

Efficient Organic Excitonic Solar Cells with Carbon Nanotubes Replacing $\text{In}_2\text{O}_3:\text{Sn}$ as the Transparent Electrode

Jao van de Lagemaat,[†] Teresa Barnes,[†] Garry Rumbles,[†] Sean Shaheen,[†] Timothy J. Coutts,[†] Chris Weeks,^{*} Paul Glatkowski,^{*} Igor Levitsky,^{*} and Jorma Peltola^{*}

NREL/PR-520-39849

Presented at the 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion (WCPEC-4) held May 7-12, 2006 in Waikoloa, Hawaii.

[†] NREL
^{*} EIKOS

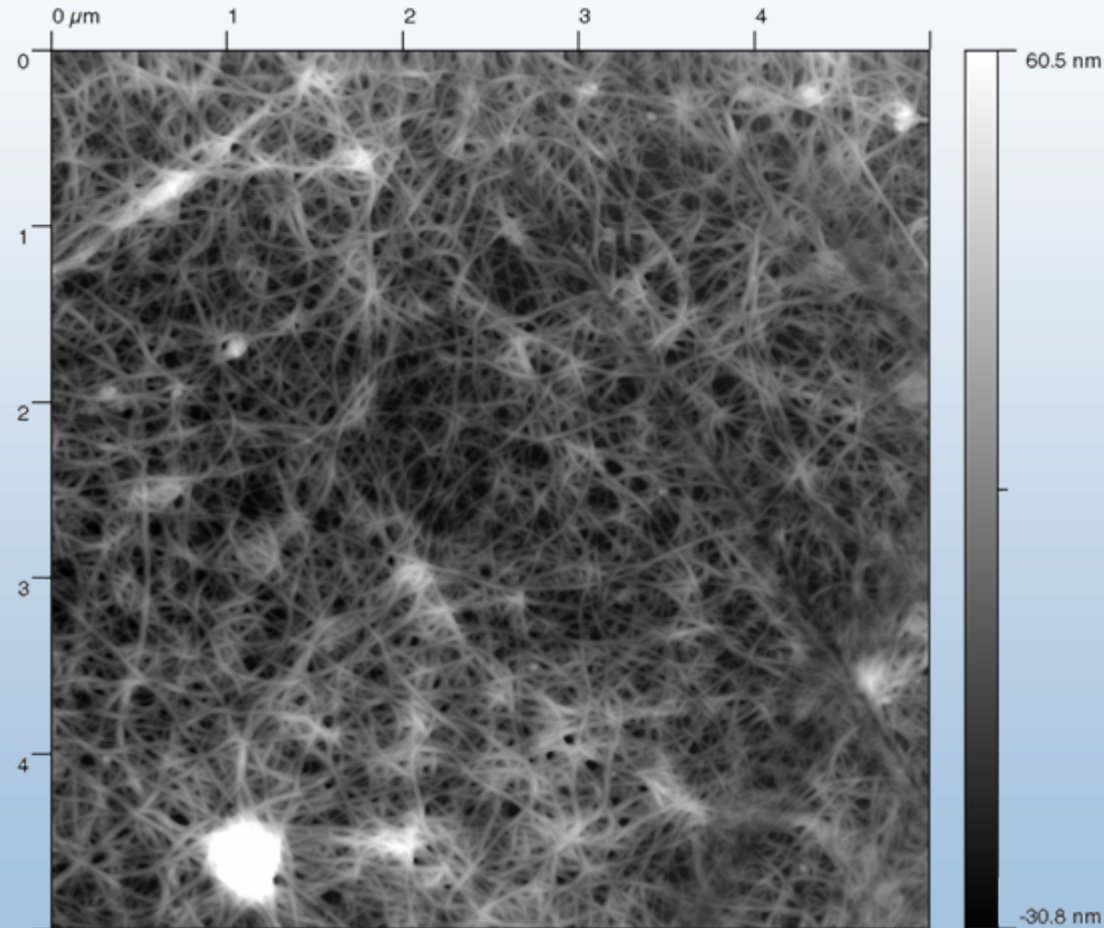
Disclaimer and Government License

This work has been authored by Midwest Research Institute (MRI) under Contract No. DE-AC36-99GO10337 with the U.S. Department of Energy (the “DOE”). The United States Government (the “Government”) retains and the publisher, by accepting the work for publication, acknowledges that the Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for Government purposes.

