**Talk**	**Speaker**	**Title**	**Affiliation**
9:15am	**Invited Speaker**	Robert Hoye	Photovoltaic Materials Development: Roadmap on Current Challenges and Future Opportunities	University of Oxford
9:45am	**Contributed**	John Murphy	Contact metallization processing considerations for silicon photovoltaics	University Of Warwick
10am	**Contributed**	Ershad Parvazian	Utilizing Low-Toxicity Solvents in Roll-to-Roll Fabrication of Carbon Electrode Perovskite Solar Cells	Swansea University
10:15am	**Contributed**	Jessica Barichello	Beneath the surface: Investigating Perovskite Solar Cells under Water	CNR - ISM Istituto di Struttura della Materia
10:30am	**Exhibitor Flash presentations**			
10:45am	**Morning Break**			
Session 5 Chair: George Koutsourakis				
11am	**Invited Speaker**	Michael Owen Bellini	Addressing durability and reliability issues for commercial and pre-commercial PV technologies	NREL
11:30am	**Contributed**	Ram Datt	Organic Solar Cells at Stratospheric Condition for High Altitude Platform Station Application	Swansea University
11:45am	**Contributed**	Nicholas Grant	Nature of Al2O3 surface passivation for high efficiency silicon photovoltaics	University Of Warwick
12pm	**Contributed**	Fátima Santos	Monolithic dye-sensitized solar cells with copper polymer gel electrolytes for indoor applications	University of Porto
12:15pm	**Contributed**	Bethany Willis	Life-cycle assessment for more sustainable photovoltaics research and manufacturing	Northumbria University

12:30pm	**Lunch**			
Session 6 Chair: Nicola Pearsall				
Time	**Talk**	**Speaker**	**Title**	**Affiliation**
1:30pm	**Invited Speaker**	Alona Armstrong	TBC	Lancaster University
2pm	**Contributed**	Zaid Haymoor	The use of Artificial neural network to enhance MPPT finding methodology on Energy Harvesting chips	Swansea University
2:15pm	**Contributed**	Sophie Pain	Hafnium oxide: A thin film passivating dielectric with controllable etch resistance	University Of Warwick
2:30pm	**Contributed**	Stefan Nicholson	Unveiling the effects of electron transport layers on all inorganic perovskite film formation	University of Strathclyde
2:45pm	**Afternoon Break**			
Session 7 Chair: Nakita Noel				
3pm	**Invited Speaker**	Ruy Sebastian Bonilla	Charged-Up Solar Cells: The Role of Interface Electric Fields in Photovoltaic Devices	University of Oxford
3:30pm	**Contributed**	Jay Patel	Terrestrial And Non-Terrestrial Environmental Effects on Perovskite Solar Cell Performance	King's College London
3:45pm	**Contributed**	Austin Kay	Realistic Performance Limits of Indoor Photovoltaics	Swansea University
4pm	**Contributed**	Udari Wijesinghe	Intense Pulsed Light Sintering of Antimony Selenide Thin Films	Northumbria University
4:15pm	**Afternoon Break**			
Session 8 Chair: Steve Ransome				
4:30pm	**Contributed**	Lethy Krishnan Jagadamma	Halide Perovskites Based Indoor Photovoltaics: Role of Interfacial Layers	University of St Andrews
4:45pm	**Contributed**	Yixin Wang	Unravelling the effects of oxygen doping on charge-carrier dynamics of AgBiS2 solar harvester	University Of Oxford
5pm	**Contributed**	Amy Neild	Unlocking the Potential of Alternative Hole Transporting Materials for Solid-State Dye-Sensitised Solar Cells through Prolonged Oxidation and Light Soaking Treatment	Newcastle University
5:15pm-5:30pm	**Contributed**	Haoxiang Zhang	Revisiting the Significance of Spectral Solar Irradiance Data: Economical Approaches to Effective Measurement	University of Southampton
7:15pm-10pm	**Drinks Reception and Conference Dinner** (Trades Hall, 85 Glassford Street, Glasgow, G1 1UH)			

Friday 12 April 2024

Session 9 Chair: Aruna Ivaturi				
Time	**Talk**	**Speaker**	**Title**	**Affiliation**
9:15am	**Invited Speaker**	Marina Freitag	TBC	Newcastle University
9:45am	**Contributed**	Mahmoud Dhimish	Do Minor Cracks in Solar Cells, Barely Visible in Electroluminescence, Really Matter?	University Of York
10am	**Contributed**	Yuelin Xiong	Self-Aligned Laser Opening and Stencil Metallisation for Silver-Free Contacts in Silicon Solar Cells	University Of Oxford
10:15am	**Contributed**	Yue Hu	Control crystallisation of perovskites in printable mesoscopic solar cells	University of Edinburgh
10:30am	**Contributed**	Nicholas Burridge	Application-Targeted Metal Grid - Enhanced Transparent Electrodes for Organic Photovoltaics	Swansea University
10:45am	**Morning Break**			
Session 10 Chair: Alex Cole				
11am	**Invited Speaker**	Kurt Barth	TBC	Loughborough University
11:30am	**Contributed**	George Koutsourakis	Hybrid satellite albedo data for bifacial PV systems in complex landscapes and comparison with hybrid ground based data	National Physical Laboratory
11:45am	**Contributed**	Lucy Hart	Understanding the Ionic Modulation of Open-Circuit Voltage in Perovskite Solar Cells	Imperial College London
12pm	**Contributed**	Matthew Wright	Characterisation of Solar Cell Interfaces using Elastic Recoil Detection Analysis	University Of Oxford
12:15pm	**Closing Remarks / Awards**			
12:30pm	**Lunch (pre-packed grab and go)**			
1:30pm	**Conference concludes and depart**			

Poster Presentations

Poster board No.	Paper Title	Presenter	Affiliation
1	Exploring the Dynamics of Risk and Quality in Solar Photovoltaic Systems	Sharmarke Mohamed Hassan	University Of York
2	Auxetic Crystalline Silicon Solar Module with Rotating Square Array Structure	Chen Cao	University of Southampton
3	Detection and identification of vacancy-related point defects in perovskite halide semiconductors	Aryaveer Singh	University Of Dundee
6	Simulating relative performance of Organic and Silicon PV in real-world conditions	Zongtai Zhang	Durham University
7	Synthesis, XRD, EDX, SEM, and TEM characterization of two sulfide nanostructures Ni(S2COBu)3 and [Ni(S2COPn)3	Abdulaziz A. Alanazi	Prince Sattam Bin Abdulaziz University
8	Floating Photovoltaic (FPV) for climate vulnerable river island communities	Yiliao Zhou	University of Southampton
9	CdTe thin film absorber layers grown under Cd-rich conditions by MOCVD: impact on film surface topography and structure	Ochai Oklobia	Swansea University
11	Evaluating the feasibility of novel PV technologies for powering PM2.5 sensors in indoor and outdoor applications	Willow Herring	University of Southampton
12	Influence of Thickness on the Electrical Properties of ITO Thin Films Grown by RF Magnetron Sputtering Technique for Concentrated Perovskite Solar Cells	Fahad M. Alsahli	University of Exeter
13	Enhancing Solar Cell Longevity: Assessing the Impact of ITO Coatings on PID Resistance	Thomas Lynch	University of York
15	Tuning the morphology and phase structure of tungsten oxides for photovoltaic applications	Ajeet Srivastav	University of Strathclyde
16	Calamitic-Type Dipolar and Quadrupolar Chromophores with Twisted Peripheral Handle: Structure-Property Outlook as Non-fullerene Acceptors for Binary Solar Cells	Praveen Chandrasekar	University of Strathclyde

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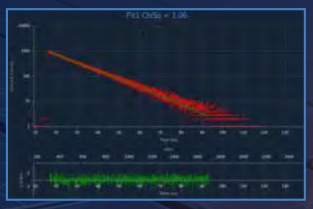

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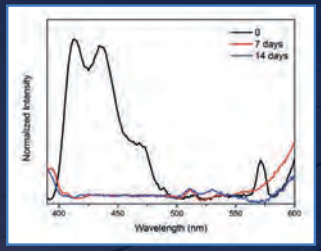

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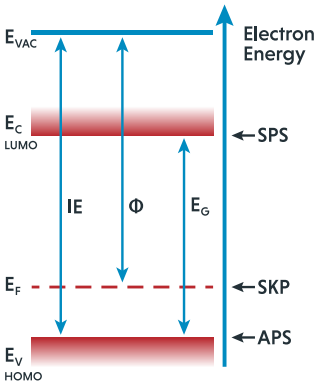

APPLICATIONS

- Charge Transport Layers
- Device Efficiency
- Diamond
- Ion Dynamics
- Lead Bromide Perovskites
- Nano Tubes
- OLEDs
- Optoelectric Properties
- Organic Solar Cells
- PEDOT:PSS
- Photocatalytic Hydrogen Production
- Photovoltaic Devices & Technology
- Quantum Dots
- TCOs
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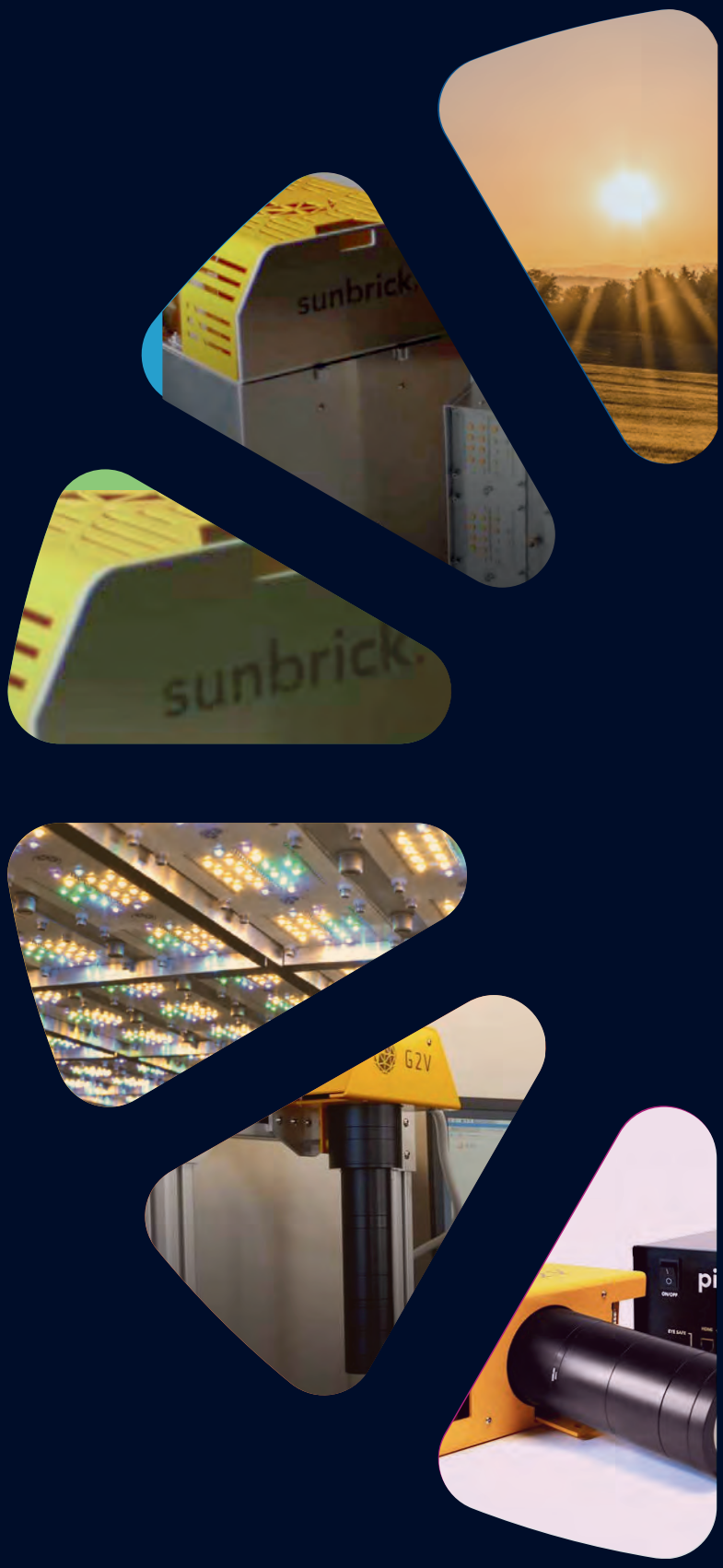

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SCAN ME!

