

# 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,<sup>†</sup> Teresa Barnes,<sup>†</sup> Garry Rumbles,<sup>†</sup> Sean Shaheen,<sup>†</sup> Timothy J. Coutts,<sup>†</sup> Chris Weeks,<sup>\*</sup> Paul Glatkowski,<sup>\*</sup> Igor Levitsky,<sup>\*</sup> and Jorma Peltola<sup>\*</sup>

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.

<sup>†</sup> NREL  
<sup>\*</sup> EIKO



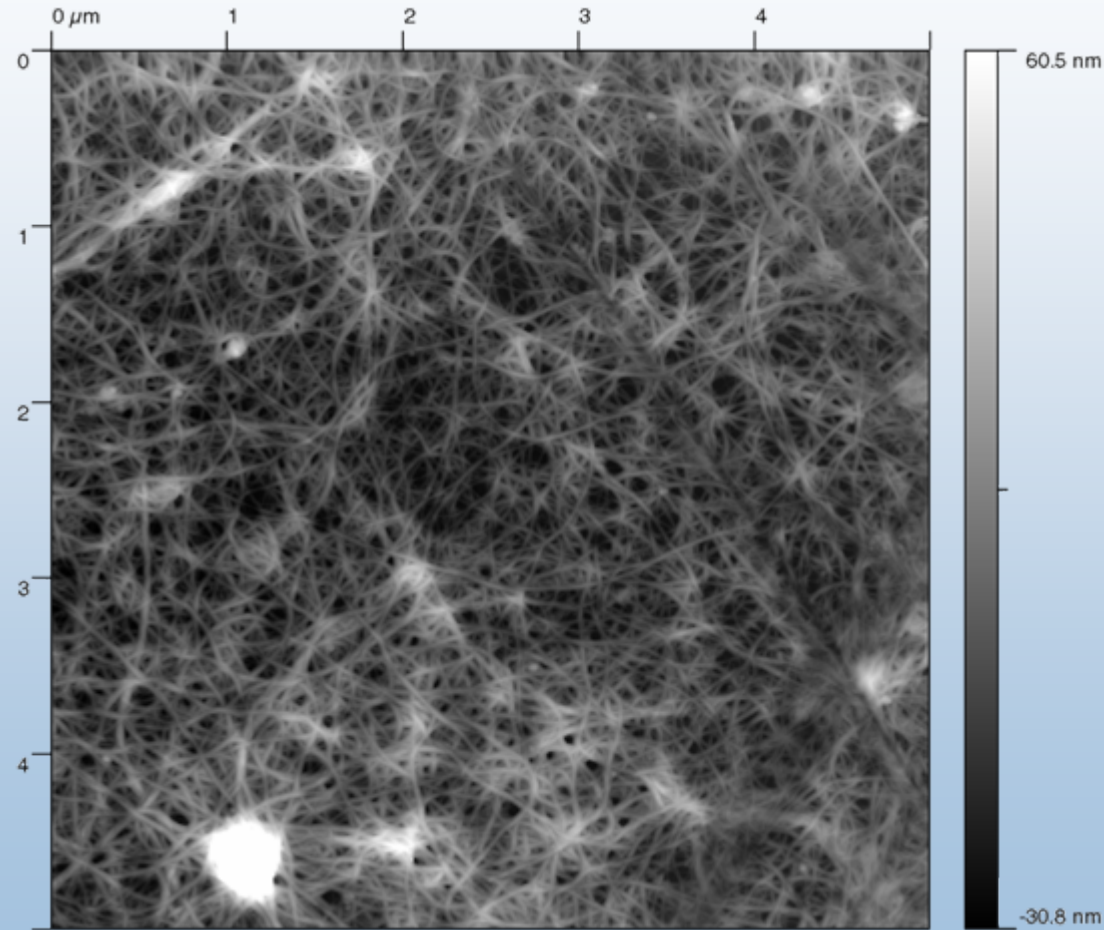
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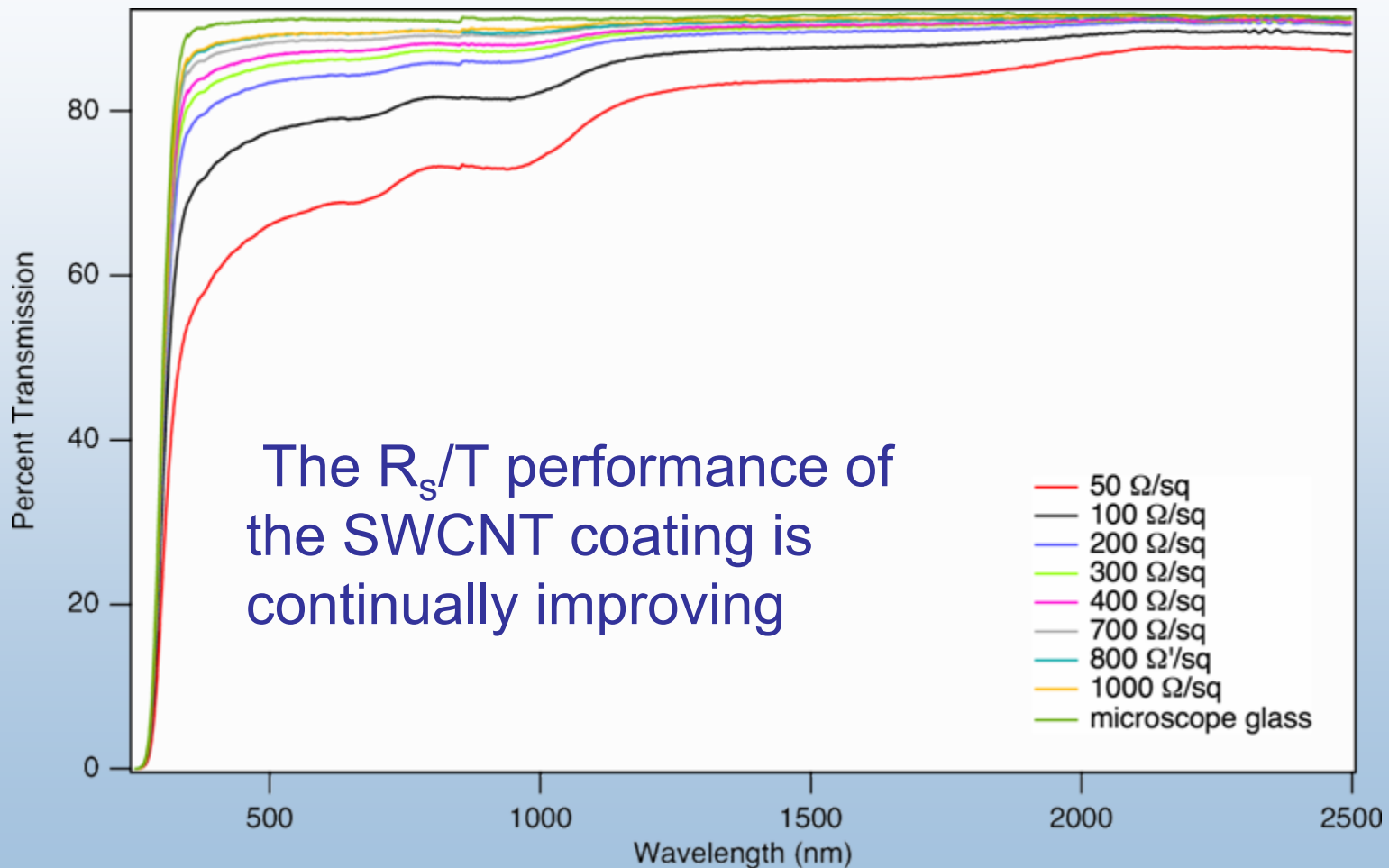
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# Why replace ITO?