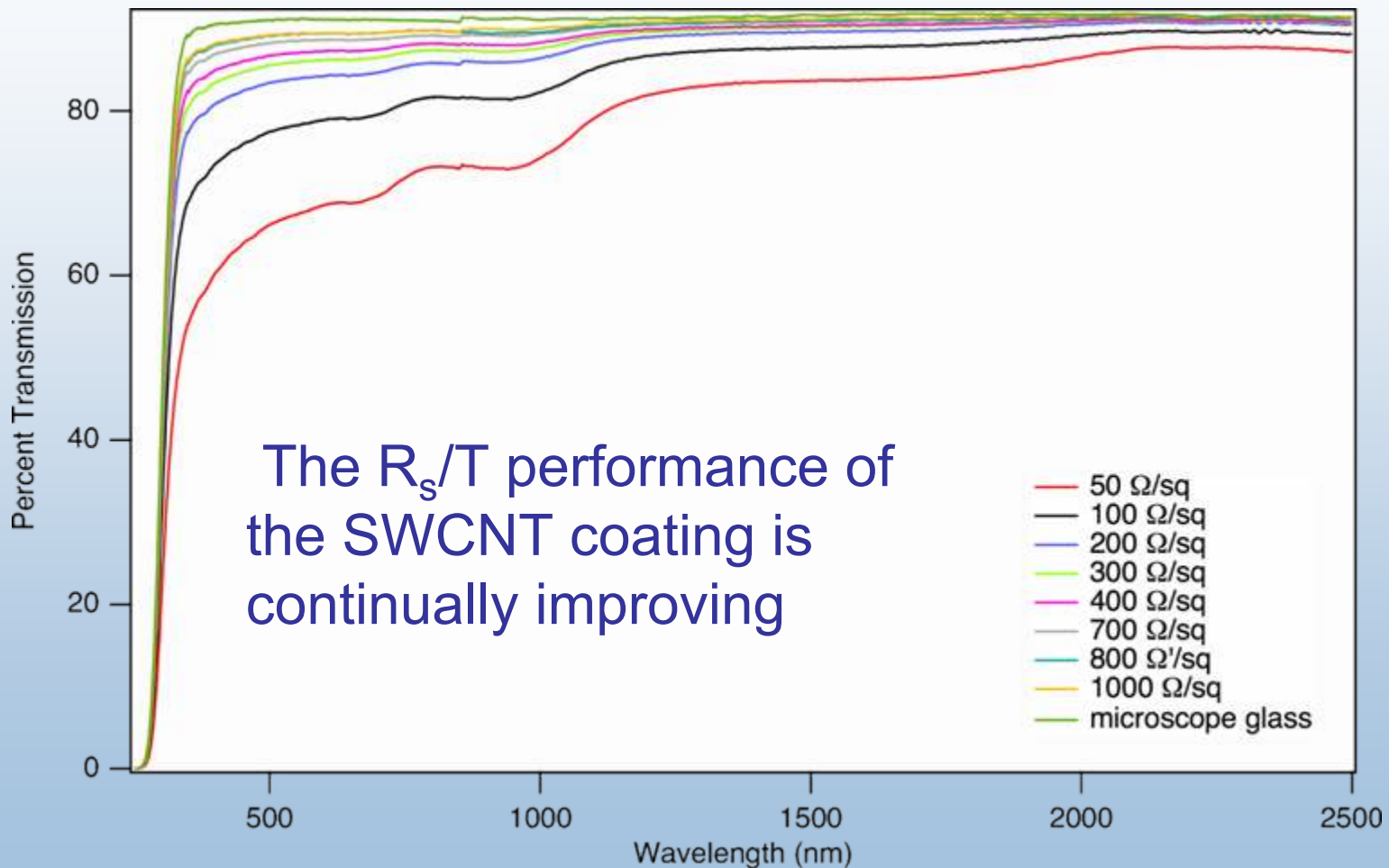
Neither MRI, the DOE, the Government, nor any other agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe any privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply its endorsement, recommendation, or favoring by the Government or any agency thereof. The views and opinions of the authors and/or presenters expressed herein do not necessarily state or reflect those of MRI, the DOE, the Government, or any agency thereof.

Why replace ITO?

- ITO is not ideal
- CNT contact could interpenetrate into the active layer
- Potentially hole selective contact
- Solution processable - fully printed cell
- Work function similar to that of ITO