Invited Speaker Presentations

Photovoltaic materials development: Roadmap on current challenges and future opportunities

Prof. Robert Hoye[1]
[1]University Of Oxford, United Kingdom

Session 4: Robert Hoye (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 09:15 - 10:30

Photovoltaics (PVs) are a critical technology for curbing growing levels of anthropogenic greenhouse gas emissions, and meeting increases in future demand for low-carbon electricity. In order to fulfil ambitions for net-zero carbon dioxide equivalent (CO2eq) emissions worldwide, the global cumulative capacity of solar PVs must increase by an order of magnitude from 0.9 TWp in 2021 to 8.5 TWp by 2050 according to the International Renewable Energy Agency, which is considered to be a highly conservative estimate. In 2020, the Henry Royce Institute brought together the UK PV community to discuss the critical technological and infrastructure challenges that need to be overcome to address the vast challenges in accelerating PV deployment. In 2023, 86 individuals from >50 groups, mostly based in academic institutions, companies and national laboratories in the UK, convened to discuss the key developments in the field as a whole, especially the progress made in the field since the earlier roadmap. In this talk, I will discuss key points raised (Figure 1), which focus both on the challenges in improving the efficiency, stability and levelized cost of electricity of current technologies for utility-scale PVs, as well as the fundamental questions in novel technologies that can have a significant impact on emerging markets, such as indoor PVs, space PVs, and agrivoltaics. I discuss challenges in advanced metrology and computational tools, as well as the growing synergies between PVs and solar fuels, and offer a perspective on the environmental sustainability of the PV industry. This talk will finish with important current challenges, as well as future opportunities, and areas in which communities from different parts of the PV field can learn from each other.

Charged-up solar cells: the role of interface electric fields in photovoltaic devices

Sebastia Bonilla[1]
[1]University of Oxford, United Kingdom

Session 7: Ruy Sebastian Bonilla (Invited Speaker) Followed by Contributed Talks, April 11, 2024, 15:00 - 16:15

In this work, we examine the relationship between interface electric fields and efficiency enhancements via surface passivation in silicon solar cells. The historical trajectory of silicon PV technologies reveals a consistent upward trend in efficiency improvements, bringing us closer to the practical limit of ~28.5%. Achieving efficiencies ever nearer this limit requires superb interface passivation with a surface recombination current J0s<5 fA/cm2. For ultimate interface passivation, two fundamental elements are required: chemical passivation and field effect. The first key ingredient, chemical passivation, involves addressing imperfections in the chemical interface, where unsaturated bonds can impede optimal performance. These imperfections contribute to a higher minority carrier capture rate, impacting the concentration of available photogenerated carriers. The second key ingredient, field effect, involves carrier density modulation by applying electric fields. Contrary to conventional perceptions that these two key ingredients operate independently, this contribution will demonstrate how they are profoundly interdependent. The intricate relationship between the chemistry of an interface and its impact on the field effect, and vice versa, forms a pivotal aspect in improving solar cell interfaces. It is well known that interface passivation strongly depends on the polarity and strength of the electric field. Here we show that the surface electric fields not only influence the surface carrier population but also affect the resulting chemical interface properties post-annealing. This has been observed in at least three interfaces crucial to Si PV technology: Ag-Si metal interfaces, polysilicon-SiOx-Si passivating contacts, and SiO2-Si surfaces.

Nanoscopic Observation of Organometal Halide Perovskite Solar Cells with Superlattice

Satoshi Uchida[1]
[1]University of Tokyo, Japan

Session 2: Satoshi Uchida (Invited Speaker) Followed by Contributed Talks,
April 10, 2024, 15:00 - 16:15

The micro-structural observation analysis of the perovskite layer with high resolution TEM is the most promising approach to understand the crystal structure. Recently we newly revealed that the tetragonal and cubic phases coexist at room temperature in the conventional MAPbI3 thin film device. Furthermore superlattices composed of these mixture of tetragonal and cubic planes without any compositional change was also found.

Recently, there has been a surge of interest in organometal halide perovskite solar cells (PSCs). These cells have exhibited a remarkable increase in power conversion efficiency (PCE), with certified PCEs reaching over 26% by employing mixed organic cations and halide anions. The PCE is significantly influenced by the photovoltaic properties of each component within the PSC. Despite the crucial role of crystallographic information, micro-structural analysis of the perovskite layer has not been extensively pursued.

It has been widely accepted that the organometal halide perovskite exists in distinct phases: orthorhombic phase < 165K < tetragonal phase < 327K < cubic phase. However, our recent observations have revealed the coexistence of tetragonal and cubic phases at room temperature in conventional MAPbI3 thin film devices. Moreover, we have made the surprising discovery of superlattices comprising a mixture of tetragonal and cubic planes without any compositional alterations. The formation of these superlattices occurs through intrinsic structural transitions, without the need for artificial modifications. Consequently, many phenomena related to structural superlattices are anticipated to occur spontaneously and automatically within relevant contexts. Organometal halide perovskites demonstrate a remarkable ability to self-adjust their micro-structural configurations and self-organize buffer layers inside crystals or at hetero-interfaces by introducing self-assembled superlattices. We believe that this report represents a pivotal advancement, bringing PCEs of organometal halide perovskite solar cells closer to their theoretical maximum and redefining the potential of these materials for a wide range of applications beyond solar cells.[1-5]

References

[1] T.W. Kim, S. Uchida, T. Matsushita, L. Cojocaru, R. Jono, K. Kimura, D. Matsubara, M. Shirai, K. Ito, H. Matsumoto, T. Kondo and H. Segawa, Advanced Materials, 30(8), 2018, 1705230.
[2] T.W. Kim, M. Kim, N. Shibayama, L. Cojocaru, S. Uchida, T. Kondo and H. Segawa, Advanced Functional Materials, 1804039 (2018).
[3] T.W. Kim, T. Matsushita, S. Uchida, T. Kondo and H. Segawa, Applied Physics Express, 11(10), 101401 (2018).
[4] T.W. Kim, M. Kim, L. Cojocaru, S. Uchida and H. Segawa, ACS Energy Letters, 3, 2743–2749 (2018).
[5] L. Cojocaru, T.W. Kim, S. Uchida, and H. Segawa, Chemistry Letters, 48, 26-27 (2019).

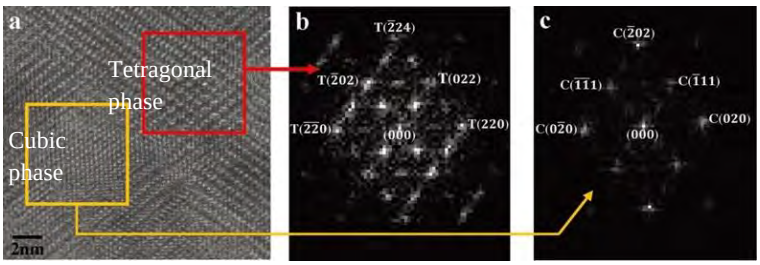


Fig. 1. TEM images (Hitachi HF-3300, 300KeV), a) HRTEM (×1,000K) image showing the coexistence of the tetragonal and cubic nano domains. b) Fourier transformed diffraction pattern (FTDP) at small area (6.5nm×6.5nm) for cubic C[101] zone axis and c) tetragonal T[111] zone axis.

Oral Contributed Presentations

Hybrid satellite albedo data for bifacial PV systems in complex landscapes and comparison with hybrid ground based data

Dr James Blakesley[1], Dr George Koutsourakis[1], Mr Daniel Parsons[1], Dr Natalie Mica[2], Suhas Balasubramanyam[2], Mark Russell[2]
[1]National Physical Laboratory, United Kingdom, [2]RINA Tech UK Ltd, United Kingdom

Session 10: Kurt Barth (Invited Speaker) Followed by Contributed Talks,
April 12, 2024, 11:00 - 12:15

Bifacial photovoltaic (PV) systems can absorb light from both their front and their rear side, hence they are able to harvest the light reflected from the ground. For this reason, ground albedo is a critical parameter in estimating the expected performance of bifacial PV systems. It is important that albedo data are available at the planning and design stage of a PV system, when site data might not be available, but when confidence in expected yield directly affects investment value. Such albedo data should be accurate and relevant, with known uncertainties, in order to increase confidence in yield modelling at the design phase.

This work investigates the challenges of different albedo data sources and proposes solutions towards more reliable datasets. Satellite sources, such as the NASA Moderate Resolution Imaging Spectrometer (MODIS) products, provide data that can be used to model effective albedo anywhere in the world [1]. Nevertheless, there are numerous sources of error that can add uncertainty in bifacial gain, reducing confidence and increasing financial risk. Especially for smaller potential sites located in varied landscapes, the scaling error caused by the low spatial resolution of MODIS data can be large [2]. By analysing case studies in complex landscapes, we investigate the accuracy of different albedo measurement approaches. Monitoring stations with reference PV cells and pyranometers were deployed to validate satellite data. Since these sites are much smaller than a MODIS pixel, we have evaluated alternative approaches, among which a novel method of combining MODIS data with higher resolution satellite data (Sentinel 2 data). This combined satellite data method offers a practical solution with good agreement with ground-based station data, showing great promise for remote estimation of effective albedo for bifacial PV systems in complex landscapes.

Unravelling the effects of oxygen doping on charge-carrier dynamics of AgBiS2 solar harvester

Yixin Wang[1], Yi-Teng Huang[1], Dennis Friedrich[2], Xiaoyu Guo[1], Yuchen Fu[1], Robert L.Z. Hoye[1]
[1]Inorganic Chemistry Laboratory, Department of Chemistry, University of Oxford, United Kingdom, [2]Institute for Solar Fuels, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Germany

Session 8: Contributed Talks, April 11, 2024, 16:30 - 17:30

I-V-VI_2 ternary chalcogenides are receiving broad research interest due to their low toxicity and abundance nature, fuelled by the high power conversion efficiency (PCE) and excellent stability of $AgBiS_2$. [1,2] Due to the high absorption coefficient, a thinner layer of $AgBiS_2$ is required for solar cell devices, which mitigates possible charge-carrier recombination and is beneficial for carrier collection. Whereas, carrier-phonon coupling leads to carrier localization, limiting carriers' mobilities and lifetimes. [3,4]

In this work, it is discovered that synthesizing $AgBiS_2$ nanocrystal (NC) under low vacuum and ambient conditions could give better optoelectronic properties of $AgBiS_2$ NC. This is attributed to the doped oxygen content that passivates the defects in NC samples. X-ray photoelectron spectroscopy (XPS) is employed to measure oxygen content and optical-pump terahertz-probe (OPTP) as well as photoluminescent (PL) are measured to extract the carrier dynamics.

The PL peak at 880 nm is recognized as the bandgap, which becomes more intense with increasing oxygen content. This reveals that the oxygen content can introduce additional density of state (DOS) near the conduction band minimum (CBM). Besides, the OPTP results suggest that with an increasing extent of oxygen doping, a slower localization rate of charge carriers is observed. This is interpreted as oxygen doping can passivate dangling bonds in the surface of NC by forming bonds to saturate the dangling bonds, avoiding carriers being trapped in defects.

In conclusion, we verify that oxygen doping can alleviate charge-carrier localization in $AgBiS_2$. This demonstrates the potential of utilizing oxygen doping to enhance the optoelectronic performance of $AgBiS_2$ NC. This insightful work opens further research in the field of passivation strategies for $AgBiS_2$ material.