- 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

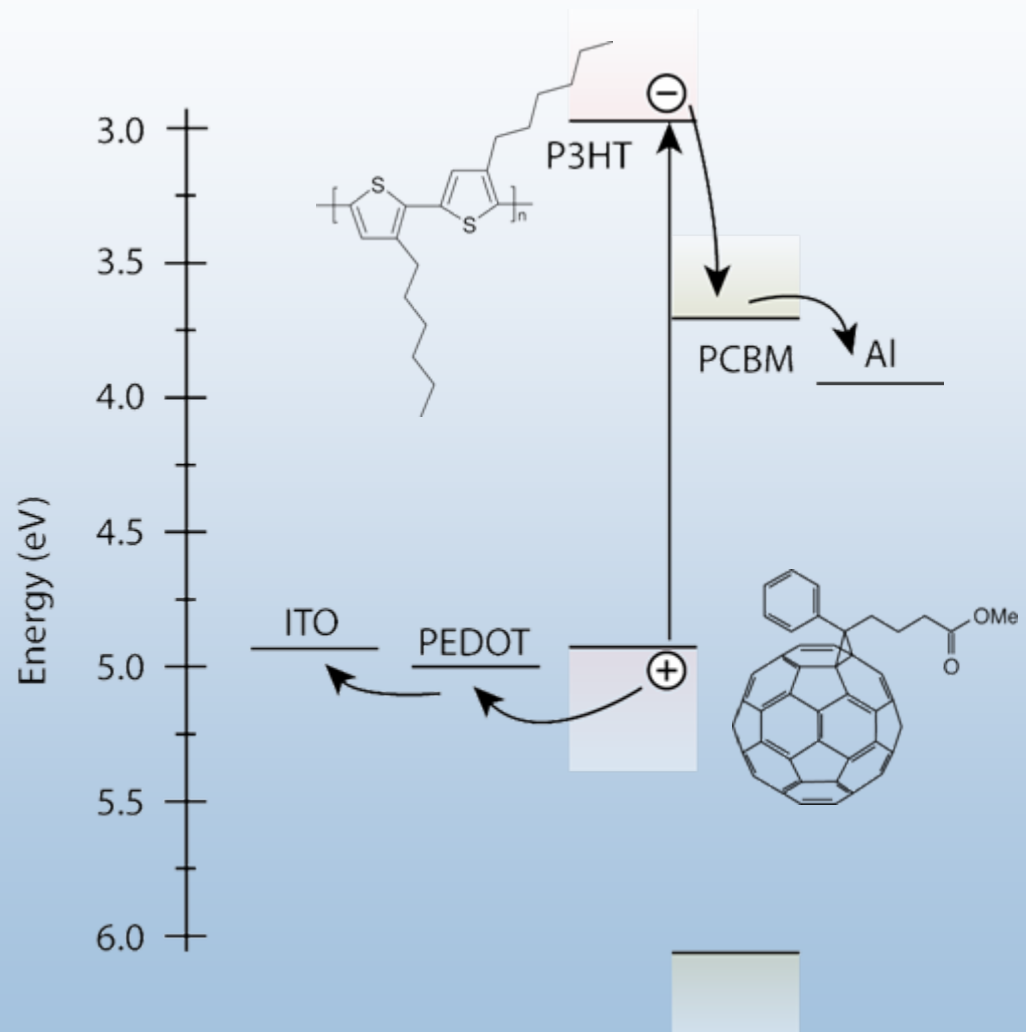


# Resistance vs. Transmittance of SWCNT layers

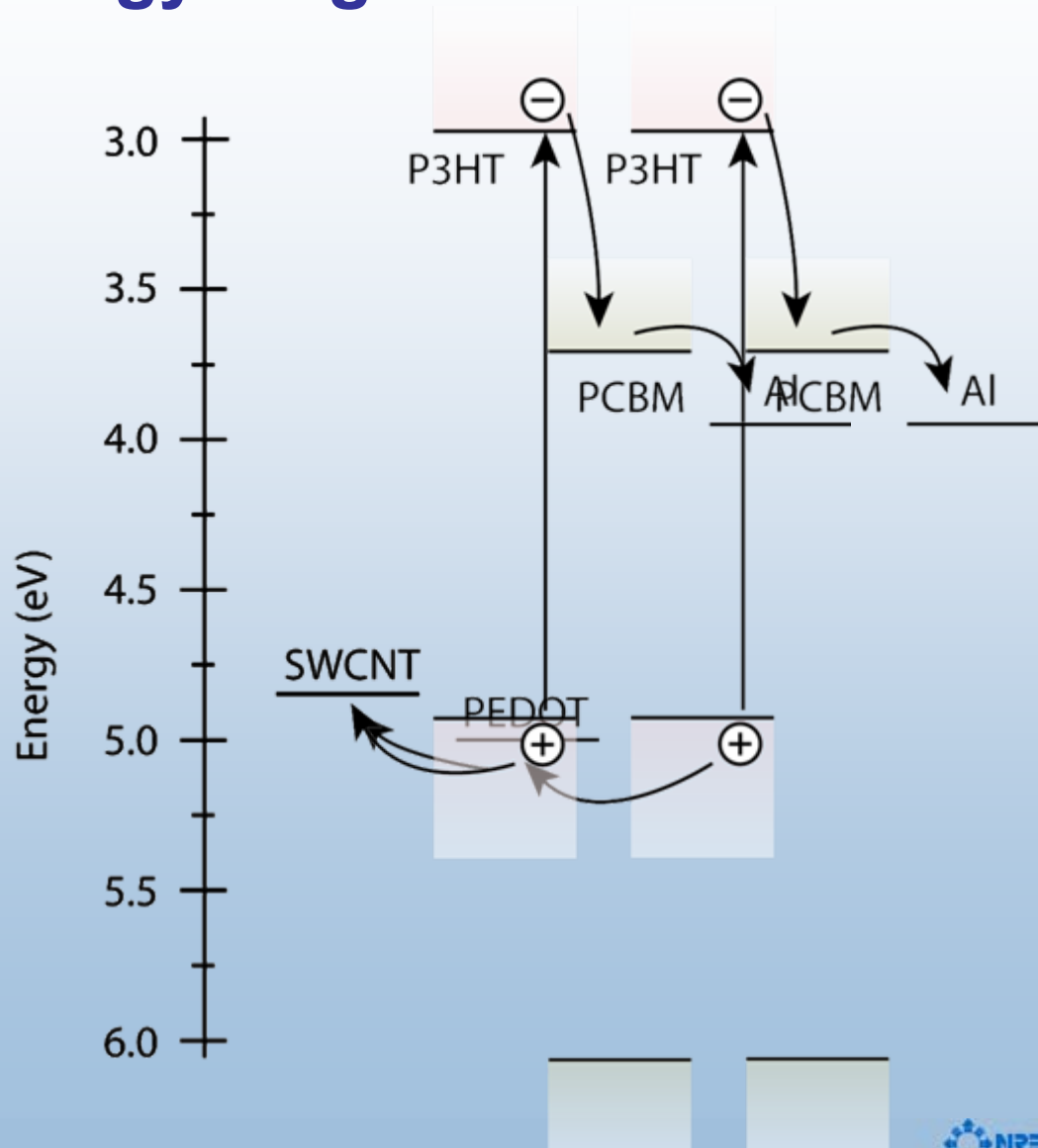


# 'Conventional' excitonic solar cell

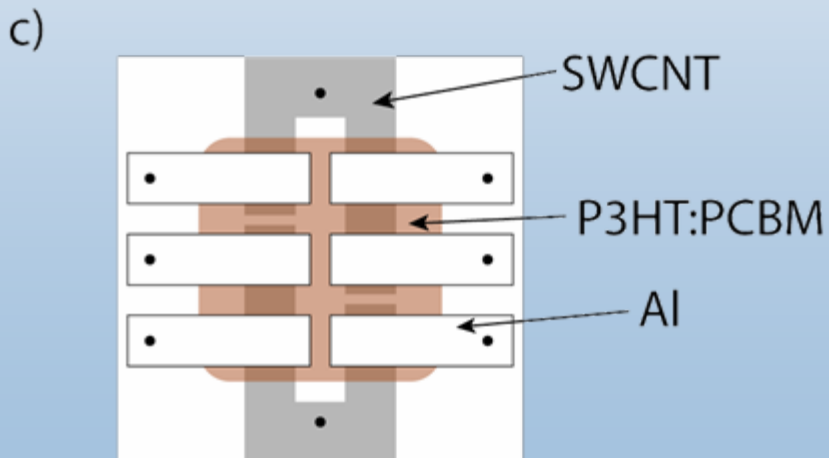