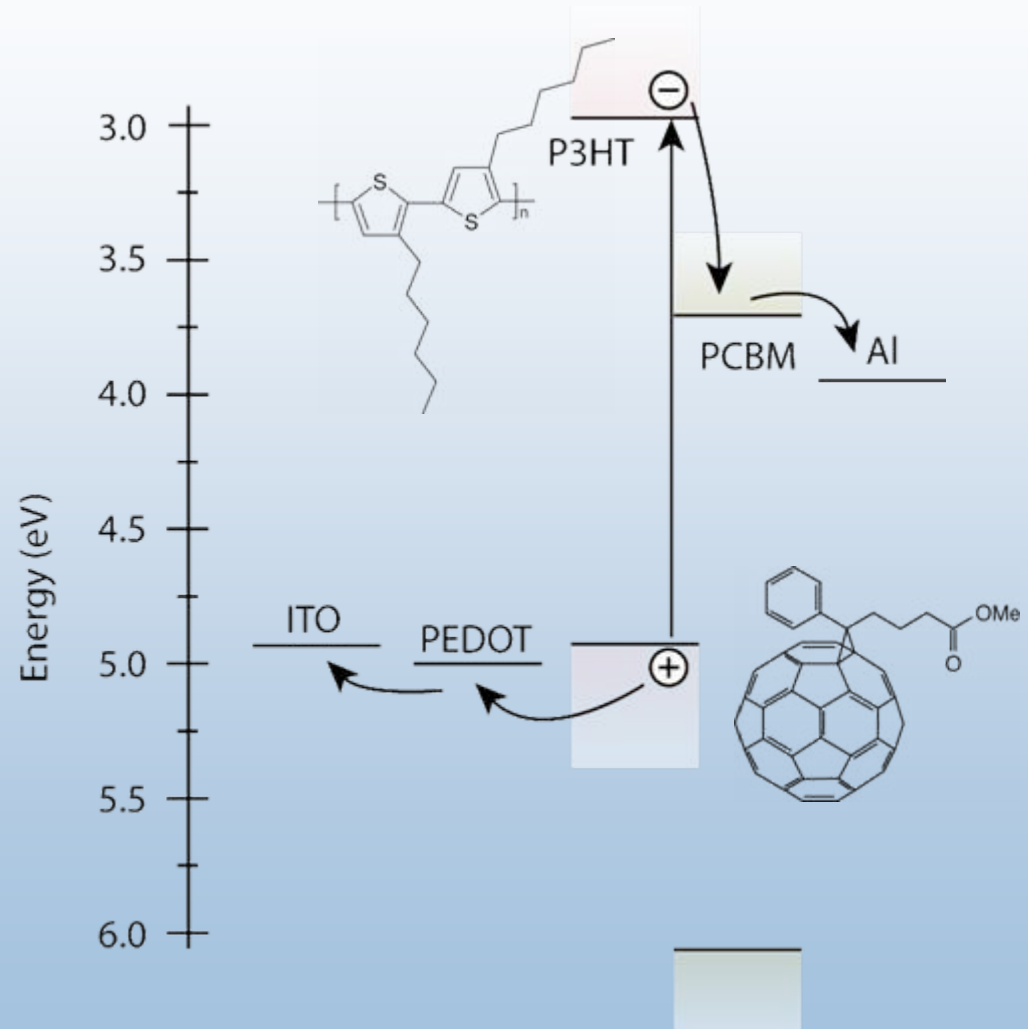


Resistance vs. Transmittance of SWCNT layers

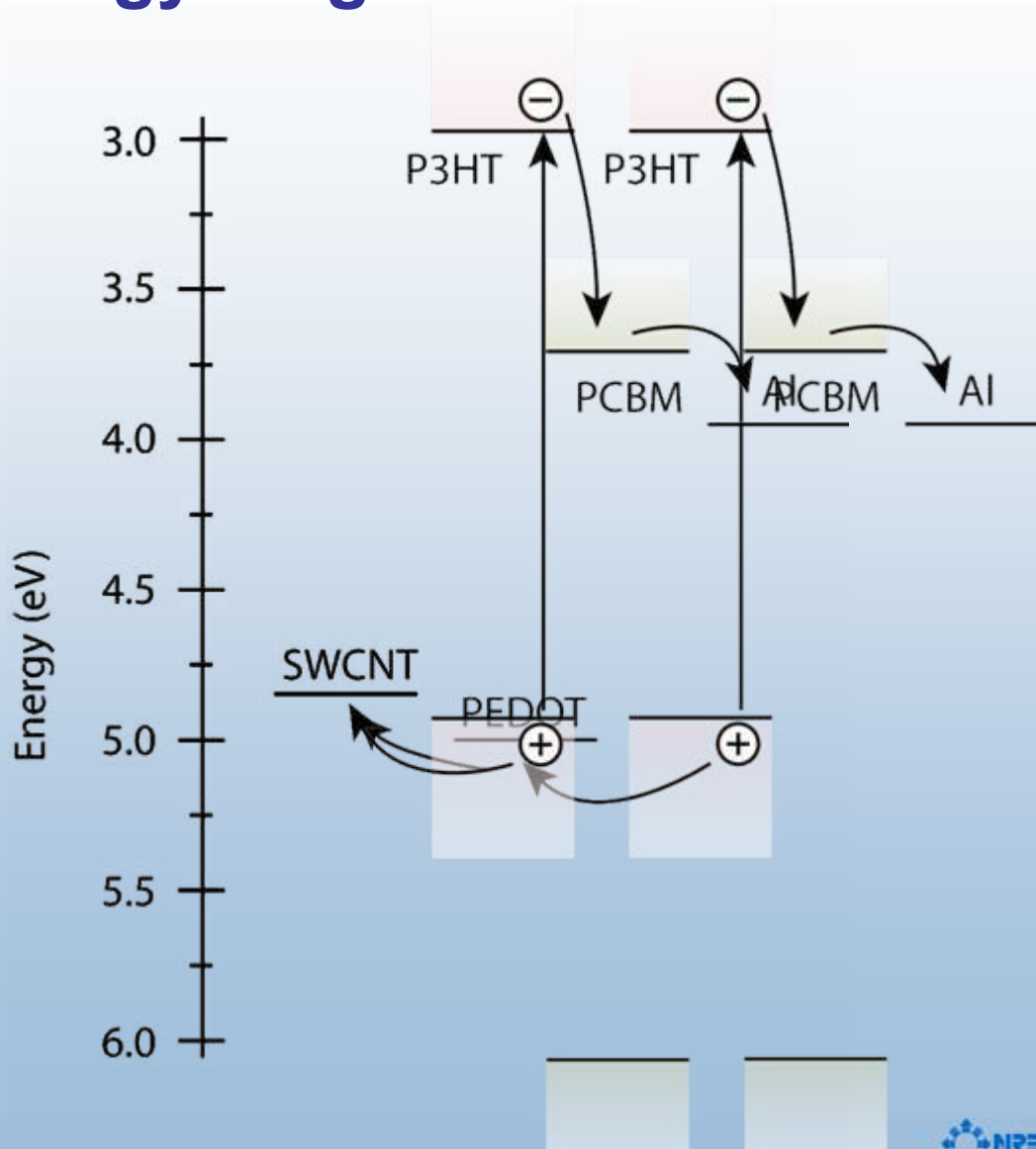


'Conventional' excitonic solar cell

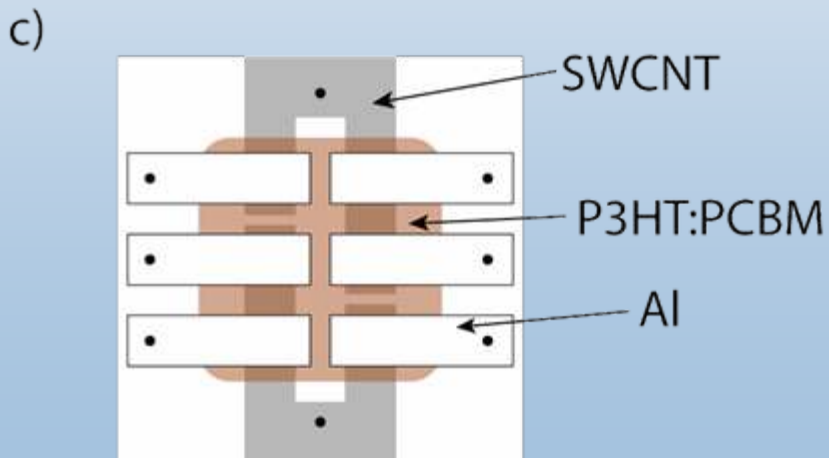
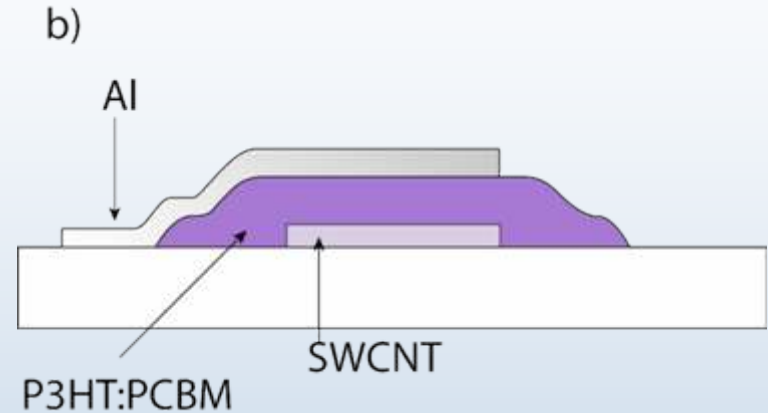
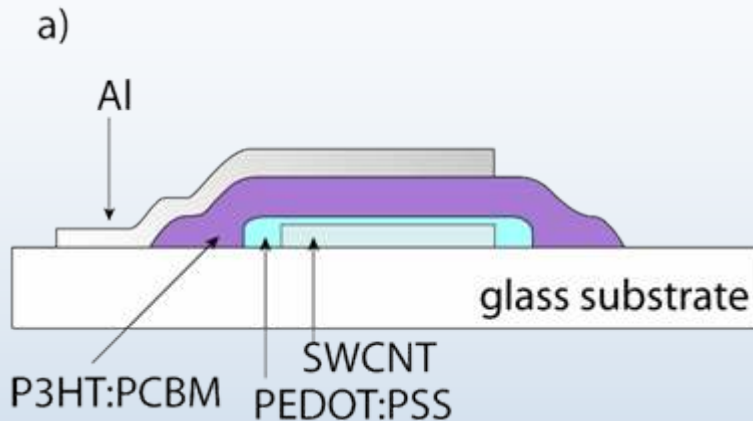
- Interpenetrated hole and electron conductors.
- Excitons dissociate at interface between P3HT and PCBM.
- Holes are transported in P3HT to PEDOT, where they transfer to ITO.