Self-Aligned Laser Opening and Stencil Metallisation for Silver-Free Contacts in Silicon Solar Cells

Yuelin Xiong[1], Ruidong Zhou[1], Anastasia Soeriyadi[1], Zongtao Liu[1], Soumyajit Maitra[1], Jingyan Chen[1], Yifu Shi[1], John O'Sulllivan[1], Pietro Altermatt[2], Ruy Sebastian Bonilla[1]
[1]Department of Materials, University Of Oxford, United Kingdom, [2]Trina Solar, State Key Laboratory for Photovoltaic Science and Technology (SKL PVST), China

Session 9: Marina Freitag (Invited Speaker) Followed by Contributed Talks,
April 12, 2024, 09:15 - 10:45

In 2020, silver accounted for 10.3% of the global supply, used extensively in PV components generating 135 GW. To meet the 2030 target of 3 TW PV production, sustainable and cost-effective metallisation approaches should be developed [1]. Moreover, the ongoing trend toward smaller finger widths for reducing the shadowing effect and material usage underscores the need for precise alignment between metal deposition and dielectric openings. In this work, we explore the possibility of a novel self-aligned process with a sustainable metal. We fabricate and place stainless steel stencil masks on the top surface of silicon solar cell precursors, enabling laser ablation defined by the stencil mask opening. Finally, thermal evaporation is used to deposit aluminium through the shadow mask without mechanical realignment. We laser raster perpendicular to the stencil finger openings, enabling point contact with precise contact area definition.

We successfully demonstrate 25 µm wide metal fingers via thermally evaporated aluminium directly deposited onto laser-patterned point contacts of 20 µm*17 µm size. This self-aligned process is demonstrated on textured silicon passivated with 75 nm silicon nitride. Optical and electron microscopy analysis shows that the UV picosecond laser ablation damage is limited, and sufficient alignment is achieved. Line resistivity of 15.74 Ω/cm and contact resistivity of <10 mΩ·cm2 show the current-carrying capabilities of the contacts, in agreement with the microstructural characterisation. PL analysis demonstrates that the passivation quality is minimally affected by the laser opening of the dielectric layer. Complete devices bearing the stencil self-aligned contacts on the front surface are characterised electrically, showing the feasibility of developing functional cells with the proposed metallisation method. This novel approach can potentially replace non-sustainable silver as front and back contacts for bifacial solar cells since other metal pastes and deposition methods can be easily integrated into a metal stencil mask process.

Do Minor Cracks in Solar Cells, Barely Visible in Electroluminescence, Really Matter?

Dr Mahmoud Dhimish[1]
[1]University Of York, United Kingdom

Session 9: Marina Freitag (Invited Speaker) Followed by Contributed Talks,
April 12, 2024, 09:15 - 10:45

In the realm of solar panel technology, short cracks near the busbar tips are a common yet often overlooked issue. These minuscule fractures are challenging to detect; they require highly optimised electroluminescence (EL) camera systems with superior resolution and specific focus adjustments [1]. Consequently, many of these short cracks remain unnoticed during standard EL testing in both manufacturing and field environments. Even when identified, the industry's current acceptance criteria tend to be lenient regarding these defects. This raises a critical question: Should there be a higher level of concern regarding these seemingly minor imperfections?

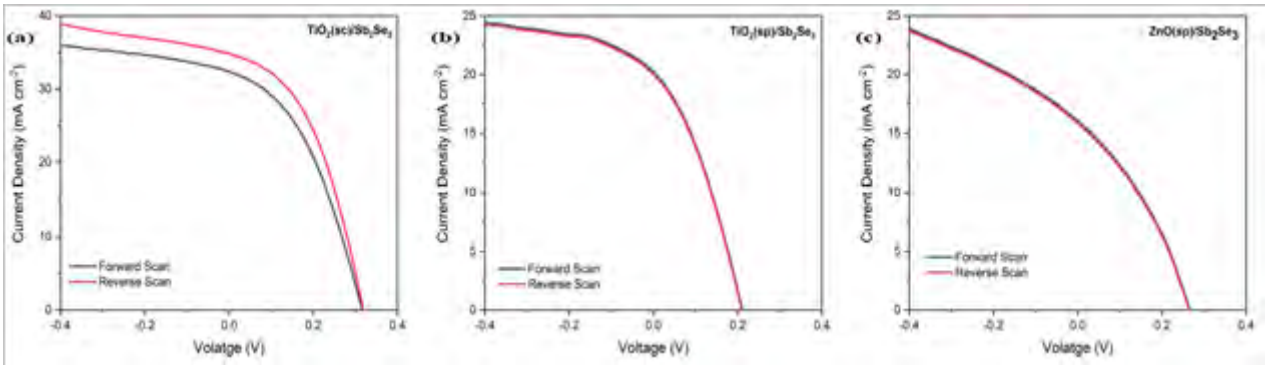
In this presentation, I will address a critical concern in the field of solar panel technology by presenting evidence from our latest research. Our study focuses on the progression of small cracks in various PV module technologies. We specifically examine modules that exhibit these minor cracks, tracking their development as we apply increasing mechanical loads on the panel fronts. This research, conducted in collaboration with Above Surveying Ltd (UK) and Brightspot Automation (USA), aims to provide a deeper understanding of how these cracks affect solar panel performance and durability. We have found that almost all short cracks evolve into longer or dendritic forms. Interestingly, cells without pre-existing short cracks rarely develop new cracks under stress. However, when a previously intact cell does crack under high load, the result is often dramatic shattering.

Hysteresis and Transient Behaviour in Current Voltage Measurements of Antimony Selenide Solar Cells

Dr Oliver Hutter[1]
[1]Northumbria University, United Kingdom

Session 2: Satoshi Uchida (Invited Speaker) Followed by Contributed Talks,
April 10, 2024, 15:00 - 16:15

Antimony selenide (Sb2Se3) is a promising light-absorber used in low-cost, non-toxic, earth-abundant thin-film solar cells with rapidly rising efficiency values. Many n-type metal oxides have been investigated as buffer layers in Sb2Se3 solar cell architectures and among them, titanium oxide (TiO2) is most commonly used. The current density–voltage measurement of Sb2Se3 solar cells in FTO/TiO2/Sb2Se3/P3HT/Au configuration shows a hysteresis-like distortion that depends on the voltage scan direction, scan rate, scan range, and voltage bias conditions prior to measurement. The presence of hysteresis can significantly influence the photovoltaic properties of devices, which can overestimate or underestimate the accurate power conversion efficiency of solar cells. The fabricated solar cells show normal hysteresis where the forward scan result exhibits lower performance than the reverse scan under certain circumstances. We identify this phenomenon to be caused by charge carrier accumulation which may be because the capacitive charge is quickly discharged through charge separation. In addition, the accumulation of oxygen vacancies at the TiO2/ Sb2Se3interface can reduce charge extraction, and at the same time, significantly accelerate the charge recombination at the interface, which also leads to unfavourable hysteresis. However, the hysteretic effects are not observed in devices utilizing alternative buffer layers like ZnO and SnO2, suggesting that the buffer absorber interfaces have a significant effect on transients in Sb2Se3 absorber devices. Therefore, further improvements of Sb2Se3 solar cells are essential through careful surface engineering of existing TiO2 or through a judicious choice of alternative interfacial layers.



Contact metallization processing considerations for silicon photovoltaics

Dr Edris Khorani[1], Dr Sophie Pain[1], Dr Tim Niewelt[1,2], Dr Nicholas Grant[1], Professor John Murphy[1]
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Session 4: Robert Hoye (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 09:15 - 10:30

The rapid growth of the c-Si photovoltaic (PV) industry over recent years has led to major technological advancements that have in-turn led to improvements in cell performance. From the Al back-surface field architecture to passivated emitter and rear cell (PERC) and now to the tunnel oxide passivated contact (TOPCon) cell, one of the ongoing primary concerns has been alleviating the electrical losses in the contacting regions. To reach the theoretical power conversion efficiency limit of 29.4 %, the existing electrical losses from the contact architectures and fabrication methods in-use must be mitigated, e.g., reaching the same level or even exceeding the performance of electron-selective contacts with the hole-selective counterpart for TOPCon. One aspect to consider is the metallization process used for contact formation. Two widely used options are electron beam (e-beam) and thermal evaporation.

In this work, we explore the difference in electrical performance when using e-beam and thermal evaporation for Al contact metallization. We examine 100 nm symmetrical Al_2O_3 passivation on p-type Si (Cz, Ga-doped, 5 Ωcm, <100>, 120 µm thick) specimen before and after 100 nm Al metallization and find that the e-beam method is unsuitable due to the detrimental radiation effects from the e-beam source. A similar procedure is performed using thermal evaporation, where we find that the degradation in passivation is negligible until the Al_2O_3 passivation layers are less than 5 nm in thickness. We also conduct superacid re-passivation to determine whether the defect-induced damage in both the e-beam and thermal evaporation specimens is surface or bulk related. We investigate the defects induced by these processes further via deep-level transient spectroscopy (DLTS). Additionally, the consequential effects on contact resistivity as well as enhancements via ‘Alnealing’ (i.e., hydrogenation effects) are also presented.

Hafnium oxide: A thin film passivating dielectric with controllable etch resistance

Dr Sophie Pain[1], Dr Ailish Wratten[1], Dr Edris Khorani[1], Ms Anup Yadav[1], Dr Tim Niewelt[1,2,3], Mr Brendan Healy[1], Dr Marc Walker[4], Dr David Walker[4], Dr Nicholas Grant[1], Professor John Murphy[1]
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Session 6: Alona Armstrong (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 13:30 - 14:45

Engineering the properties of dielectric nanoscale thin films according to desired applications will enable the next generation of photovoltaics. First, excellent surface passivation is required to give long effective charge carrier lifetimes for high-efficiency solar cells. Second, cell manufacturing often requires selective thin film removal, hence controllable etch resistance can be useful. Third, passivating contacts - now needed for state-of-the-art devices - need to be selective for efficient hole/electron extraction and this can be enabled by tuneable fixed charge polarity.
Atomic layer deposition (ALD), based on sequential self-terminating reactions, is one means to grow ultra-thin passivation layers, and offers a large degree of control over film growth conditions, and subsequent properties. It is scalable and Al_2O_3 grown by ALD is used in ~30% of solar cells produced today. Recent studies have identified HfOx as a potential ALD-grown alternative. 10-20 nm HfOx films achieve surface recombination velocities (SRVs) 10 cm/s possible (c.f. <1 cm/s for ALD Al_2O_3).

In this contribution, we will demonstrate the flexibility offered by hafnium oxide and summarise recent improvements in passivation. We utilise carrier lifetime measurements, Kelvin probe analysis, corona charging, atomic force microscopy, X-ray diffraction and X-ray photoelectron spectroscopy to characterise properties of HfOx nanolayers. Careful selection of growth conditions and post-deposition processing allows the etch resistance to be controlled. Furthermore, literature reports of ALD-grown HfOx suggest both negative and positive charges are possible, depending on growth conditions. Via Kelvin probe and corona charge analysis, we determine that charge polarity is not influenced by growth co-reactant or post-deposition processing, with the role of the hafnia precursor yet to be determined. Recent work has also improved passivation qualities achievable (with SRVs now competitive with Al_2O_3) and suggested that HfOx has the potential to provide multiple routes towards passivating contacts.