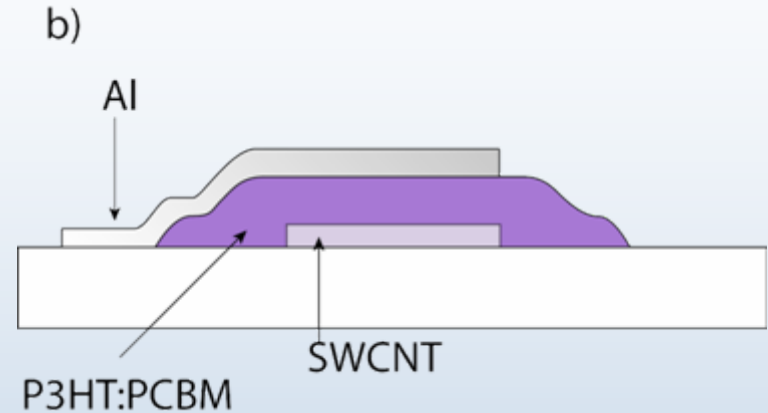
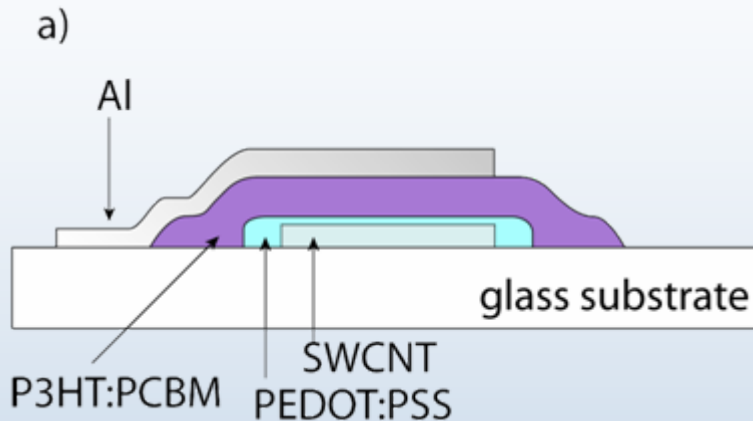
- Interpenetrated hole and electron conductors.
- Excitons dissociate at interface between P3HT and PCBM.
- Holes are transported in P3HT to PEDOT, where they transfer to ITO.