Energy diagram SWCNT based cell



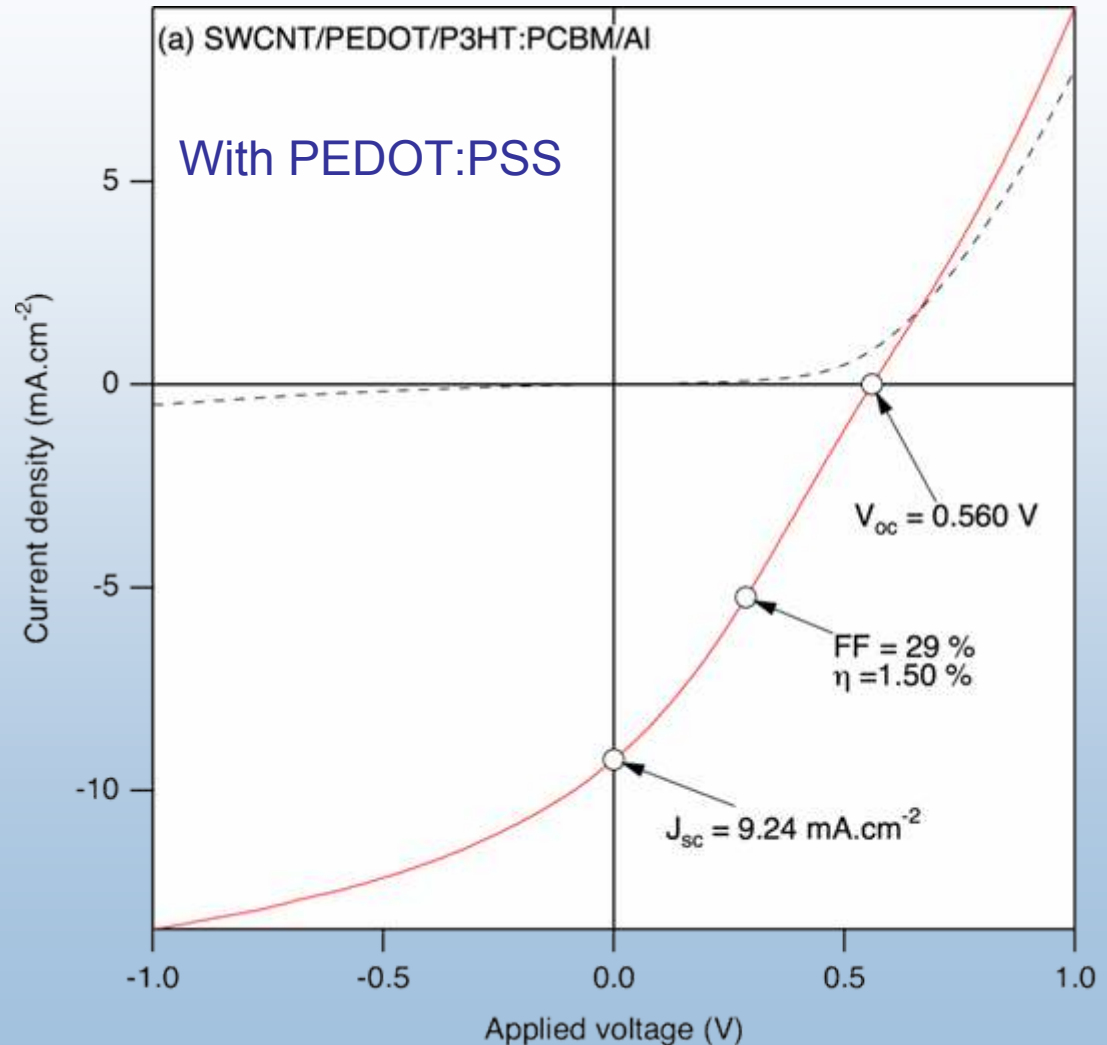
Device structures



- SWCNT Deposition by spraying of nanotube dispersion in ethanol onto heated (65°C) substrates
- PEDOT:PSS deposited by spin coating
- P3HT:PCBM deposited from chlorobenzene by drop casting or spin coating
- Al vapor deposited