Intense Pulsed Light Sintering of Antimony Selenide Thin Films

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Session 7: Ruy Sebastian Bonilla (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 15:00 - 16:15

Antimony selenide (Sb_2Se_3) has emerged as a promising photoelectric material owing to its excellent material properties. Post-deposition annealing treatments have been carried out to improve the degree of crystallinity and optical properties. However, these thermal annealing treatments typically require 60 minutes or more of thermal annealing at high temperatures (>300 °C), severely limiting the throughput and substrate choice. For the first time, we report a low thermal budget annealing technique using a photonic curer to produce crystalline Sb_2Se_3 thin films starting with amorphous Sb_2Se_3. Photonic curing can heat Sb_2Se_3 thin film to several hundred degrees over a short time while maintaining the substrate at a low temperature. Here, the effect of photonic curing conditions on the conversion of amorphous Sb_2Se_3 to obtain crystalized Sb_2Se_3 using a single pulse was analyzed. For a given radiant exposure, short pulse length pluses (<1 ms) cause damage to Sb_2Se_3 films due to the higher power delivered by the shorter pulse, resulting in higher temperatures at the Sb_2Se_3 layer and thermal expansion of the top surface of the underneath layer. Longer pulses (>5 ms) allow heat transfer to the substrate during the light pulse, limiting the temperature reached at the sample surface and resulting in a crystallized Sb_2Se_3 layer with no or minimum surface damage. Similarly, for a constant pulse length, an increase in the radiant exposure eventually damages the Sb_2Se_3 due to increased power delivery and higher surface temperatures of the sample. Therefore, increasing the pulse length or decreasing the radiant exposure can avoid damage caused to the Sb_2Se_3 layer. Hence, photonic curing shows the capability of sintering Sb_2Se_3 thin films and creating crystalline films without sacrificing surface coverage. This opens up new opportunities in the manufacturability of Sb_2Se_3 solar cells by eliminating the rate-limiting annealing step.

Zn(x)Mg(1-x)O buffer layer for CZTSSe solar cells using co-sputtering technique.

Dr Prabeesh Punathil[1], Dr Giray Kartopu, Dr. Pietro Maiello, Prof Vincent Barrioz, Prof. Neil S Beattie, Prof. Guillaume Zoppi
[1]Northumbria University, United Kingdom

Session 3: Contributed Talks, April 10, 2024, 16:30 - 17:30

Kesterite solar cells based on Cu2ZnSn(S,Se)4 (CZTSSe) absorbers have recently demonstrating efficiency >14% after a decade long period of stagnation. While a clear Voc deficit remains, a further boost in efficiency can be generated by maximizing the optical properties of the structure and providing better band alignment with the window layer. Furthermore, the most common n-type partner layer, cadmium sulfide (CdS), is toxic and deposited using chemical bath methods producing large amount of waste, thereby reducing the sustainable nature of kesterite solar cells. Here we explore alternative buffer other buffer layers that can be used to maintain the non-toxic nature of CZTSSe solar cell without a compromise in energy conversion efficiency.
In this work, MgxZn1-xO is used as a replacement for the CdS buffer layer. The MgxZn1-xO is one of the most favorable candidates for replacing the CdS because it has a higher tunable band gap as compared to CdS and the Conduction Band Offset (CBO) can be tuned to a more optimal value through modification of the Zn/Mg ratio. Due to its wider bandgap, MgxZn1-xO also shows a higher optical transmission than that of CdS thus increasing output current of the device. In this study, MgxZn1-xO thin films were deposited by co-sputtering of ZnO and MgO targets and their physical properties were studied by changing the doping ratios. Different x = Zn/Mg ratio films were obtained by changing the MgO (0 to 100 W) and ZnO (30 to 80 W) sputtering power ratio. The bandgap of the films varied from 3.21 eV to 4.46 eV as x increases from 0 to 0.66. CZTSSe photovoltaic devices with MgxZn1-xO buffer layers of varied properties were fabricated and compared with reference devices made using a CdS buffer layer. The performance of completed devices will be discussed insight of the information collected.

Characterisation of Solar Cell Interfaces using Elastic Recoil Detection Analysis

Matthew Wright[1], Dr Matthew Sharpe[2], Callum McAleese[2], Yan Wang[1], Yifu Shi[1], Sebastian Bonilla[1]

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Session 10: Kurt Barth (Invited Speaker) Followed by Contributed Talks, April 12, 2024, 11:00 - 12:15

The passivation of crystalline silicon (c-Si) surfaces with hydrogen (H) is critical in achieving the recently observed record cell efficiencies [1]. In addition, surface-related degradation in passivating contact structures has been attributed to an accumulation of hydrogen at the c-Si / SiOx interface [2]. Therefore, it is critical to analyse the distribution of hydrogen throughout the passivating structure following firing, particularly near the c-Si / SiOx interface. The hydrogen distribution is typically measured using a SIMS depth profile [3]. However, this can be inaccurate as the remnant H background gas in the chamber can distort the measured H concentration and primary ion bombardment can cause an apparent shift in the detected H species, skewing the measured distribution. In our previous work (presented at PVSAT-17), we introduced time-of-flight elastic recoil detection analysis (ToF-ERDA) as an alternative characterisation approach to measure the distribution of H in TOPCon structures. This proved a promising way to distinguish between deuterium (D) and H profiles, however, the ability to resolve the interface was limited due to two reasons: i) The surface of the silicon was thus quite rough, ii) the sample stack was > 100 nm thick, meaning the interface was deep in the sample. In this work, we aim to overcome these experimental issues by fabricating simple dielectric passivating layers onto flat silicon surfaces.

We perform ToF-ERDA measurements on both SiNx and Al2O3 passivation stacks. These results show a clearer ability to resolve the interface between the c-Si and passivation layers, further presenting ToF-ERDA as a useful tool for solar cell analysis.

Impact of Surface Electric Fields on Light Soaking Enhancements in SHJ Solar Cells

Matthew Wright[1], Donghao Liu[1], Dr Audrey Morisset[2], Prof Franz-Josef Haug[2], Prof Sebastian Bonilla[1]

[1]University of Oxford, United Kingdom, [2]Ecole Polytechnique Fédérale de Lausanne, Switzerland

Session 2: Satoshi Uchida (Invited Speaker) Followed by Contributed Talks, April 10, 2024, 15:00 - 16:15

The current silicon solar cell world record efficiency of 26.81% was achieved with a silicon heterojunction (SHJ) device architecture. Light-soaking SHJ solar cells has been to shown to increase the efficiency, due to improved VOC and FF. In fact, the world record cell received a light soaking process under 60 sun illumination to boost efficiency. Although it is a well demonstrated phenomenon, the exact mechanism leading to light soaking improvements is still under investigation. The current hypothesis is that hydrogen migrates to the a-S(i) / c-Si interface under light-soaking, when in the presence of doped layers, which improves the surface passivation. The aim of this work is to investigate this hypothesis by applying surface electric fields to SHJ lifetime samples during light soaking, to assess the impact on the observed enhancements. Surface electric fields were applied to SHJ lifetime precursors using corona charging. a sample subjected to negative surface corona charge during light soaking. When negative charge was applied to the surface, almost no lifetime enhancement is seen, thus the charge suppresses the changes seen due to light soaking. Applying positive surface charge leads to a far greater enhancement, the lifetime increases from 11.9 ms to 15.1 ms. These results indicate two key findings, i) surface electric fields can modulate light soaking enhancements in SHJ samples and ii) the direction of the field impacts this modulation. These results could provide evidence to strengthen the hypothesis that efficiency gains are related to the migration of hydrogen ions through the a-Si to passivate defects at the interface.

Nature of Al2O3 surface passivation for high efficiency silicon photovoltaics

Dr Nicholas Grant[1], Dr Sophie Pain[1], Dr Edris Khorani[1], Dr Richard Jefferies[1], Dr Ailish Wratten[1], Dr Shona McNab[2], Dr David Walker[3], Dr Yisong Han[3], Prof Richard Beanland[3], Dr Ruy Bonilla[2], Prof John Murphy[1]

[1]School of Engineering, University of Warwick, United Kingdom, [2]Department of Materials, University of Oxford, United Kingdom, [3]Department of Physics, University of Warwick, United Kingdom

Session 5: Michael Owen Bellini (Invited Speaker) Followed by Contributed Talks, April 11, 2024, 11:00 - 12:30

The re-emergence of aluminium oxide (Al_2O_3) in 2006 has enabled high levels of surface passivation to be achieved on the rear side of PERC solar cells, owing to the high levels of negative charge and good chemical passivation properties of the film. With the recent introduction of passivating contact structures, Al_2O_3 passivation is now being utilised on the front surface of TOPCon solar cells which use n-type substrates. As such, Al_2O_3 is playing an ever-increasing role in mitigating surface recombination on either the front or rear surface. However, as the efficiency continues to rise, front side surface passivation is becoming every more sensitive to recombination at the Si-Al_2O_3 interface, meaning efforts to understand this interface and thus develop solutions to mitigate interface defects could have very large impact.

In this work, we subject atomic layer deposited Al_2O_3 coated silicon samples to annealing temperatures of 350–600°C and show how recombination at the silicon-Al_2O_3 interface can be inhibited to maximise its passivation potential for silicon based solar cells (e.g. TOPCon). We subject Al_2O_3 passivated samples to corona charging in order to separate chemical from field-effect passivation contributions as a function of annealing temperature. For films thicker than 2.5 nm, we achieve an interface defect density of 3×10^{10} /eVcm^2 and a fixed charge density of ~5×10^{12} q/cm^2, which collectively yield a surface recombination velocity of 0.75 cm/s when annealed at 450°C. By examining the Si-Al_2O_3 interface by transmission electron microscopy and energy dispersive x-ray spectroscopy, we show that in the as-deposited state, a relatively thick SiO_2 layer of ~5 nm is present between the Al_2O_3 film and silicon surface, however post annealing at temperatures ≥350°C, Al from the Al_2O_3 layer diffuses into the SiO_2 and forms an alloy, whereby the oxide layer reduces in thickness to <2 nm with a composition of $SixAlyO_2$.

Detection of vacancy-related point defects in antimony selenide

Professor David Keeble[1], Dr Julia Wiktor, Dr Theo Hobson, Dr Marcel Dickmann, Dr Werner Egger, Dr Jon Major, Professor Ken Durose
[1]University Of Dundee, United Kingdom

Session 1: Aruna Ivaturi (Invited Speaker) Followed by Contributed Talks,
April 10, 2024, 11:15 - 12:15

Antimony selenide (Sb2Se3) is photovoltaic material with an optimal bandgap and a high optical absorption coefficient comprising of earth abundant elements. Solar cell power conversion efficiencies initially increased markedly but more recently the rate of increase has slowed. There is a large open circuit voltage deficit which is consistent with the presence of detrimental concentrations of point defects.

Vacancy defects are a centrally important class of point defect. Positron annihilation spectroscopy (PAS) methods have specific sensitivity to neutral or negatively charged vacancy-related defects. Positrons trap at missing atom defects. An implanted positron eventually annihilates with an electron resulting in two annihilation photons. The lifetime of the positron state increases for positrons localized at vacancy defects compared to that for the delocalized perfect lattice state. Two component density functional theory (TC-DFT) enables the lifetimes of these states to be calculated (Fig. 1).

The possible ground state configurations monovacancy defects in Sb2Se3 have been recently determined by DFT. It was reported that both the Se and Sb vacancies, due to negative-U behaviour, are amphoteric with midgap charge transition levels from positive states to negative charge states for Fermi level positions higher in the gap.

Here we report positron lifetime measurements on crystal and closed-space sublimated film Sb2Se3 samples exhibiting p-type, intrinsic, and n-type conductivity. No positron trapping to monovacancy defects was observed for p-type. Trapping to positron states localized at vacancy defects with lifetimes consistent with the TC-DFT calculated monovacancy values was observed for intrinsic and n-type samples. Evidence of trapping to larger divacancy defects was also observed.

Multiphysics Modelling for the Design of >35% Efficient Perovskite-on-Silicon Tandem Solar Cells

Mr James McQueen[1], Mr Darshit Trevadia[1], Professor Sebastian Bonilla[1]
[1]Department of Materials, University of Oxford, United Kingdom

Session 3: Contributed Talks, April 10, 2024, 16:30 - 17:30

Computational modelling and simulation of tandem solar cells have emerged as crucial tools in enabling and maintaining rapid performance improvements at every level. In this work, we develop advanced device models, verifying them to produce highly accurate analysis and design of perovskite-on-silicon devices. The resulting finite element simulation is used to establish the guidelines and materials targets for practically achievable tandem solar cells, with significantly reduced research and development overheads compared to extensive experimental work. Current state-of-the-art tandem simulations must employ a multiphysics approach, including advanced optics with ray tracing and the Transfer Matrix Method (TMM). They also require coupling standard drift-diffusion modelling with ion migration in perovskites to account for the recent physical understanding of degradation and ionic charge effects. Such complexity, however, can make the models less accessible for wider investigation. A user-friendly device model grounded in all the essential underlying physics is developed in this work, and used to inform the practical limits for device design, including surface recombination velocity and parasitic resistances at contacts. Hence, a roadmap is established for achieving maximum tandem device efficiency, contributing to existing work.

