Semi-transparent PV coatings for greenhouse application

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Abstract

This project develops coating materials and techniques to enable fabrication of semi-transparent photovoltaics (PV) that are specifically suited for greenhouse agriculture, with the goal of realizing Net Zero Energy (NZE) Greenhouses with economically viable agricultural functions. Greenhouse-agriculture-specific requirements on PV—i.e. desirable transparency at different parts/wave-length ranges of the solar spectrum—are determined via biological/physiological studies by our IEB team, where the growth characteristics of various commodity plants under various PV-simulating shading conditions are quantified. Using the biological/physiological data as guidance, our NTU team develops a facile area-selective coating technique to fabricate perovskite solar cells (PSC) meeting the transparency requirements. Moreover, our Gdańsk Tech team joins force with the NTU team to carry out a comprehensive approach to enhance the efficiency and stability of the PSC's, encompassing additive engineering, interface passivation, device physics modeling, device stability characterization, developing high-performance encapsulants, developing wave-length-selective reflectors, and developing transparent electrodes with high conductivity and stability. Working concurrently, our IPV team leverages its commercial capabilities to turn the lab-scale results into large-area, high-throughput, and manufacturing-worthy processes, culminating into the production of a prototype greenhouse that can be used for field study and demonstration. The project is on pace to accomplish its stated objective at the end of the project period, with all partners onboard in planning continued collaboration to see the project results through full fruition, making real contributions to addressing the global issues of climate change and sustainability.

IEB Team

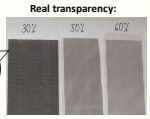
Institute of Experimental Botany of the AS CR, v. v. i.

Partial-spectrum transmission is not viable for plants, and >50% full-spectrum-transmission is required for most plants, necessitating PVs with a > 50% open-grid-like structure.

Similar carrot production

Low light stress: longer petioles, delayed carrot formation

Real transparency:



Foils

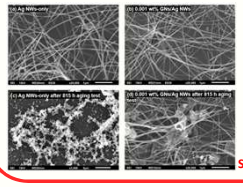
Infinity PV

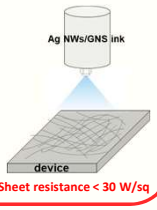
Upscaling large-area coating

Slot-die coater

Roll-to-roll coater

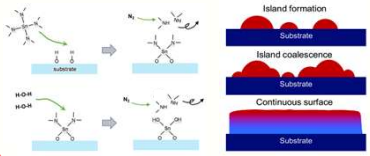
Transparent top electrodes from Ag nanowires and graphene nanosheets



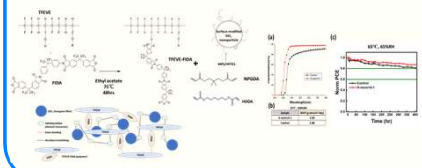


Sheet resistance < 30 W/sq

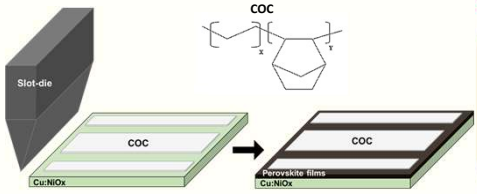
ALD SnO_x electron-transporting layer (ETL) and protection layers for PSCs

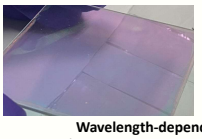


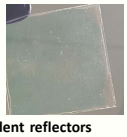
High-performance transparent and opaque encapsulants from polymer nano-composites



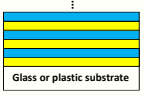
Highly efficient, transparent, and stable perovskite solar cells (PSC)





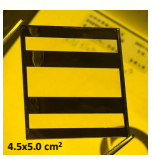


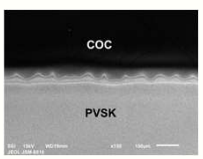
Wavelength-dependent reflectors



- Screen printed oxide particles layer
- Screen printed COC polymer layer
- ✓ Vary the thicknesses of the two types of layer to obtain desired wavelength dependence

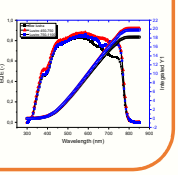
Polymer-mediated area-selective coating techniques enable facile fabrication of >50% open-grid PSCs



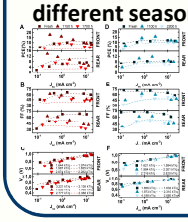


Wavelength-dependent reflectors enhance the PCE of PSCs by 10% (relative) and 1% (absolute)

Wavelength-dependent reflectors	Relative PCE Improvement	Absolute PCE Improvement
450-750 nm	10.7%	2.1%
750-1100 nm	8.7%	1.7%



PSCs were found to degrade via the same electrical mechanisms in different seasons but at varying rates



Simulation parameters for summer season	Fresh	1150h	1700h
Bulk defect densities (m^{-3})	2.74×10^{21}	1.06×10^{22}	1.63×10^{22}
Electron mobilities ($cm^2\ V^{-1}\ s^{-1}$)	2.22	2.45	0.57
Hole mobilities ($cm^2\ V^{-1}\ s^{-1}$)	2.22	1.21	0.12

Simulation parameters for fall season	Fresh	1100h	2200h
Bulk defect densities (m^{-3})	3.38×10^{21}	6.16×10^{21}	4.54×10^{21}
Electron/hole mobilities ($cm^2\ V^{-1}\ s^{-1}$)	4.59	0.80	0.49

Summary

- ✓ **Commodity crops were found to require > 50% full-spectrum transmission for reasonable growth, necessitating a PVs with open-grid like structure**
- ✓ **Polymer-mediated area-selective coating techniques were developed to enable facile fabrication of >50% open-grid PSCs**
- ✓ **PSC efficiency and stability were improved via a multi-pronged approach encompassing experimental and theoretical works**