# Energy diagram SWCNT based cell



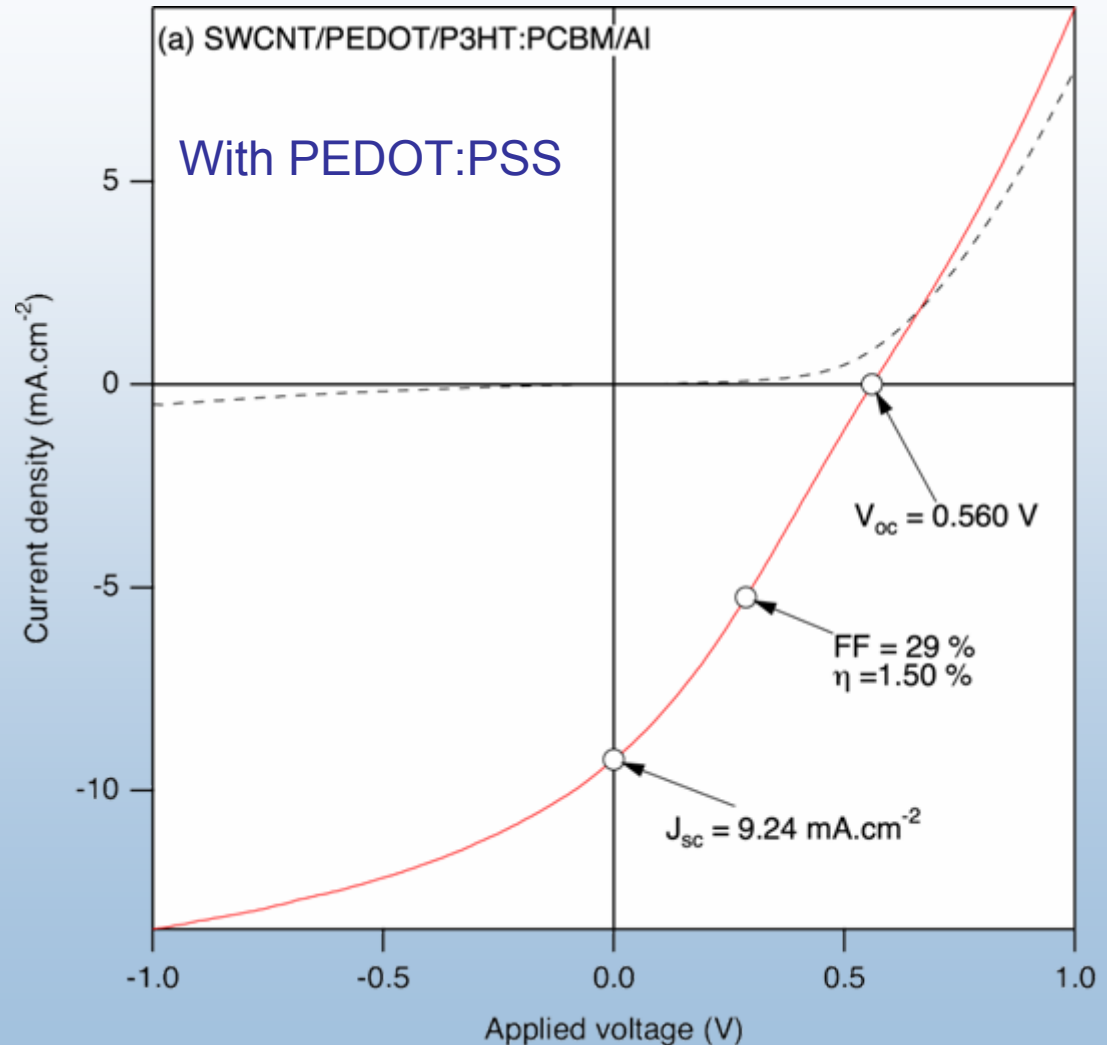
# Device structures



- 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

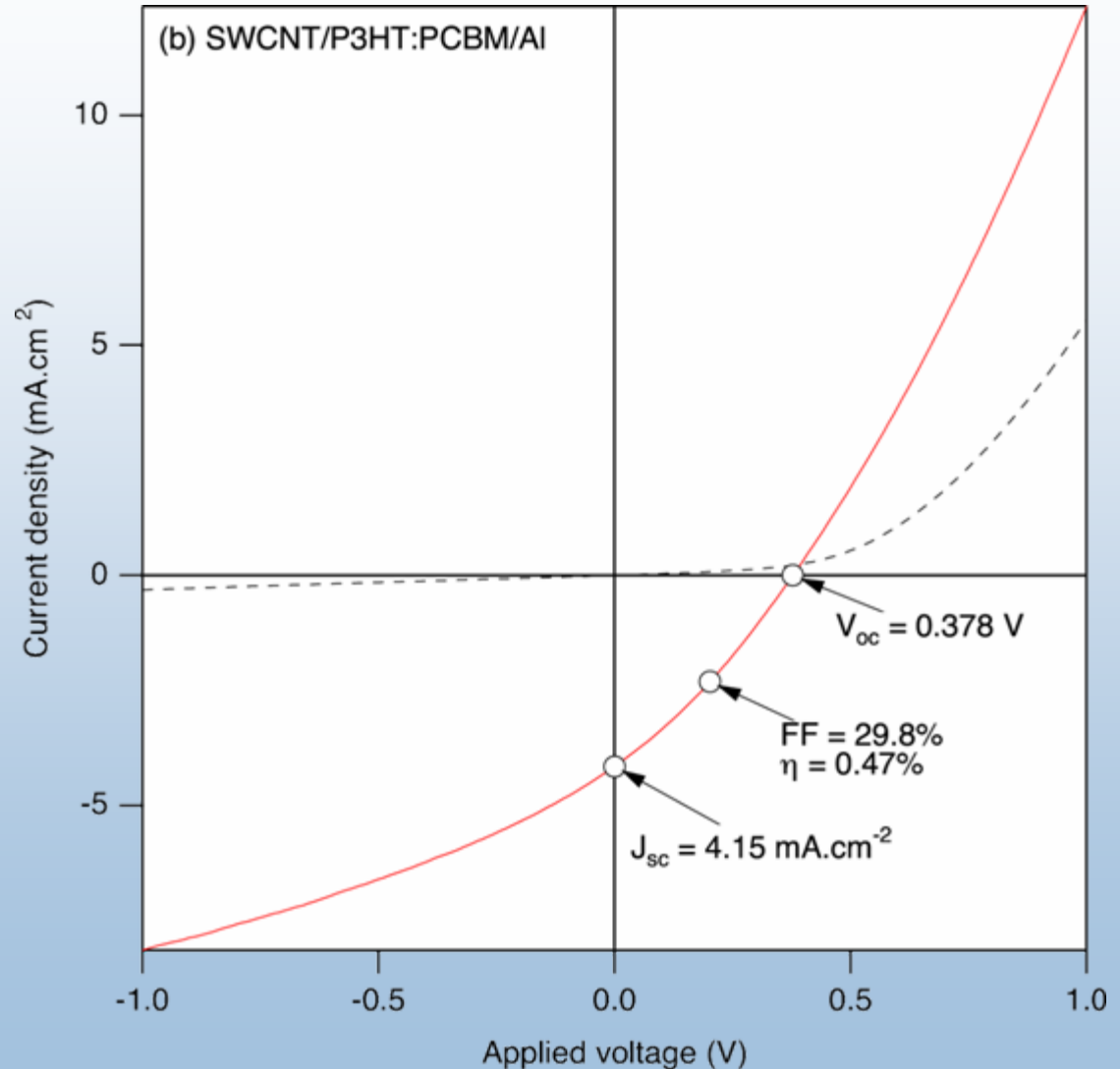
- Active layer thickness of 500-1000 nm
- Strong rectification - SWCNT is hole specific contact