We focus on perovskite-on-TOPCon device models in SCAPS, a popular solar cell simulation software for its low barrier to entry and overall versatility. We extend the modelling in SCAPS to bring it in line with the state-of-the-art literature work, thus developing an accessible tandem device simulation which includes the TMM and an ion migration model in the perovskite cell. The completed simulation is finally used to suggest targets for key experimental device parameters, including SRV and contact resistivity effects, whilst also uniquely shedding light on the effect of spatial bandgap variation through the perovskite layer. The materials and devices selected for this investigation are chosen to remain closely aligned with industrial development of TOPCon solar cells.

Life-cycle assessment for more sustainable photovoltaics research and manufacturing

Miss Bethany Willis[1], Mr Michael Jones[1], Dr Stephen Campbell[1], Dr Giray Kartopu[1], Dr Prabeesh Punathil[1], Dr Wai Ming Cheung[1], Dr Elliot Woolley[2], Dr Lewis C. R. Jones[2], Dr Vincent Barrioz[1], Dr Guillaume Zoppi[1], Dr Yongtao Qu[1], Prof Neil S. Beattie[1]
[1]Northumbria University, United Kingdom, [2]Loughborough University, United Kingdom

Session 5: Michael Owen Bellini (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 11:00 - 12:30

Photovoltaics (PV), like other renewable electricity sources, for electricity generation has been labelled as “sustainable” for decades throughout markets and research. Although the definition of sustainable is well understood it is often difficult to compare technologies from a sustainable point of view due to the lack of quantitative data.

Life-cycle assessment (LCA) is an environmental evaluation tool which provides quantitative data regarding the environmental impact through the impact on humans, ecosystems and natural resources – thus the sustainability of a product. From analysis of emissions and materials flows, the environmental impact of the entire life-cycle of a product can be measured from the mining of its raw materials, use, disposal and ideally, recycling, in a “cradle-to-cradle” flow. LCA can be conducted on any product at any stage in its development from its design and prototype to the final commercial version making it a valuable tool to explore new possibilities in sustainability research.

Here, a research grade, lab-scale manufacturing process involving the synthesis of Cu2ZnSnS4 (CZTS) nanoparticles used for the absorber layer of inorganic thin film solar cells is investigated. Guided by an LCA, the fabrication of the CZTS nanoparticles is adapted to demonstrate more sustainable synthesis without loss of the eventual PV performance. In addition to this, an LCA is carried out on commercial silicon passivated emitter rear contact (PERC) cells identifying “hotspots” in the manufacturing process and cell fabrication stages to suggest where improvements in its sustainability can be improved. Both studies demonstrate how LCA can improve new and existing PV technologies and inform ecodesign of more sustainable PV products.

Irradiance Estimation for Vertical Bifacial AgriPV Systems: Integrating Regression Analysis and Decomposition-Transposition Matrix in the UK Context

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Session 2: Satoshi Uchida (Invited Speaker) Followed by Contributed Talks,
April 10, 2024, 15:00 - 16:15

Agricultural Photovoltaics (AgriPV), is a key technology for sustainable development, particularly targeting the Food-Energy-Water Nexus [1]. This method allows the dual use of land for farming and photovoltaic (PV) power generation. Despite its potential, accurate assessment of irradiance gains and Land Equivalent Ratios (LER) in the UK faces hurdles. An obstacle is the lack of availability of stations measuring irradiance components. Costs and maintenance issues impede thorough data collection. Measurements like Diffuse-Horizontal-Irradiance (DHI) and especially Photosynthetically-Active-Radiation (PAR) and its diffuse component (dPAR) are rarely recorded. In the UK, only 1 site actively measures PAR and dPAR, and 3 sites offer open-source data on Global-Horizontal-Irradiance (GHI) and DHI. Analysis of 104 decomposition models was conducted to derive DHI from GHI. The Engerer2h [2] model demonstrated a consistent Mean-Bias-Deviation (MBD) of 0.07% across datasets and locations as per Fig1. Additionally, 105 mathematical regression models were used to estimate PAR, employing a methodology that quantifies irradiance in the 400-to-700 nm range. The Xia3 [3] model yielded an MBD of -0.30% concerning PAR databases classified under the Köppen-Geiger “Cfb” category, encompassing 12 stations. Future work will focus on validating transposition models, utilizing Engerer2h, by comparing to pyranometer readings gathered at the University of Southampton’s Outdoor-Testing-Facility in Chilbolton. Following this, techniques will be employed to calculate the back-of-array (BOA) irradiance, quantifying the irradiance impacting the rear side. The Xia3 model, in combination with Engerer2h, will be employed to estimate dPAR, validated against data from Auchencorth Moss. Ultimately, the research will quantify the irradiance on both panel sides, PAR in unshaded areas and dPAR in shaded regions caused by vertical systems (see Fig 2). Thus, this research will evaluate and quantify different UK sites for LER assessment. This approach will provide deeper insights into AgriPV's potential in the UK, underlining its significance in sustainable land management.

A Novel System for Performance measurements of Indoor Photovoltaic Devices under Indoor Standard Testing Conditions (ISTC)

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Session 3: Contributed Talks, April 10, 2024, 16:30 - 17:30

There has been a lack of specified measurement conditions for indoor photovoltaic (IPV) devices until the recently published in the IEC TS 62607-7-2:2023 standards In this work, we present the first reported system for IPV characterisation which is compliant with this newly released standard. The system uses digital light processing (DLP) to deliver a spectrally invariant light source and has been classified for spectral coincidence, spatial uniformity and temporal stability. The system has been used to determine the IV parameters of commercial and emerging IPV technologies and it will feature in national and international intercomparisons, to investigate the clarity of the IEC TS 62607-7-2:2023 standard.

Unveiling the effects of electron transport layers on all inorganic perovskite film formation.

Mr Stefan Nicholson[1,2], Dr Jochen Bruckbauer[2], Dr Paul Edwards[2], Dr Carol Trager-Cowan[2], Professor Robert Martin[2], Dr Aruna Ivaturi[1]
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Session 6: Alona Armstrong (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 13:30 - 14:45

Perovskite photovoltaics have emerged as a promising technology with combined advantages of high efficiency, low materials cost, along with easy and scalable fabrication. The choice of electron transport layer (ETL) is important for achieving high efficiencies. The main properties that are considered for this choice are the band alignment, conductivity, transparency and the extraction performance. Whilst these characteristics are important, the effects of the underlying layer on the crystallographic and emissive properties of the film should not be ignored.
In the presented study, correlative studies between cathodoluminescence (CL), electron backscatter diffraction (EBSD) and x-ray diffraction (XRD) are presented, unveiling a resounding impact on an all-inorganic absorber from the choice of the underlying electron transport layer. SnO2, TiO2 and ZnO have been compared as the electron transport layers for the growth of CsPbI2Br. The impact of the underlying ETL layer on the grain level heterogeneity within the perovskite films is explored Detailed EBSD measurements revealed Zinc oxide to be the ETL which promoted grain growth, directs preferential orientation of the perovskite grains, and forms a more homogeneous layer. Bulk characterization by XRD confirms the observations made in EBSD, showing that the localized grain data is replicated across the entire film surface for the CsPbI2Br films grown on ZnO. Cathodoluminescence shows a more uniform emission with less grain boundary non-radiative recombination effects, showing improved optoelectronic properties of the all-inorganic CsPbI2Br films grown on ZnO.

These insights into the growth of perovskites portray fundamental understanding that must be applied when designing solar cell stacks.

Utilizing Low-Toxicity Solvents in Roll-to-Roll Fabrication of Carbon Electrode Perovskite Solar Cells

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Session 4: Robert Hoye (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 09:15 - 10:30

Perovskite solar cells (PSCs) are emerging as key players in sustainable solar energy, offering high efficiency in lab settings. Yet, commercializing these cells requires overcoming the use of toxic solvents like DMF/DMSO and Chlorobenzene/Chloroform, crucial in creating perovskite and hole transporting layers. These chemicals, while effective, pose significant health and environmental risks, especially in large-scale manufacturing. Additionally, PSCs face stability challenges under real-world conditions, particularly humidity, leading to performance degradation over time.

Our study introduces a transformative approach: developing roll-to-roll (R2R) coated PSCs with carbon electrodes using low-toxicity solvents. This method aims to minimize environmental impacts and enhance the safety and practicality of mass production. We replaced hazardous solvents with safer alternatives: DI water for the tin oxide layer, Acetonitrile (ACN) for the perovskite layer, and Oxylene for the hole transporting layer. The carbon ink incorporates 2-Methylanisole, promoting safer, more cost-effective production.

Our results are encouraging. The R2R coated PSCs with carbon electrodes not only achieved a power conversion efficiency (PCE) over 10% but also maintained 85% of this efficiency after 90 days, demonstrating improved stability. This advancement is significant, as it indicates the potential of PSCs as durable, sustainable solar cells.

Conclusively, our research marks a crucial step in transitioning PSCs from laboratory innovations to scalable, environmentally-friendly, and economically feasible energy solutions. By addressing toxicity, stability, and cost challenges, we pave the way for broader adoption of PSCs in the solar energy sector, contributing to a greener energy future.

Organic Solar Cells at Stratospheric Condition for High Altitude Platform Station Application

Dr Ram Datt[1], Dr Harrison Ka Hin Lee[2], Dr Guichuan Zhang[3], Prof Hin-Lap Yip[4], Dr Wing Chung Tsoi[1]

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Session 5: Michael Owen Bellini (Invited Speaker) Followed by Contributed Talks, April 11, 2024, 11:00 - 12:30

In summary, we have studied organic photovoltaic (OPV) for space applications. In space, particularly in a High-altitude platform station (HAPS) environment. In this study, we have selected the PM6: Y6 and PM6: IT-4F blend systems based on OPV and studied their photovoltaic performance under a broad range of temperatures, vacuum, and light spectrum according to HAPS environment conditions. The PM6: Y6 device was found to perform well, and the PCE dropped between -20 to 10 oC, which is negligible. Whereas, for PM6: IT-4F device, the PCE dropped almost 12% at -20 oC compared to its peak value. Moreover, the device characteristics are also measured under a broad range of temprature, including -100 to +80. The recombination mechanism was studied under three different temperatures: 80, 20, and -100 oC. The slope (kT/q) and recombination parameter (α) have been calculated under 80, 20, and -100 oC temperatures. This work provides an in-strength study on a benchmark OSC system PM6: Y6 and highlights its great potential for HAPS or space applications.

Understanding the Ionic Modulation of Open-Circuit Voltage in Perovskite Solar Cells

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Session 10: Kurt Barth (Invited Speaker) Followed by Contributed Talks,
April 12, 2024, 11:00 - 12:15

Metal halide perovskites are a promising class of materials for use in the active layer of next generation solar cells, with the highest performance lab-scale perovskite solar cells (PSCs) achieving efficiencies of over 25%. Aside from their promising photovoltaic performance, these materials are of scientific interest due to their high densities of mobile halide vacancies which mean they can conduct both ionic and electronic charge. Thus, when an electrical bias is applied to a PSC, the electric field experienced by the electronic carriers is modulated by the redistribution of ionic charge in response to the same applied field. This fundamentally changes the device physics of PSCs and has been shown to lead to extraction losses and carrier accumulation under short-circuit conditions. However, the presence of mobile ions can also reduce recombination currents at the perovskite/transport layer interfaces and so can lead to an increase in open-circuit voltage (VOC).