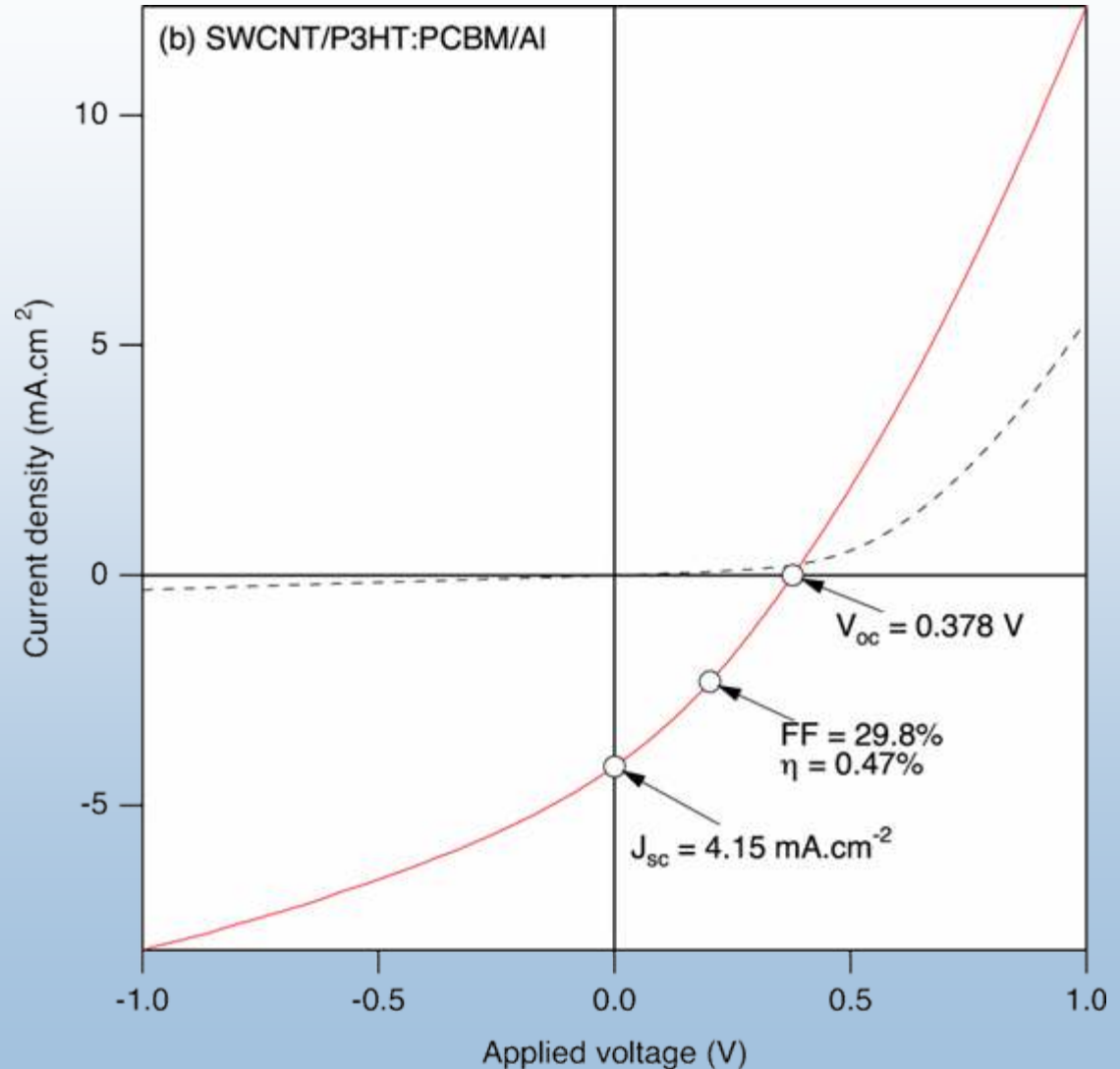
Devices made by drop casting

- Active layer thickness of 500-1000 nm
- Strong rectification - SWCNT is hole specific contact



