Solution-processable Metal Oxide Materials in Multijunction Architecture Organic Photovoltaics for Optimized Tunnel Junction Layers and Improved Device Lifetime

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Background and Introduction

Organic-based photovoltaics have come a long way in the past 17 years. From 1% efficient demonstration devices in 1995, lab efficiencies have topped 10%. Device lifetimes on the order of years in ambient conditions are now common. US-based start-up companies such as Konarka, Plextronics, and Solarmer and more established companies like Mitsubishi have reported record efficiencies and lifetimes, and fundamental research into material development and loss mechanisms at universities and national labs have enabled US companies to lead the way globally.

Bringing technology to installation-scale:

- Further increases in efficiency
    - Multijunction architectures
    - Powerhouse electrical plastics
- Reduce material costs (e.g. eliminate ITO)
- Increase process yield by stabilizing fabrication
- Increase lifetimes from current state-of-the-art (years) to decades

San Francisco Municipal Transportation Agency Bus Shelters by Lundberg Design using Konarka Power Plastics. Plastic photovoltaic roof produces enough power to keep the shelter, with a wi-fi router, LED bus schedule updates, lighting, and advertising, day and night. Pictures from (http://greenarchitecturenotes.com/2010/01/san-francisco-municipal-transportation-agency-bus-shelters-a-new-design-technology-business-model-for-green-architecture/).

World-class innovation:

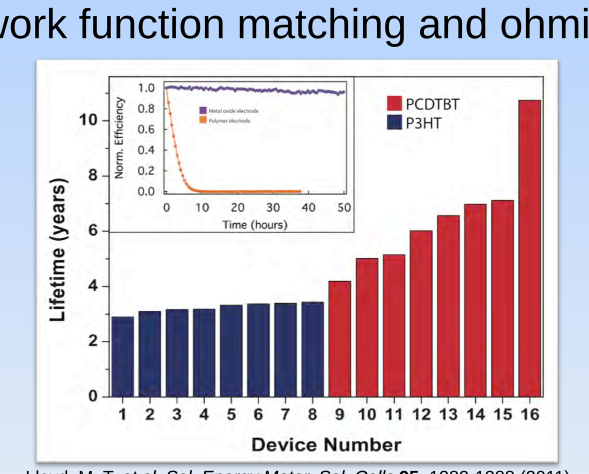
- Metal oxide electrodes
- Push-pull copolymers

Solution-processable metal oxide precursors: ZnO (left) and NiO (right).

Metal oxides reduce cost and prolong lifetime

- Act as water and oxygen getters
- Excellent work function matching and ohmic contact

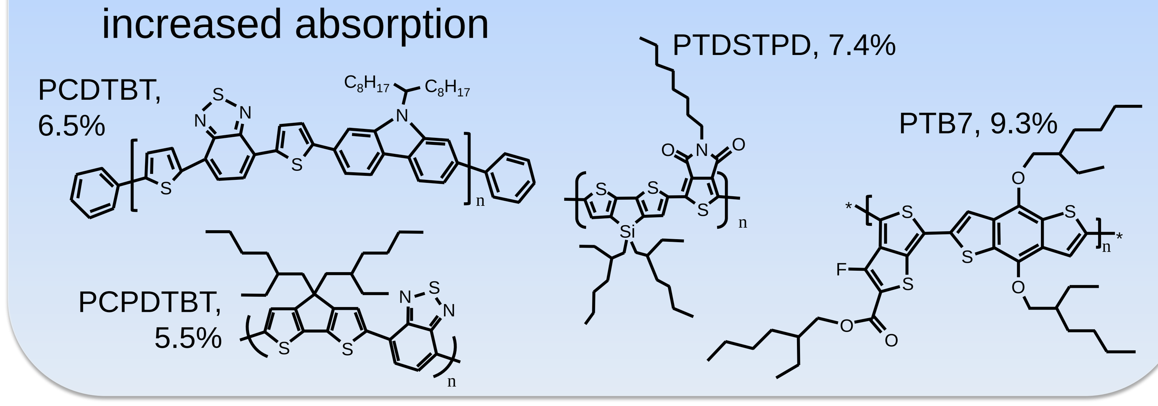
- **ZnO**
- **NiO**
- **MoO_3**
- **TiO_2**
- **V_2O_5**
- **$CsCO_3$**



Lloyd, M. T. *et al. Sol. Energy Mater. Sol. Cells* **95**, 1382-1388 (2011).
Peters, C. H., *et al. Advanced Energy Materials* **1** 491–494 (2011).