Herein, we use device level drift-diffusion simulations to determine the conditions under which the presence of mobile ions can increase VOC. We find that mobile ions lead to the largest improvement in VOC in PSCs where there is both a large energetic offset to the transport layers and where surface recombination is the dominant loss pathway. This is because, under these conditions, it is possible to have an accumulation (depletion) of halide vacancies at the interface between the perovskite and the electron (hole) transport layer. This distribution of mobile ions results in smaller potential drops in the perovskite layer when compared to a device with the same parameters, but no mobile ions, and thus reduces surface recombination currents, increasing VOC. We then use Stabilise and Pulse measurements to experimentally verify the results of our simulations by probing how VOC depends upon the ionic configuration in n-i-p PSCs with varying electron transport layers.

Application-Targeted Metal Grid -Enhanced Transparent Electrodes for Organic Photovoltaics

Nicholas Burridge[1], Dr. Gregory Burwell[1], Dr. Oskar Sandberg[2], Dr. Ardalan Armin[1], Prof. Paul Meredith[1]

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Session 9: Marina Freitag (Invited Speaker) Followed by Contributed Talks, April 12, 2024, 09:15 - 10:45

Despite recent developments in organic photovoltaic (OPV) devices at lab scales (< 1 cm^2), commercially viable OPV devices suffer performance losses at scale (> 10 cm^2),[1,2] largely due to the large series resistance exhibited by state-of-the-art monolithic transparent conducting electrodes (m-TCEs). To reduce the series resistance of TCEs, one solution is to use the TCE in conjunction with a metallic grid to form gridded-TCEs (g-TCEs),[3–5] which essentially divides a cell into an array of smaller sub-cells.[6] Although TCE materials exhibit a trade-off between average visible transmittance (AVT) and conductivity, the use of TCEs with metallic grids allows the electro-optical properties of high-performance TCEs to be optimised. In this work, the scaling-related performance barrier for OPVs is presented. The performance impact of critical grid geometry is studied with varying light intensity for different OPV applications. At high irradiances, smaller grid critical dimensions (CD) result in improved OPV device performance and can be combined with TCEs with high AVT. At low irradiances, the requirement for a highly conductive TCE reduces, because of the reduced photocurrent, allowing coarser grid structures to be utilised. To overcome the challenging surface morphology of on-plane metal grids, a method to recess metallic grids into substrates is demonstrated through exemplary planar (± 30 nm) 5 cm^2 g-TCEs, demonstrated with silver nanowires and aluminium-doped zinc oxide (AZO). The AZO g-TCEs were shown to provide a sheet resistance of 0.5 $\Omega/\square$, with AVT greater than 77 %. These results show that high-performance g-TCE structures are a highly versatile approach for utilising OPV in various applications.

Realistic Performance Limits of Indoor Photovoltaics

Austin Kay[1], Shimra Ahmed[1], Nicholas Burridge[1], Dr. Gregory Burwell[1], Dr. Oskar Sandberg[2], Prof. Ardalan Armin[1], Prof. Paul Meredith[1]
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Session 7: Ruy Sebastian Bonilla (Invited Speaker) Followed by Contributed Talks, April 11, 2024, 15:00 - 16:15

By recycling low-intensity, artificial light generated by LEDs and fluorescent lamps, indoor photovoltaics (IPVs) based on next-generation semiconductor materials, like organics and perovskites, could power billions of wireless devices and sensors in the forthcoming Internet-of-Things.[1]

Alongside the benefits of flexibility and solution-processibility, organic semiconductors and perovskites have tailorable optical properties, which are extremely desirable as the spectral fingerprints of indoor light sources differ from source to source.[2] Due to the infancy of the field, however, the performance limits of IPVs are poorly understood beyond the Shockley-Queisser limit. These performance limits are herein defined, and the limiting effects of shunt and series resistances, as well as radiative and non-radiative recombination, are clarified.

Following this, a methodology and computational tool are presented for extrapolating measurements made under AM1.5 G conditions to arbitrary illumination conditions.[3] This methodology is applied to predict the performance of several state-of-the-art systems under illumination by LED-B4 – a light source specified in the new indoor testing standard.[4]

Figure 1: Power conversion efficiencies (PCEs) simulated for state-of-the-art perovskites, organics, and inorganics under LED-B4 light at 500 lux, then plotted against the optical gap.

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CdTe-based PV on ultrathin glass for emerging large area space applications

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Session 1: Aruna Ivaturi (Invited Speaker) Followed by Contributed Talks,
April 10, 2024, 11:15 - 12:15

This paper will describe the emerging space applications that will require large area PV arrays and the new performance drivers that could require a sea change from the ubiquitous multi-junction III-V based PV to a low-cost, light weight single-junction solution. The paper will address some of the challenges of direct deposition of PV material onto ultrathin glass. Discussion will be made on the additional characterization that a PV technology must undergo when designed for space deployment. Finally, a summary of the data and lessons learned from the CdTe payload aboard the AlSat Nano CubeSat mission between 2016 and 2023.

Monolithic dye-sensitized solar cells with copper polymer gel electrolytes for indoor applications

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Session 5: Michael Owen Bellini (Invited Speaker) Followed by Contributed Talks, April 11, 2024, 11:00 - 12:30

Internet of Things devices have been increasing considerably in the last decade, and continuous growth is expected for the coming ones. With power conversion efficiencies (PCEs) of 30 % under room light, low-cost fabrication, safe materials and attractive aesthetics, dye-sensitized solar cells (DSSCs) became one of the most favorable indoor photovoltaics to cover their power needs. The most efficient DSSCs use copper redox mediators in a volatile electrolyte; the liquid-junction devices often suffer electrolyte leakages, compromising their long-term performance. Polymer gel electrolytes (PGE) are a reliable alternative; their higher viscosity reduces leakage problems, while keeping adequate ionic conductivity and diffusion of redox species. Moreover, the charge transport limitations through the polymeric network are considerable under 1-sun illumination, but less pronounced under low-light conditions. Therefore, PGE-DSSCs are less efficient than the liquid-junction devices under 1-sun, but present comparable or even superior performance under room light conditions. Up to now, the highest PCEs for DSSCs using Cu-PGE are 5.0 % (AM1.5G) and 25.5 % (1000 lx). F Santos et al. prepared Cu-PGE by adding polyethylene oxide (PEO, average MW ~ 400 000) and poly(methylmethacrylate) (PMMA, average MW ~ 120 000) to the liquid Cu-electrolyte using 3-methoxypropionitrile (MPN) solvent, and by heating the mixture to 100 ºC for 4 h under constant stirring. These Cu-PGE were used in monolithic DSSCs (M DSSCs) with Y123 sensitizer and a carbon counter-electrode, which delivered PCEs of 6.6 % (AM1.5G) and 28.4 % (1000 lx), a record for DSSCs using Cu-PGE. The monolithic structure uses a single transparent conductive oxide (TCO) substrate, reducing the material costs and making the module's fabrication more straightforward. The high viscosity of PGE permits cell separation by TCO scribing after deposition techniques, allowing module encapsulation using a single sealant frame, which is more attractive for market-scale production of M-DSSCs for indoor applications.

The use of Artificial neural network to enhance MPPT finding methodology on Energy Harvesting chips

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Session 6: Alona Armstrong (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 13:30 - 14:45

Getting the most out of indoor solar panels is crucial for better energy harvesting. Current market chips employ a conventional yet rudimentary approach—the fractional open circuit voltage method—to identify the MPP. Our investigation delves into the limitations of this method, particularly in high irradiance scenarios, such as near windows and within clean rooms. A comprehensive review of datasheets from market-leading energy harvesting chip manufacturers (e-peas, Texas Instruments, ST, and Analog Devices) revealed the prevalence of the fractional open circuit voltage method in chip design. While this method is low complexity and power-efficient, its performance falters under intense lighting conditions. Modules, especially those with high series resistance, experience a flattened I-V curve and a substantial drop in fill factor, resulting in significant deviations in the maximum power point voltage, which lowers energy harvesting efficiency under the fractional open circuit MPPT method.

Our research aims to highlight the flaws of the standard method and proposes a solution based on a light intensity sensor and a pre-trained neural network. The experiment started by collecting data using our indoor low light testing box, focusing on a module from epshine across a range of lighting conditions. Using MATLAB, we developed an artificial neural network to predict the optimal power point voltage based on lux levels only. Our experimental framework involves a comparison between the traditional fractional open circuit voltage method and our neural network-based approach. The analysis spans a spectrum of lighting intensities, revealing the efficacy and superiority of our proposed methodology in optimising indoor photovoltaic energy harvesting.

We gathered data on light intensity, I-V curve, and the key parameters MPP and VMPP . The dataset was divided into training and testing sets. Notably, the impact of temperature change was omitted from our analysis, considering the controlled nature of temperature in indoor environments.

Halide Perovskites Based Indoor Photovoltaics: Role of Interfacial Layers

Lethy Krishnan Jagadamma[1], Mr Shaoyang Wang
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Session 8: Contributed Talks, April 11, 2024, 16:30 - 17:30

With the explosive development of the Internet of Things (IoT) technology, indoor photovoltaics (IPVs) are becoming a promising candidate to sustainably power billions of wireless sensors for secured and smart buildings. Among the various photovoltaics technologies available today, halide perovskite-based IPVs are most promising for integration with IoT because of their excellent optoelectronic properties, easy and cost-effective processability using solution1based methods such as roll-to-roll printing, high specific power, and earth-abundance. The low intensity of the indoor light sources means the absence of beneficial light-induced trap filling of the perovskite photoactive layer. This demands stringent defect minimisation approaches at every functional layer to maximize the power conversion efficiency of IPVs and thereby reduce the efficiency gap (more than 20 % now) between the theoretically predicted and experimentally observed power conversion efficiency of IPVs [1].

In this talk, I will discuss the effect of interfacial layer selection in maximizing efficiency and suppressing the hysteresis effects under indoor lighting [2]. Our study shows that even though under 1 Sun, different interlayers have comparable efficiencies, under indoor lighting their performance can be drastically different and requires separate defect passivation to maximise the indoor light harvesting. Compared to organic-based charge transport layers, the metal oxide-based transport layers are found to be detrimental for indoor light harvesting and require interface engineering to suppress the charge accumulation at the buried interfaces. This conclusion has been arrived at by a series of systematic investigations of completed photovoltaic devices and their partial heterostructures.

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Beneath the surface: Investigating Perovskite Solar Cells under Water

Jessica Barichello[1], Peyman Amiri[2], Paolo Mariani[2], Farshad Jafarzadeh[2], Miguel Angel Molina[3], Marilena Isabella Zappia[3], Luca Gabatel[3], Sebastiano Bellini[3], Francesco Bonaccorso[3], Francesca Brunetti[2], Matthias Auf der Maur[2], Aldo Di Carlo[1,2], Fabio Matteocci[2]
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Session 4: Robert Hoye (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 09:15 - 10:30

In an always-connected world with an urgent need for clean energy, considering never-thinking solutions may help address the challenges of future cities. While photovoltaic (PV) devices have traditionally been used in rooftop and building-integrated photovoltaic applications, their versatility extends to agrivoltaics and even space-based power generation. However, the untapped potential of underwater (UW) PV systems remains unexplored. The Internet of Underwater Things (IoUT) is an emerging technology that has the potential to revolutionize the way we interact with the underwater world. IoUT devices can be used to monitor marine life, collect data on water quality, and even control underwater infrastructure. As water depths increase, the higher-wavelength components of sunlight are absorbed, leaving predominantly blue-green light (400-600 nm) at depths of 50 meters and beyond (figure 1). Recent theoretical analyses [1] suggest that high-bandgap (2-2.2 eV) PV devices are ideal candidates for deep-UW applications, making them suitable for powering IoUT devices [2]. Perovskite solar cells (PSCs) stand out as a promising technology with high-power conversion efficiency, tunable bandgap, and the unique characteristics of being colored and semi-transparent. Moreover, PSCs are lightweight, making them ideal for deployment in remote locations. This work presents a pioneering experimental application of two PSCs: a high-bandgap, semi-transparent, and bifacial FaPbBr3 device, and a reference narrow-bandgap triple-cations perovskite solar cell ($Cs_{0.08}FA_{0.80}MA_{0.12}Pb(I_{0.88}Br_{0.12})_3$). Following the testing of PIB encapsulant robustness in PSC devices, we investigated the sensitivity of the perovskite to a humid environment by testing the three devices at depths of -1, -3, and -6 cm. Moreover, we combined experimental results with theoretical simulations to extend the evaluation to a depth of -10 meters. Notably, all devices exhibited enhanced PCE at a depth of -1 cm, suggesting a novel approach to floating PV systems that leverages the increased PCE on water and the cooling benefit associated with submersion.