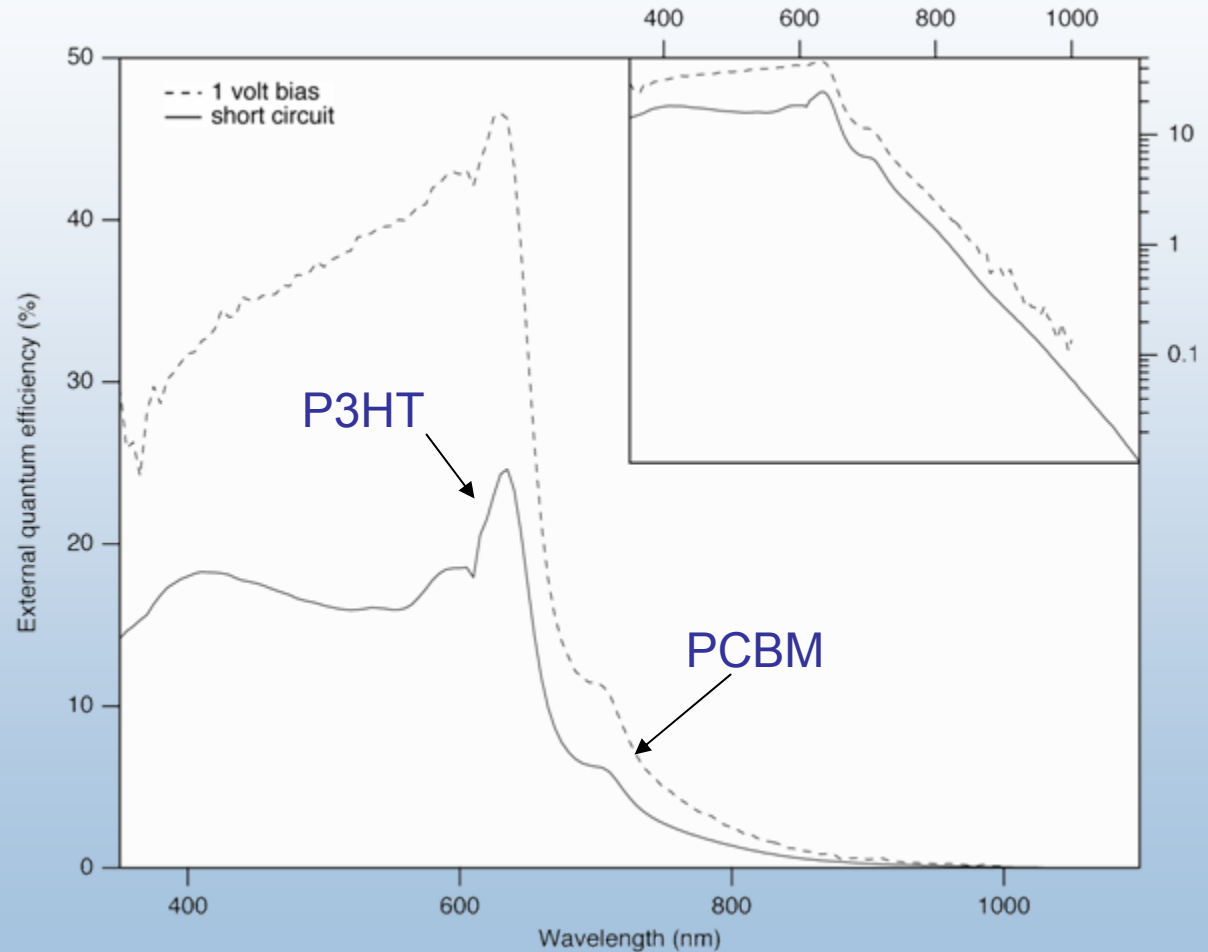
Device without PEDOT

- Lower efficiency, but still rectifying.
- Room for improvement
 - Layer thickness
 - Solvent
 - Reduce contact resistance
 - Increase shunt resistance

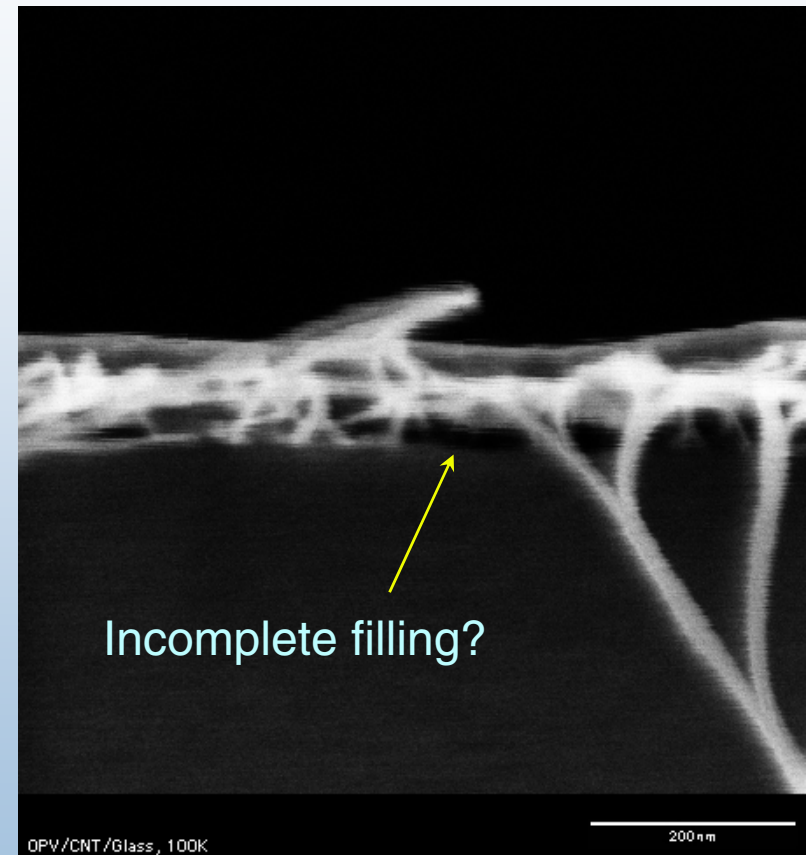
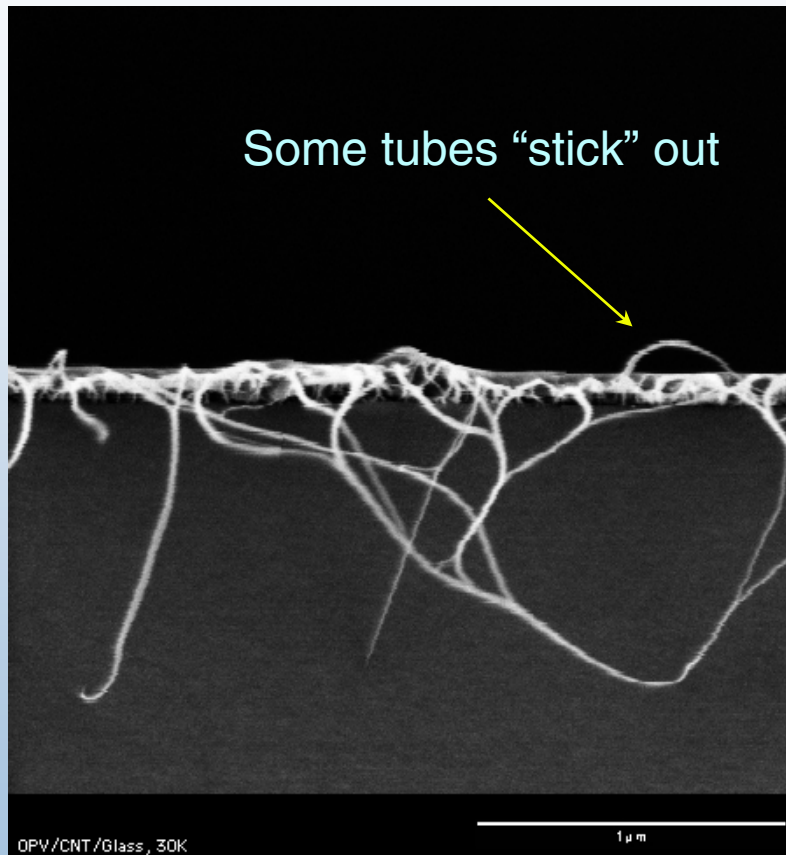