Push-pull copolymers improve stability and efficiency

- Donor-acceptor structure stabilizes charge separation
- Increases absorption coefficient and lowers bandgap for increased absorption



Approach

We propose to determine design criteria for the metallic interlayers acting as tunnel junction electrical contacts for monolithic multijunction organic photovoltaics.

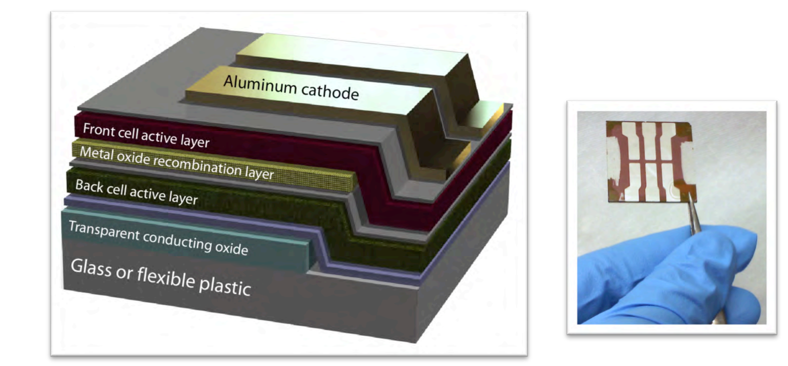


Figure 1: Standard multijunction device architecture using organic semiconducting and metal oxide materials.

Preliminary design parameters:

- Optical transparency
- "Metallic" electrical contact of the quasi-Fermi levels of one cell to the next
- Efficient charge recombination of cell current to prevent voltage and power loss

Contact materials "tool box":

Solution-deposited metal oxides
Thin metals
pH-neutral doped organic films
Carbon nanotube films
Self-assembled monolayers (SAMs)

→ Control surface energy, transparency, conductivity, and charge selectivity

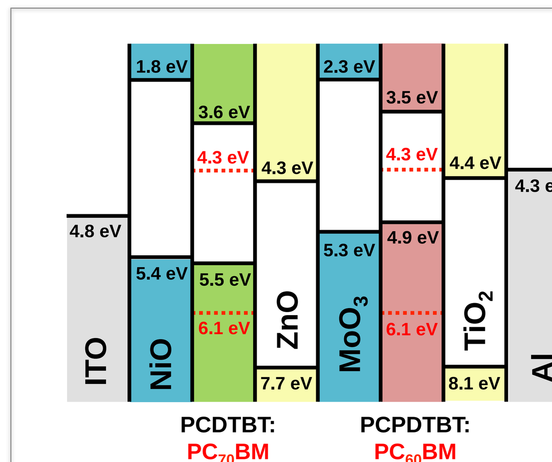
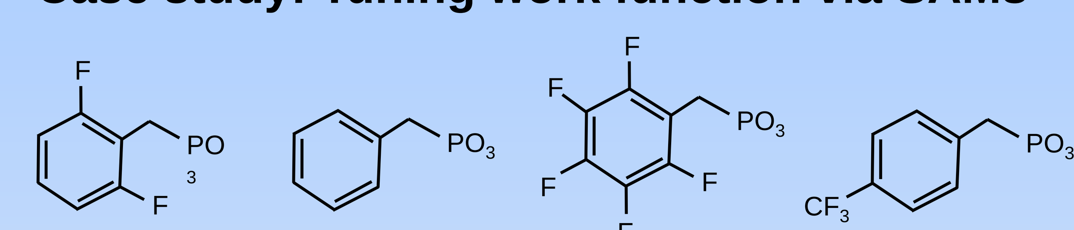


Figure 2: Energy levels for a PCPDTBT/PCDTBT multijunction solar cell using metal oxide electrode materials. Thin metals and self-assembled monolayers including thiols and phosphonic acids, may assist energy level alignment for efficient charge recombination.