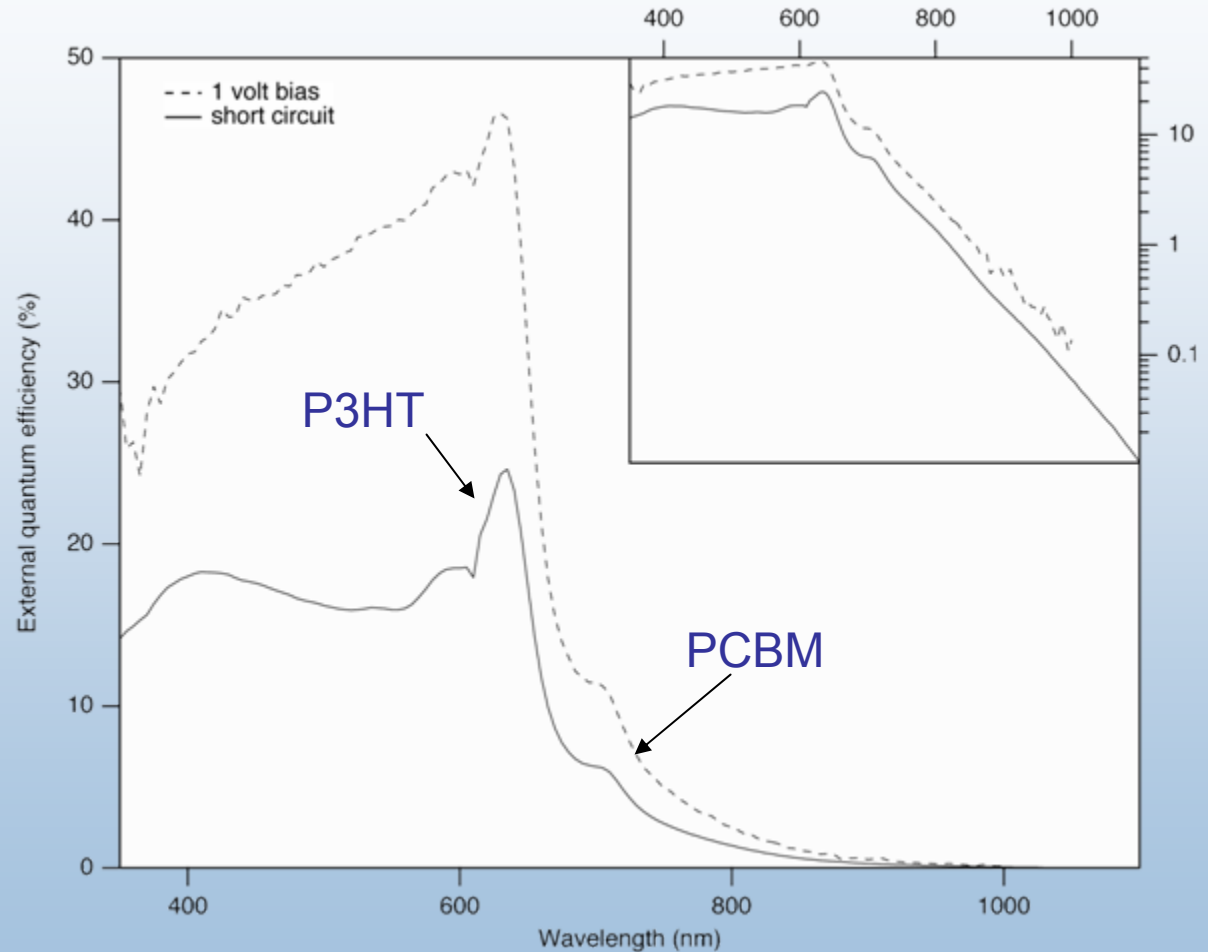
# Device without PEDOT

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