EQE of device without PEDOT

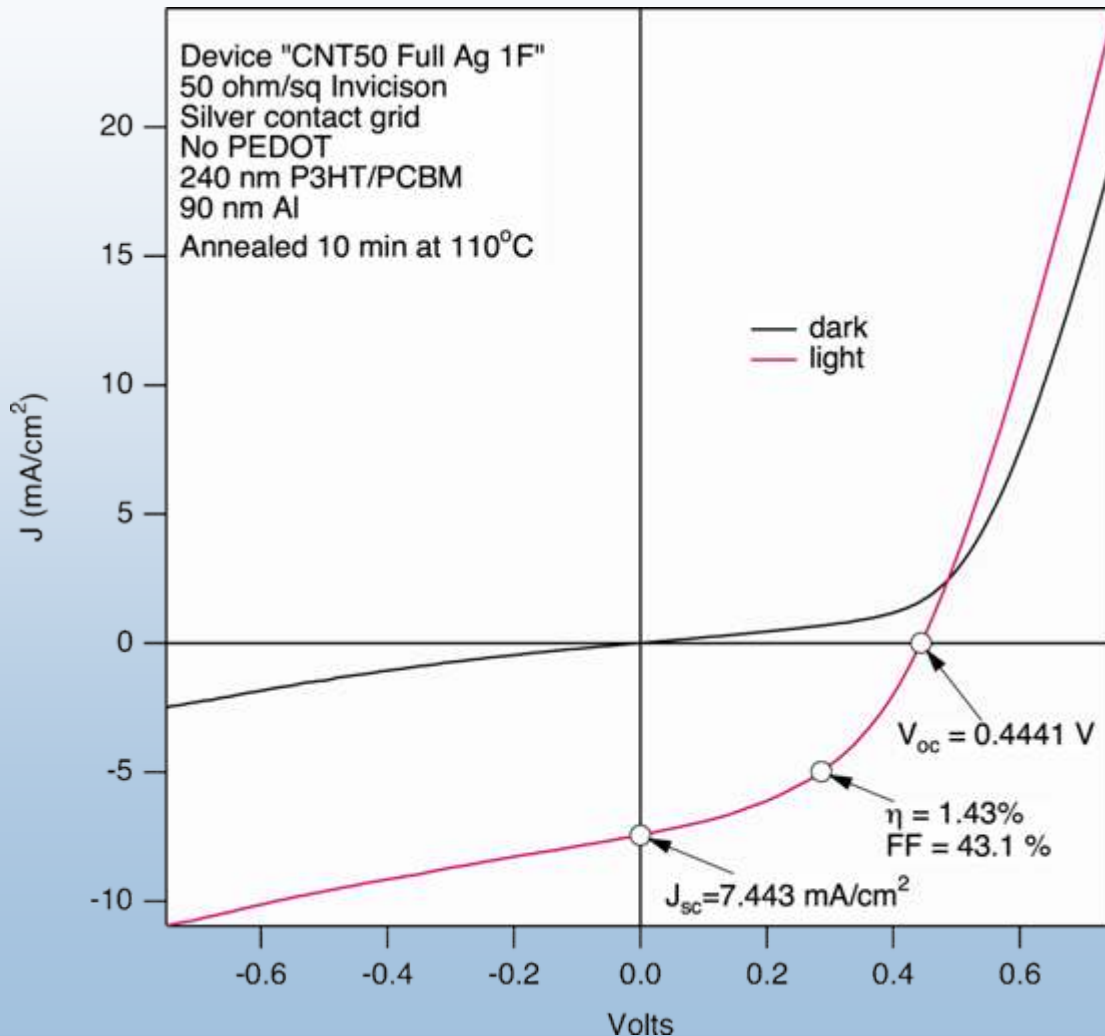
- Large amount of recombination in the bulk of the device.
- Needs optimization of layer thickness - spin casting!