Case study: Tuning work function via SAMs



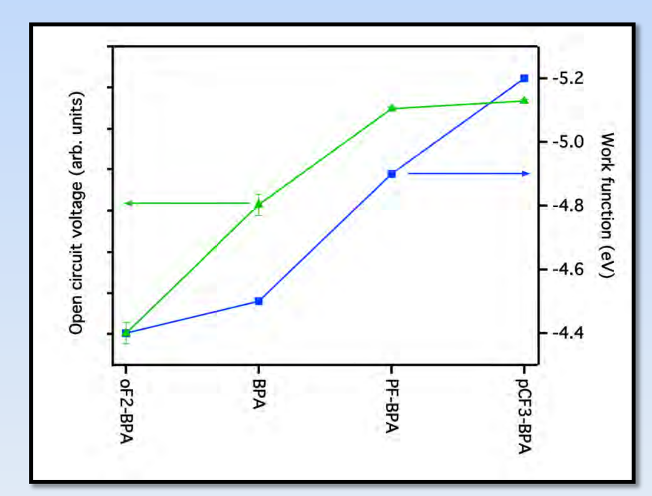


Figure 3: Demonstration of phosphonic acid SAMs tuning the open circuit voltage in BHJ solar cells roughly linearly with increasing work function of the modified substrate, glass/ITO/SAM.

Case study: Optical modeling predicts efficiency gains based on new contact materials

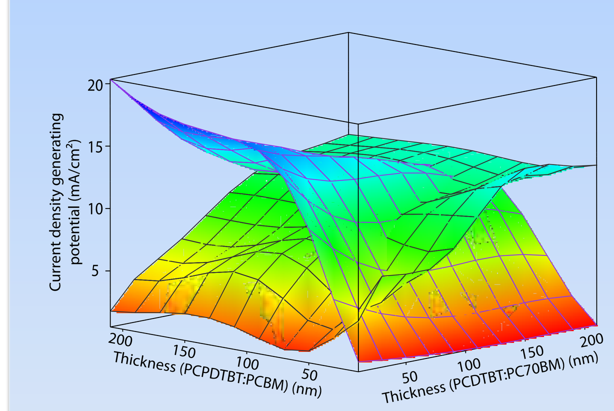


Figure 4: Current matching condition determined via transmission matrix optical modelling

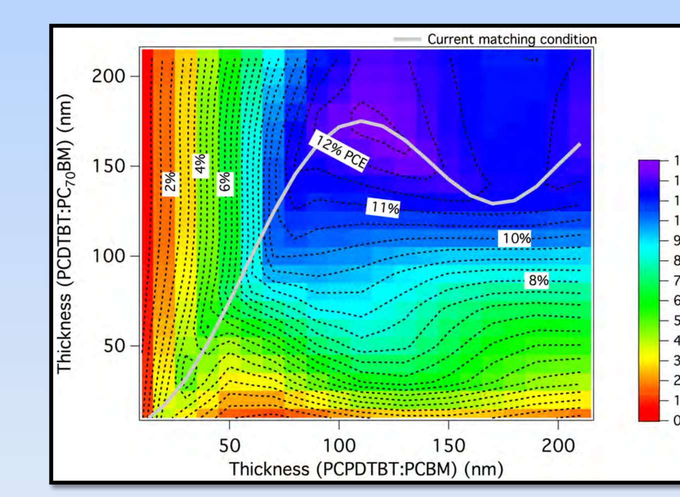


Figure 5: Optimal processing conditions determined via optical modelling for the PCPDTBT/PCDTBT multijunction solar cell

Impact

Through a thorough study of contacts and interfaces, this research will quantify a set of design parameters for a stable, low-resistance tunnel junction layer, likely utilizing a combination of self-assembled monolayers and solution-deposited metal oxides, which will enable progress in organic multijunction device efficiencies. Recent studies note that cost per watt for organic photovoltaics reduced from 35€ per watt in 2009 to 8€ per watt in 2010, with a large percentage of the total cost from expensive materials such as indium tin oxide. Innovations to increase the efficiency and replace high-cost materials components with materials such as those proposed in this study will be part of the effort to push the cost efficiency of organic PV below $1 per watt.

Acknowledgments

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Developing interlayers for reliably high efficiency and long lifetime organic solar cells.