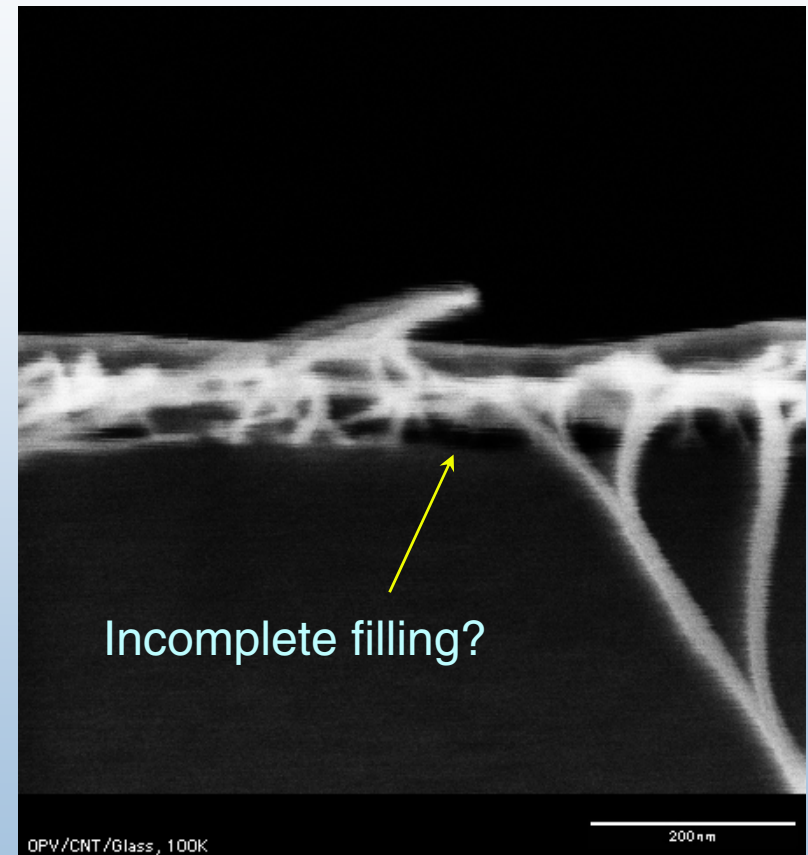
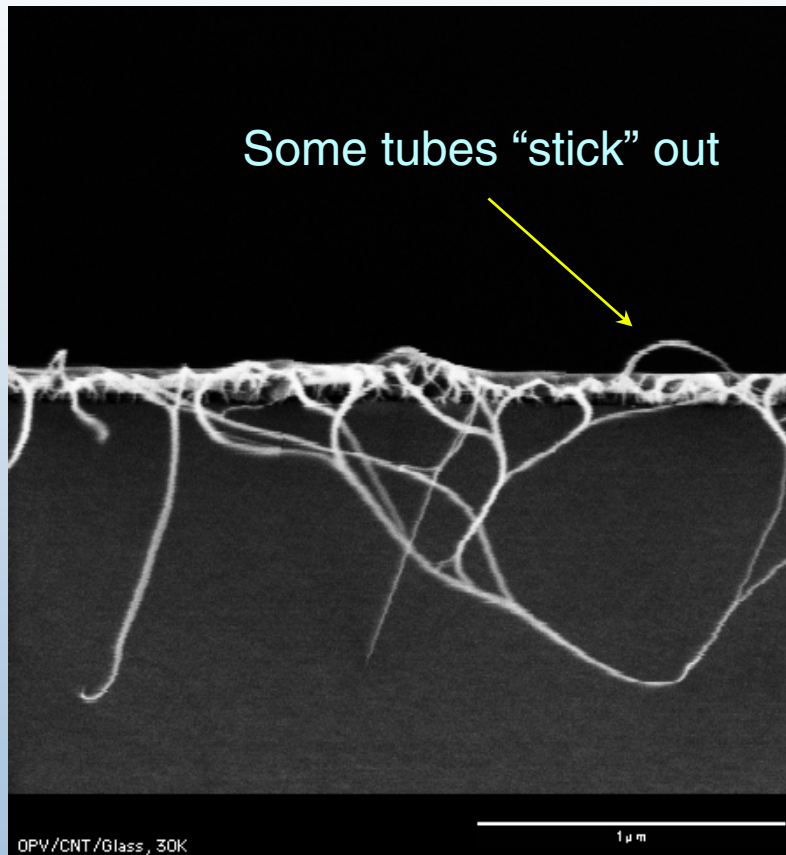