Indoor Characterisation and Performance Analysis of Static Hexagonal Concentrators for Building Integrated Low Concentrating Photovoltaic Applications

Mr Lewis Tamuno-Ibuomi[1], Dr Roberto Ramirez-Iniguez[1], Prof A Sheila Homles-Smith[1], Dr Geraint Bevan[1]
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Session 3: Contributed Talks, April 10, 2024, 16:30 - 17:30

The use of optical concentrators, together with solar cells is gaining traction as a technology that can improve the electrical performance of building integrated photovoltaic (PV) systems. These photovoltaic cells are usually small in size, evaluated under 1 sun (1000 W/m^2) and have low conversion efficiency. The gain of optical concentrators designed to improve their performance is less than 10 and are therefore classified as low gain concentrators. When the concentrated photovoltaic system (concentrator and cell) is incorporated within the building envelope, it is called building integrated low concentrating photovoltaic (BILCPV). This technology can generate clean, affordable, and sustainable electricity within the building infrastructure. It offers a comparable alternative to fossil fuels and hence, promotes net zero and low emissions energy. This paper discusses the indoor experimental characterisation and performance of two static, nonimaging, 3D, novel hexagonal concentrators that were recently developed. These new families of solar concentrators were conceived from two independent methodologies. One is created using the dielectric totally internally reflecting concentrator (DTIRC) approach, and it is named rotationally asymmetrical hexagonal DTIRC (RAHDTIRC) while, the other is based on parametric equations, formulated from 3D polar coordinates, and named low concentrating hexagonal photovoltaic (LCHPV) system. The concentrators and solar cells were tested indoors under standard test conditions of 1000 W/m^2, room temperature of 25°C and air mass of 1.5G. From the indoor experiments, it was found that at normal incidence, the RAHDTIRC-PV unit can increase the power output of the PV cell by 3.6x, while the LCHPV unit increased the cell power by 3.7x. When compared with their optical power gains, the RAHDTIRC-PV unit was 12.4% lower, while the LCHPV unit was only 3.9% lower. The total height of the RAHDTIRC-PV and LCHPV prototypes are 30mm and 18mm respectively, while their geometrical concentration gains are 4.58x and 4.13x respectively.

Terrestrial And Non-Terrestrial Environmental Effects on Perovskite Solar Cell Performance

Dr Jay Patel[1]
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Session 7: Ruy Sebastian Bonilla (Invited Speaker) Followed by Contributed Talks,
April 11, 2024, 15:00 - 16:15

Metal halide perovskite-based photovoltaics are emerging as a promising alternative to conventional silicon-based photovoltaics for both terrestrial and space applications. As we progress towards the commercialization of perovskite-based photovoltaic technology, several critical questions must be addressed:

1) The impact of shading on the panels
2) The influence of daily temperature fluctuations and varying climatic conditions
3) The effects of high vacuum and the Air Mass 0 solar spectrum in space

In this presentation, I will discuss experimental findings that shed light on the chemical and physical processes affected when these solar cells operate in diverse environments. Firstly, I will explore the consequences of partial shading on the panels, as caused by typical weather events such as cloud cover or snow [1,2]. This includes examining both reversible and irreversible degradation processes. Secondly, the presentation will cover how the performance of single-junction and multijunction perovskite-based photovoltaics is altered by changes in operating temperature, along with the resulting energy yield variations in different geographic locations [3]. Lastly, the behavior of perovskite solar cells under space conditions will be discussed, focusing on various encapsulation techniques and their impact on device durability [4].

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Unlocking the Potential of Alternative Hole Transporting Materials for Solid-State Dye-Sensitised Solar Cells through Prolonged Oxidation and Light Soaking Treatment

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Session 8: Contributed Talks, April 11, 2024, 16:30 - 17:30

Aromatic amides serve as promising hole transporting materials (HTMs) due to their facile synthesis via condensation chemistry. TPABT is an example of an amide-based small molecule that exhibits high conductivity values (~10-5 S cm-1 upon the addition of standard ionic additives) at an estimated cost of only $5/g, reaching power conversion efficiencies of ~15% when employed as a HTM in perovskite solar cells. In this work, utilisation of TPABT as a HTM in solid-state dye-sensitised solar cells highlighted that extended aging compared with the common benchmark HTM Spiro-OMeTAD was essential for dye regeneration to allow for oxidation of TPABT. This emphasises the different oxidation pathways for alternative HTMs, which for TPABT is ascribed to the closer molecular packing. Initially, 2 day old TPABT devices exhibited significant hysteresis with a poor power conversion efficiency of 0.19%. However, after performing a light soaking treatment on 3-month-aged devices the power conversion efficiency improved from 0.33% to 1.48% and hysteresis was no longer observed. This raises the question, should we be reassessing devices that initially underperformed while utilising alternative HTMs? Furthermore, should we adopt a different approach in analysing materials when optimising the concentration of additives?

Control crystallisation of perovskites in printable mesoscopic solar cells

Yue Hu[1]
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Session 9: Marina Freitag (Invited Speaker) Followed by Contributed Talks,
April 12, 2024, 09:15 - 10:45

Perovskite solar cells (PSCs) have attracted intensive attention due to their ever-increasing power conversion efficiency (PCE), low-cost materials constituents, and simple solution fabrication process. In printable mesoscopic PSCs, the perovskite is deposited on a triple-layer scaffold, made of screen printed mesoporous TiO2 layer, ZrO2 spacer layer and carbon electrode; such devices use carbon electrodes to replace the noble metal back contacts and do not require a hole-conducting layer.

Controlling the crystallization of organic–inorganic hybrid perovskite is of vital importance to achieve high performing perovskite solar cells. The growth mechanism of perovskites has been intensively studied in devices with planar structures and traditional structures. However, for the printable mesoscopic perovskite solar cells, it is difficult to study the crystallization mechanism of perovskite owing to the complicated mesoporous structure. In this talk, I am going to share the development of the printable mesoscopic PSCs and how we manage to control the crystallization in mesopores.

Revisiting the Significance of Spectral Solar Irradiance Data: Economical Approaches to Effective Measurement

Haoxiang Zhang[1], Dr Stuart Boden[1], Dr Tasmiat Rahman[1]
[1]University Of Southampton, United Kingdom

Session 8: Contributed Talks, April 11, 2024, 16:30 - 17:30

This study introduces a cost-effective spectroradiometer built for PV related spectral irradiance measurement. Spectral irradiance has a significant impact on analysing the performance of PV systems for both cell levels and system levels, including effective spectral irradiance from a certain spectral response, spectral albedo for bifacial PV, module temperature, tracking strategies, etc.

However, the measurement instrument, spectroradiometers are notably costly, which leads to a scarcity of available measured spectral data and consequent research, particularly in regions with temperate climates, such as the United Kingdom. The spectroradiometer built in this work uses USB2000+ spectrometer from ocean optics, with cosine correctors attached to the optical fibres. A raspberry pi 5 is used as a controller and a data logger. The low cost of the prototype spectroradiometer will help make spectral data more accessible and facilitate further research in these areas.

A breakdown of the system components and functions is shown in Figure 1. In terms of accuracy, the absolute irradiance measurement is calibrated by a radiometrically calibrated light source HL-3P-CAL-INT from ocean optics. A comparison between measured spectra and reference spectra of HL-3P-CAL-INT is shown in Figure 2a, and measured spectra of solar simulator ABET Sun3000 is shown in Figure 2b.

The maximum number of connected spectrometers is not limited. As shown in Figure 3, potential applications include albedometer, spectral POA measurement, spectral BOA measurement and spectral GHI measurement. The study presents an analysis of the spectral irradiance data, along with a comprehensive evaluation of the reliability and accuracy of the prototype spectroradiometers.

Poster Presentations

Exploring the Dynamics of Risk and Quality in Solar Photovoltaic Systems

Mr Sharmarke Mohamed Hassan[1], Dr. Mahmoud Dhimish[1]
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Flash Poster Presentations A, April 10, 2024, 12:15 - 12:30

The study presents an in-depth analysis of solar photovoltaic (PV) systems' performance, encompassing a dataset of 85 ground-mounted installations spread across the entire United Kingdom, as depicted in the map provided (Figure 1(a)). The geographical spread of the locations, highlighted in red on the map, was deliberately chosen to represent the wide variety of climatic and operational challenges that solar installations encounter throughout the UK. By evaluating 85,000 modules—equivalent to 5,592,000 solar cells—with a service life ranging from 6 to 9 years, the research offers a comprehensive perspective on the health and efficiency of PV systems in differing environments. Electroluminescence (EL) imaging [1,2] conducted at night served as the primary method for identifying microcracks and latent defects, with initial findings exposing a range of defect types. The study's extensive scope and methodical approach, integrating EL image analysis with the geographic distribution of PV systems, provides valuable insights into the factors that influence the durability and performance of solar installations across diverse UK locations.

In this poster, we will delve into a comprehensive analysis of various defect types observed in the examined PV systems, as showcased in Figure 1(b). The figure illustrates a range of defects such as line cracks, corrosion, complex cracks, edge ribbon cracks, and potential-induced degradation (PID), each of which can significantly impact the performance and longevity of PV modules. Through meticulous EL imaging, our study categories these imperfections and evaluates their prevalence and severity. We will discuss the implications of these findings, including the probable causes and the potential effects on the overall efficiency of PV modules. Our analysis aims to inform maintenance strategies and guide improvements in PV module design to mitigate such defects, thereby enhancing the durability and reliability of solar energy systems.

Synthesis, XRD, EDX, SEM, and TEM characterization of two sulfide nanostructures Ni(S2COBu)3 and [Ni(S2COPn)3

Abdulaziz A. Alanazi[1]
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Flash Poster Presentations A, April 10, 2024, 12:15 - 12:30

Nickel sulfides are well known for their various properties and applications, including their use as modified thin films for photocatalytic applications [1,2]. Herein, we report the synthesis of two stable and pure nickel sulfides nanostructures Ni(S2COBu)3 and Ni(S2COPn)3 from K(S2COBu)] Potassium butyl xanthate and [K(S2COPn)] Potassium pentyl xanthate single metal xanthate precursors using the melting method at two different temperatures 400 and 500°C. The obtained nanoparticles were characterized using powder X-ray diffraction (Figure), energy-dispersive X-ray spectroscopy (EDX), scanning electron microscopy (SEM), and transmission electron microscopy (TEM) techniques. The results disclosed that the size of the nanoparticles increases with the increase of the alkyl chain length of the xanthate ligand and the melting temperature. Further, the increase in temperature is accompanied by the appearance of a distinctive β NiS phase. In continuity of this work, the synthesized nanostructures will be further assisted for their photocatalytic applications.

Enhancing Solar Cell Longevity: Assessing the Impact of ITO Coatings on PID Resistance

Mr Thomas Lynch[1], Dr Mahmoud Dhimish[1], Professor Keith McKenna[1]
[1]University of York, United Kingdom

Flash Poster Presentations A, April 10, 2024, 12:15 - 12:30

The use of photovoltaic (PV) cells is critical in the sustainable generation of electricity. However, the performance of PV cells can decline over time due to Potential Induced Degradation (PID), a phenomenon where the power output of a module decreases significantly during exposure to certain conditions such as high voltage, temperature, and humidity.
Indium Tin Oxide (ITO) is commonly applied as a transparent conductive oxide layer in various electronic devices, including solar cells. Its role in mitigating PID effects has been a subject of research, with the aim to enhance the durability and lifespan of solar cells. This study examines the effectiveness of ITO coatings in reducing power output loss due to PID in solar cells.