SEM cross section of spin cast devices of 100 nm-thick active layer

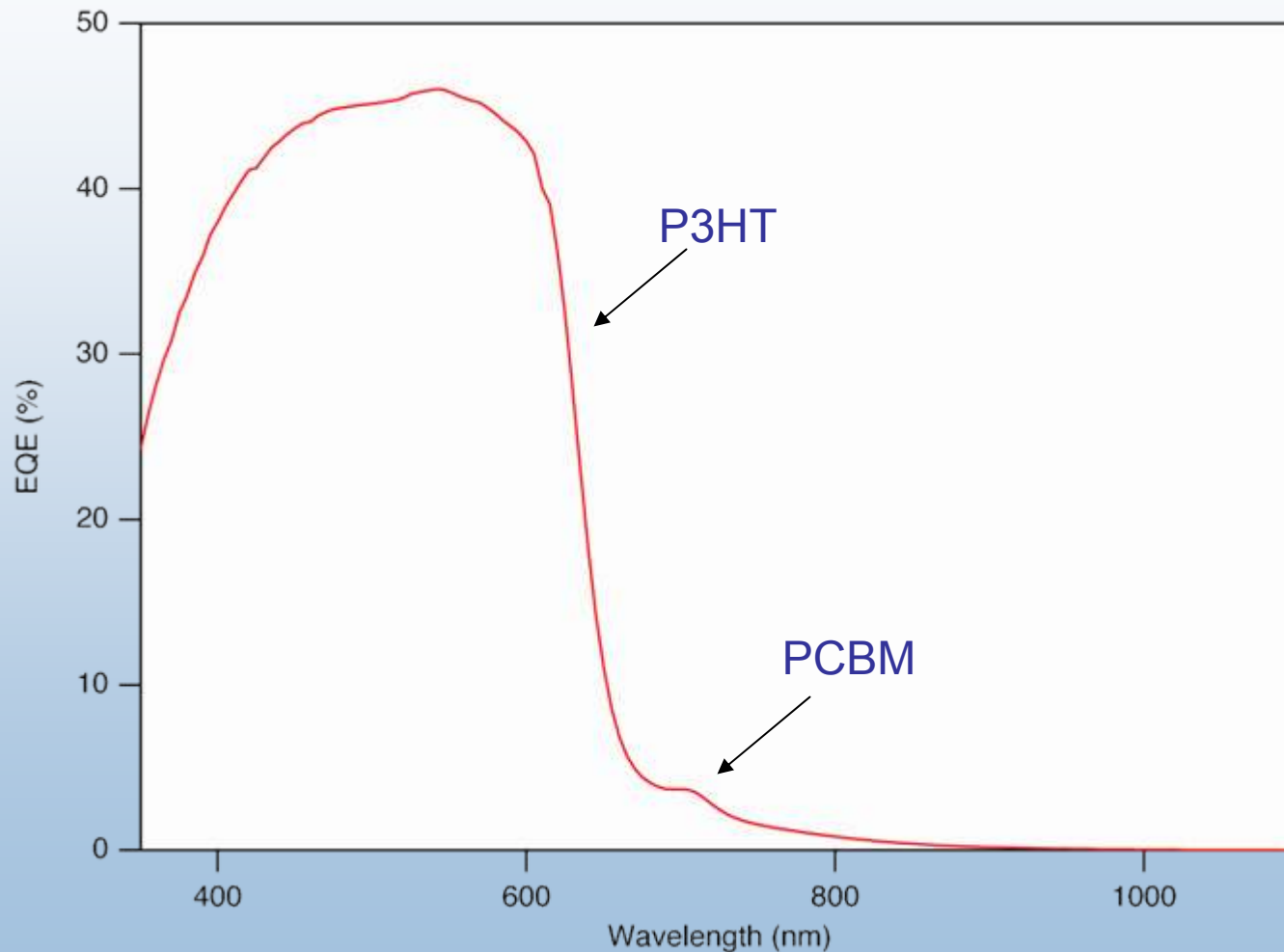


1.4 % Device without PEDOT



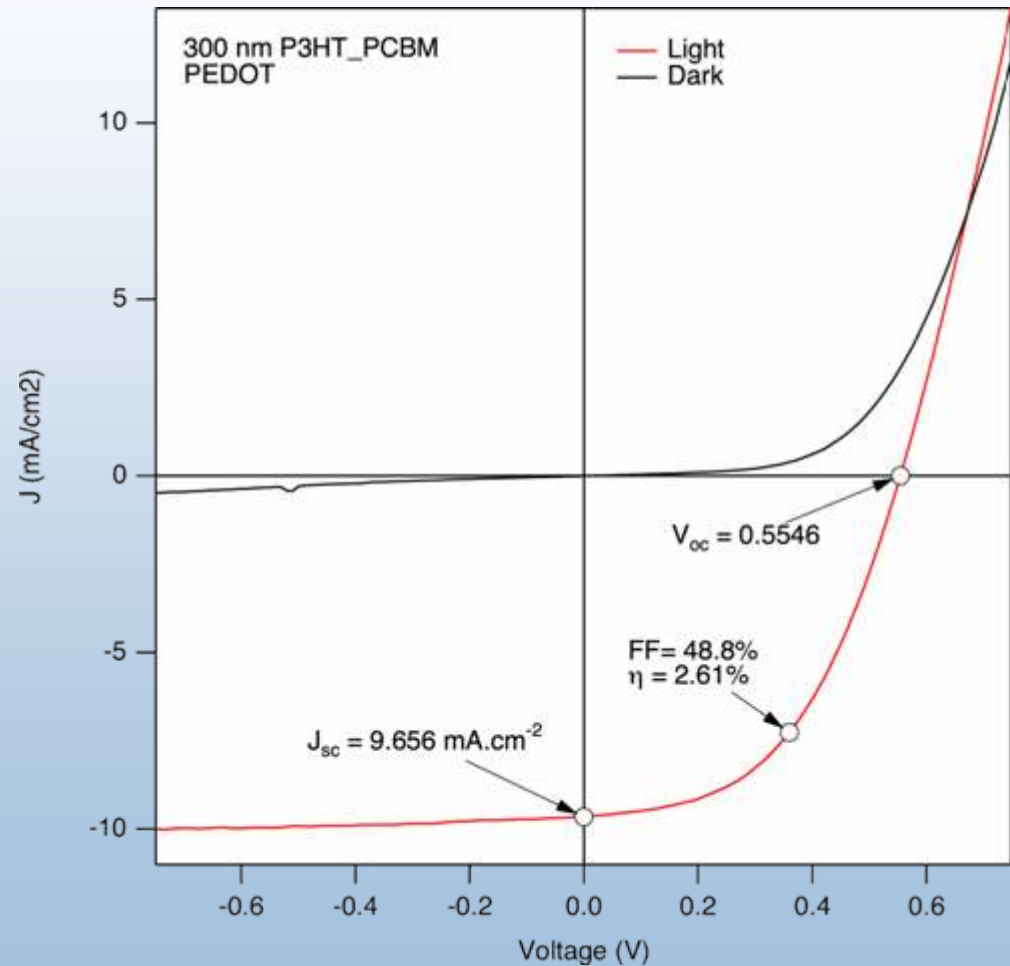
- Device is still slightly shunted.
- 1.4% efficiency is 3 times higher than the drop cast device
- Further optimization is possible.

External Quantum efficiency of 1.4% device



SWCNT-based Device with PEDOT:PSS

- Di-chlorobenzene solvent
- Efficiencies of 2.6%
- Very good rectification
- Less recombination than device without PEDOT
- Contact of nanotubes with PCBM in the active layer is detrimental?



Conclusions

- Organic solar cells with efficiencies of up to 1.43% conversion efficiency that use no ITO and no PEDOT:PSS, are demonstrated.
- A cell without ITO, but with PEDOT:PSS gave 2.6% conversion efficiency
- Due to porous nature of SWCNT substrates, optimization of the active layer is essential.
- SWCNT electrodes bring one step closer the goal of a fully printable, organic solar cell.