# EQE of device without PEDOT

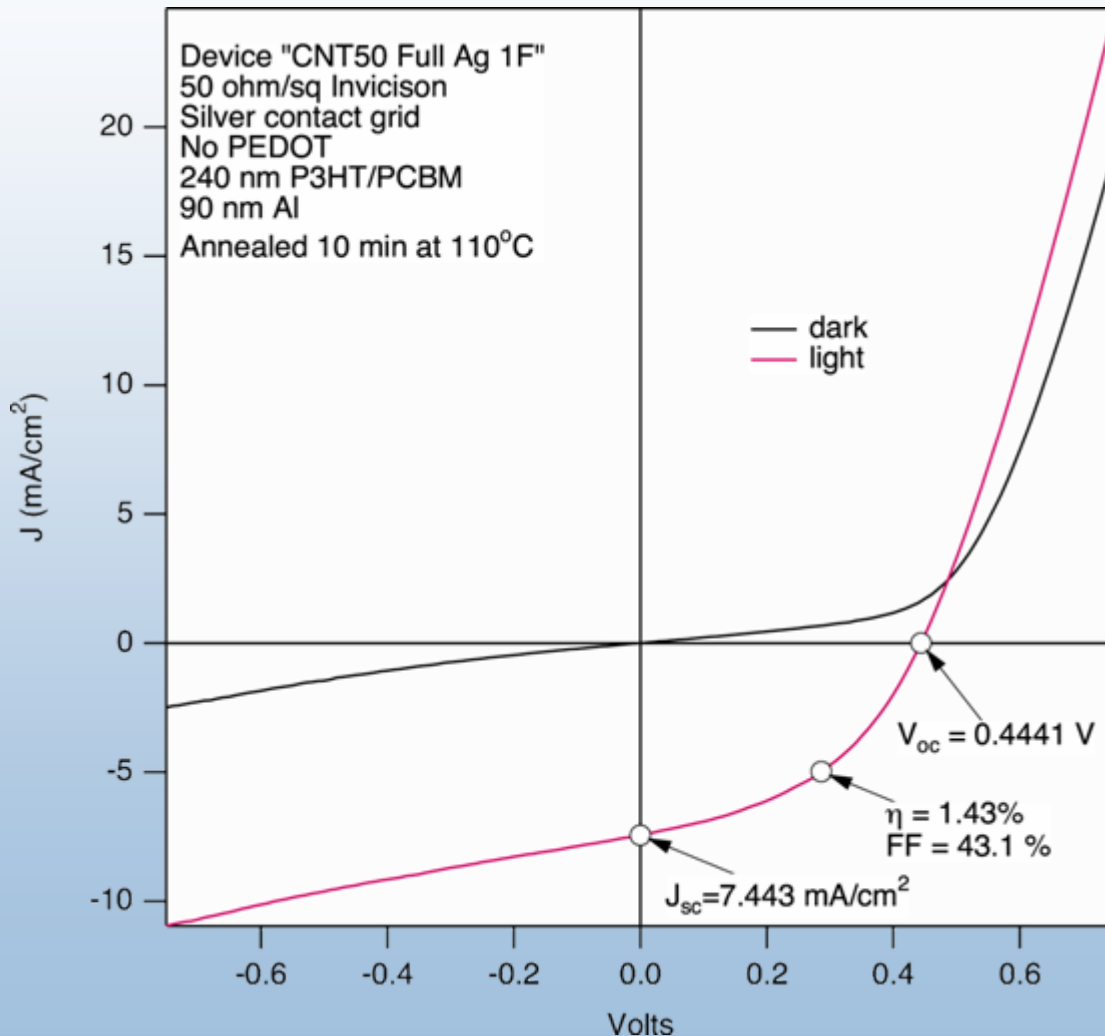
- Large amount of recombination in the bulk of the device.
- Needs optimization of layer thickness - spin casting!