Influence of Thickness on the Electrical Properties of ITO Thin Films Grown by RF Magnetron Sputtering Technique for Concentrated Perovskite Solar Cells

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Flash Poster Presentations A, April 10, 2024, 12:15 - 12:30

Recent development on tandem silicon/perovskite solar cell becoming popular to overcome high efficiency limit. Increasing light flux is enable further to enhance its efficiency though low concentrated optical integration, while Indium tin oxide (ITO) has become a crucial material in the fields of photovoltaics and nanotechnology due to its great electrical properties and exceptional chemical stability. This study provides a thorough analysis of growing ITO thin films with various thicknesses to indicate the impact of thickness on electrical properties for low concentration optical device for perovskite solar cells. ITO has been prepared by RF magnetron sputtering using Argon gas only with no alteration of temperature followed by annealing in a tube furnace under inert conditions. An investigation of the influence of thickness on the electrical properties of the films was conducted using a four-point probe. We have found that the best thickness for ITO with respect to electrical performance is 75 nm. This work has led us to acquire excellent ITO thin films for the applications of perovskites solar cells.

Detection and identification of vacancy-related point defects in perovskite halide semiconductors

Mr Aryaveer Singh[1], Dr Julia Wiktor, Dr Mingze Li, Dr Maciej Liedke, Mr Zhifang Shi, Professor Jinsong Huang, Professor David Keeble
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Flash Poster Presentations A, April 10, 2024, 12:15 - 12:30

The intensive development of metal halide perovskite solar cells is driven by the unprecedentedly rapid increase in cell efficiency values. While this success has been in part attributed to defect tolerance and reports of modest defect densities. Nevertheless, there has been a refocusing of efforts to identify and quantify point defects in these materials.
Vacancy defects are a centrally important class of point defect. Positron annihilation spectroscopy (PAS) methods have specific sensitivity to neutral or negatively charged vacancy-related defects. Positrons trap at missing atom defects. An implanted positron eventually annihilates with an electron resulting in two annihilation photons. The lifetime of the positron state increases for positrons localized at vacancy defects compared to that for the delocalized perfect lattice state. Two component density functional theory (TC-DFT) enables the lifetimes of these states to be calculated.
Previous positron lifetime studies of crystal and thin $MAPbI_3$ measured values consistent with positrons localized at B-site, Pb, vacancies. The spectrum exhibited close to saturation trapping to this positron state. Here we extend these studies and report measurements on other perovskite halides, including $MAPbBr_3$ and $FAPbBr_3$ to investigate the effects of changing anion and the A-site cation. Measurements included depth-profiling variable energy positron annihilation lifetime measurements were performed using the mono-energetic positron source beamline at the Helmholtz–Zentrum Dresden–Rossendorf.
The positron lifetimes in $MAPbBr_3$ were measured to be shorter in $MAPbI_3$. Positron lifetime spectra were measures that yielded a dominant lifetime component consistent with the TC-DFT value for positron trapping to Pb vacancy defects.

Auxetic Crystalline Silicon Solar Module with Rotating Square Array Structure

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This work combines an elastomer substrate with a planar rotating-square auxetic structure and the concept of dividing c-Si PERC solar cells into small tiles and restructuring them into an array to produce a lightweight, flexible and stretchable solar module as shown in Figure 1. Due to the negative Poisson's ratio of the auxetic structure, bi-directional expansion with uniaxial stretching is achieved, allowing the area coverage and so interception of light by the solar cell tiles to be adjusted. Output voltage and current can be tailored according to the combination of series or parallel connections between tiles in the design. Potential applications include BIPV (e.g. partially shaded windows), AgriPV (e.g. greenhouse roofs), portable PV devices and indoor PV.
The prototype modules are designed with 20×20mm and 31.75×31.75mm square tiles, determined by the number of busbars on the original solar cell. Extensive current-voltage (I-V) characterization of the individual solar cells/tiles under AM1.5 illumination (see Figure 2(a)), reveals slight performance degradation due to the saw damage and un-passivated edges however, good power conversion efficiencies are retained. Tensile testing has been carried out on the polyurethane material (Clear Flex 50, Smooth-on) cast into the configurations used for the flexible array (see Figure 2(b)). At a strain of approximately 29%, the tiles reach their maximum rotation angle of 45°, at which the module transmittance area is 28 cm2.
Analysis of the electrical, optical and mechanical properties of the auxetic array prototype with fully encapsulated and interconnected solar cell tiles will be presented.

Evaluating the feasibility of novel PV technologies for powering PM2.5 sensors in indoor and outdoor applications

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Solar power presents an ideal solution for powering low cost particulate matter sensor nodes in an IoT application where mains power is not a feasible solution, however the different environments such a sensor could be used in stand to benefit different cell topologies. This research characterises the power demands of some of the most popular particulate matter sensors on the market, with a focus towards using novel PV technologies to power them. We discovered that most of the sensors under test at 4.5v consumed between 60 and 80mA mean, with standard deviations varying between 2.4 and 31mA.

Floating Photovoltaic (FPV) for climate vulnerable river island communities

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There are arguably no more vulnerable communities in Bangladesh than the agricultural and fishing communities of the populated and land-limited river island chars. A key consequence of this remoteness is poor access to clean, affordable, and reliable energy. In this study, a workshop with char communities in Northern Bangladesh explored annual energy consumption variations linked to different livelihoods. Our goal was to assess gender-specific energy demands, both present and future. We suggested a Hybrid Renewable Energy System (HREs), focusing on FPV and Wind energy, and optimized its design using HOMER PRO. A detailed FPV analysis was conducted using PVSyst. The study also examined the social and environmental impacts of FPV, considering local energy needs and the HREs load profile.

Based on the load profile acquired at the workshop, significant diesel usage is noted in irrigation. Peak demand occurs from January to March. Addressing these fluctuating needs, the optimal eco-technical approach recommended is a hybrid system combining photovoltaic (PV), diesel, and battery components. The proposed PV facility has a 64.6kW capacity, with wind power excluded due to inadequate local wind resources. When contrasted with entirely diesel-powered alternatives, the optimized Hybrid HREs are expected to decrease annual CO2 emissions by 115 tons. Simulations in PVsyst revealed that optimizing six parameters, as illustrated in Figure 1, led to a reduction in the Levelized Cost of Energy (LCOE) from $0.1058/kWh to $0.0774/kWh. Based on the sensitivity check result presented in Figure 1, albedo and degradation were identified as crucial factors in this optimization process. Post-installation of HREs, surplus energy production during post-irrigation periods holds the potential to support the local sewing industry, contributing to the alleviation of gender-based livelihood inequalities. Additionally, a considerable proportion of solar power in the energy mix is expected to mitigate the greenhouse effect, local pollution, and smoke damage.

CdTe thin film absorber layers grown under Cd-rich conditions by MOCVD: impact on film surface topography and structure

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Cd-rich composition growth combined with group-V element doping is a promising approach for producing CdTe absorber, with increased p-type doping for high efficiency CdTe solar cells [1]. This development was significant to achieving of As doped CdSeTe solar cell record efficiency of 22.3%, recently reported by First Solar Inc. [2]. In a previous study, high quality CdTe absorber layers from in-situ Cd-rich metal organic chemical vapour deposition (MOCVD) growth were reported, demonstrating impressive increase and control in the incorporation of As dopants, with a corresponding enhancement in device VOC [3].
In this study, the impact of Cd-rich growth conditions on the surface morphologies and structural properties of CdTe absorber layers fabricated by MOCVD are investigated. Atomic force microscopic (AFM) surface topography measurements, using non-saturated growth conditions, revealed a much rougher surface compared to a Cd-rich grown CdTe sample. The RMS roughness was noted to be reduced by a factor of 2.6 with Cd-rich growth. The Cd precursor partial pressure (pDMCd)was kept constant at 3.11 × 10-4 atm and the Te precursor partial pressure (pDIPTe) decreased to yield a range of pDMCd:pDIPTe ratios from 2:1 to 5:1. The resulting CdTe film surface roughness was found to increase at higher the pDMCd:pDIPTe ratios. CdTe absorber layers fabricated using pDMCd:pDIPTe ratios of 2:1 and 3:1, having a comparatively smoother surface presented intense interference fringes in their transmittance spectra. This was absent in samples (pDMCd:pDIPTe = 4:1 and 5:1) with rougher surface morphologies, accompanied with increased absorption in the long wavelength region. XRD characterization of these layers revealed that the crystal quality improved under Cd-rich growth conditions. The crystallographic and topological analysis in this work will provide further insights into the structural mechanism in CdTe absorber layers for increased PCE with Cd-rich growth conditions.

Simulating relative performance of Organic and Silicon PV in real-world conditions

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To understand the electrical behaviour of Organic photovoltaics (OPVs), the most common equivalent electrical circuit used to model OPVs is the one-diode model (ODM). Our study introduces a modified De Soto ODM for predicting the power output of OPVs in real-world conditions. By applying this model to historical weather data including temperature and irradiance from London in the UK, we provide time-resolved power output predictions for OPVs. These predictions are then analysed in the context of the UK's dynamic power pricing and carbon emissions data. Our findings highlight the significance of considering non-standard atmospheric conditions (non-AM1.5) in evaluating OPV performance. Furthermore, we establish a correlation between climate/seasonal variations and CO2 emissions in the electrical grid. This analysis underscores the potential impact of renewable energy sources like OPVs in achieving Net Zero goals and provides a comparative yield analysis with conventional silicon panels.

Tuning the morphology and phase structure of tungsten oxides for photovoltaic applications

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In this work, we report the synthesis of three different classes of tungsten oxides taking tungsten powder as a sole precursor by optimizing the experimental conditions. The combined effects of high energy ball milling and change in furnace atmosphere (air and H2O vapor) during heat treatments are key for phase, morphology, and structure tuning. The heat treatment of nanocrystalline tungsten in the open atmosphere results in nanocrystalline WO3 with altered bandgap. Heat treatment of tungsten powder in water vapor atmosphere resulted in W18O49 nanowires. Whereas nanocrystalline cubic H0.5WO3 can be formed by adopting similar experimental techniques by simply replacing the precursor with nanocrystalline tungsten. These oxides can be used as charge transport materials for designing more stable and efficient solar cell devices owing to their phase, morphology, and oxygen deficient structure.

Calamitic-Type Dipolar and Quadrupolar Chromophores with Twisted Peripheral Handle: Structure-Property Outlook as Non-fullerene Acceptors for Binary Solar Cells

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Owing to their unique optoelectronic and structural characteristics, tetracyanobutadiene (TCBD) based active layer materials have gained momentum in organic solar cells (OSCs).[1-5] In the present contribution,[3] symmetrical and unsymmetrical π-molecules possessing TCBD as π-twisted end group on carbazole/fluorene backbone were synthesized as non-fullerene acceptors (NFAs). Structural correlation of these chromophores on optoelectronic, electrochemical and physicochemical properties revealed better acceptor properties for symmetrical molecules compared to their unsymmetrical counterparts. High molar absorptivity, deep HOMO–LUMOs and other complementary functional properties are some of the associated factors for their better acceptor character. In a binary solar cell configuration blended with a standard P3HT donor, quadrupolar-type symmetrical chromophores displayed higher power conversion efficiencies compared to dipolar-type unsymmetrical analogues. In particular, the carbazole-based symmetrical chromophore with an efficiency of 5.37% emerged as the best candidate with further enhancement to 6.30% upon additive processing (Figure 1). The dependence of processing in augmenting photo-induced current was attributed to the better nanoscale morphology, crystallinity, and electron mobility of the active layer. In terms of efficiency, it is the third highest for any TCBD-based NFA material. Overall, this work validates the impact of a non-planar TCBD auxiliary positioned within a calamitic-type π-backbone in realizing alternative NFAs. From a fundamental perspective, our initial results are promising and further fine-tuning of molecular structure could possibly enhance the cell efficiency.

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