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

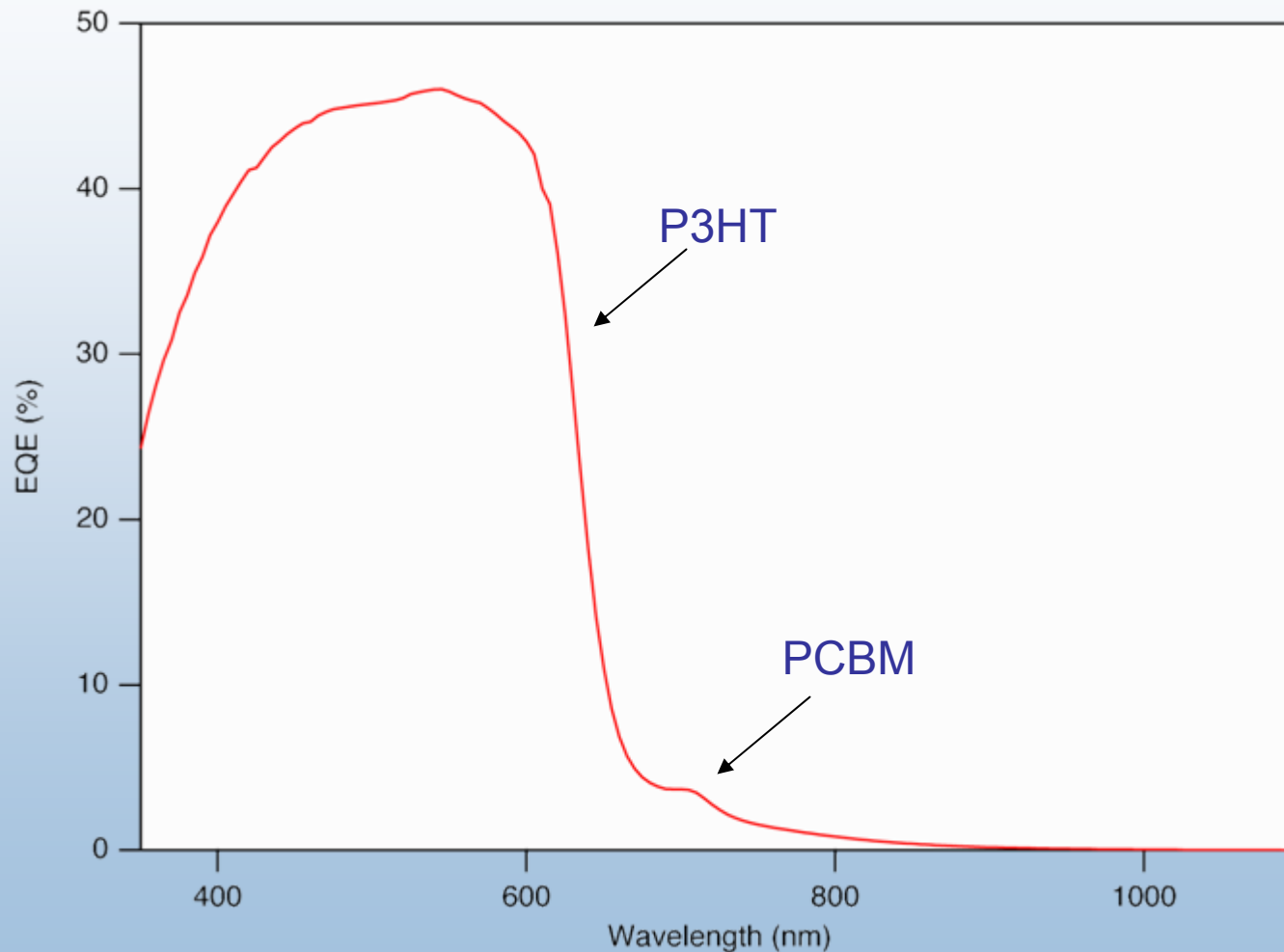


# 1.4 % Device without PEDOT



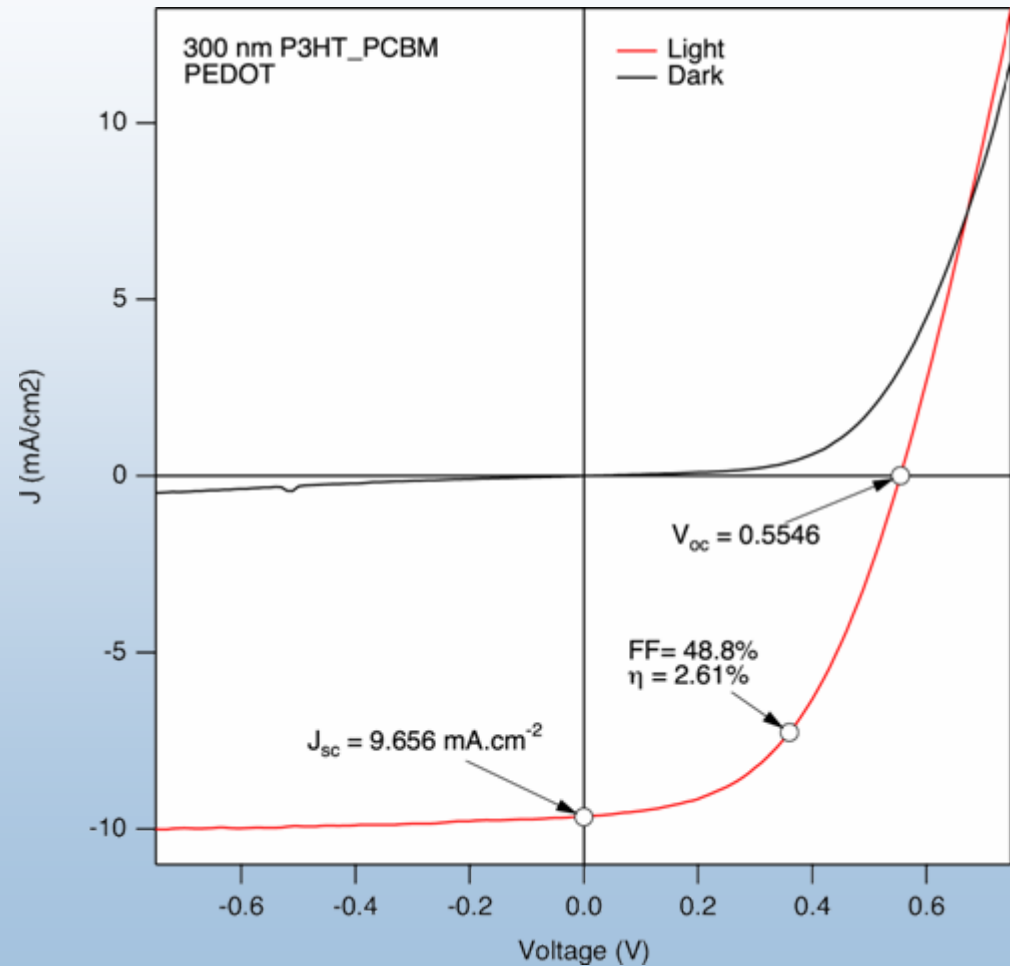
- Device is still slightly shunted.
- 1.4% efficiency is 3 times higher than the drop cast device
- Further optimization is possible.

# 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.