Graphene-based Polymer Bulk Heterojunction Solar Cells

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APS March Meeting 2012, Boston

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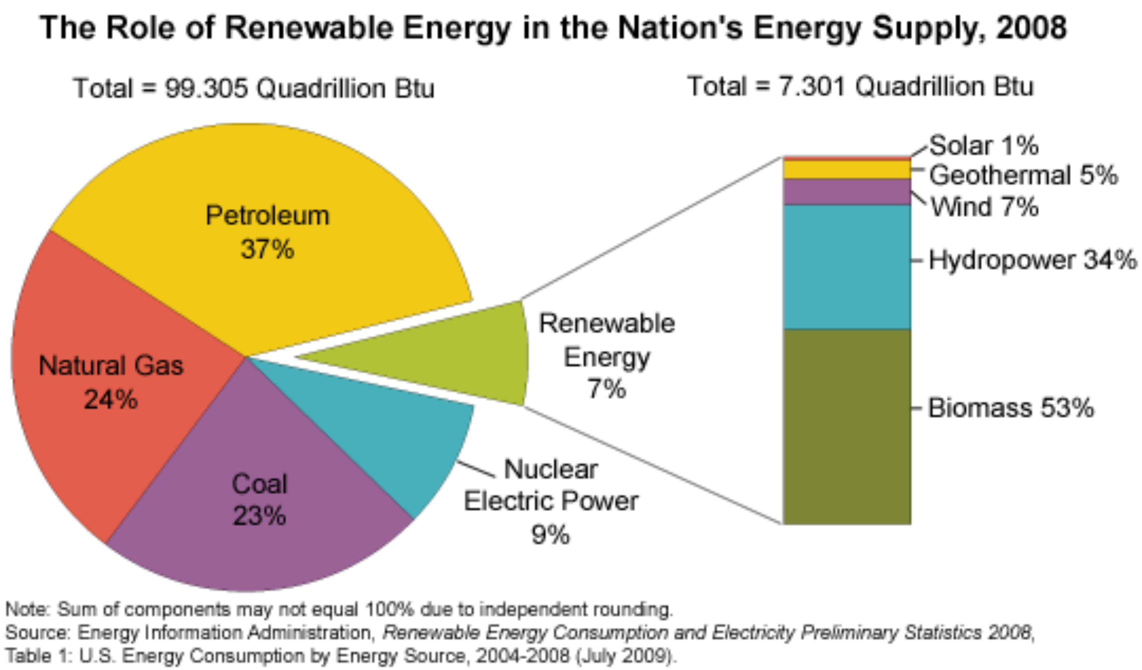
Solar Energy In Development

- Renewable
- Potential for High coverage
- Low emission



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A comparison

Inorganic solar cells

- From 1941
- High processing cost
- Thickness in microns
- Not flexible
- 25.0% for Si cells*

Organic solar cells

- From 1954
- Solution processible
- 100~300 nm thick
- Flexible
- 6.1% for polymer BHJ cells**

* Green, Progress in Photovoltaics, 2009. **17**(3): p. 183-189.
** Park *et al.*, Nat. Photonics, 2009. **3**(5): p. 297-U5.

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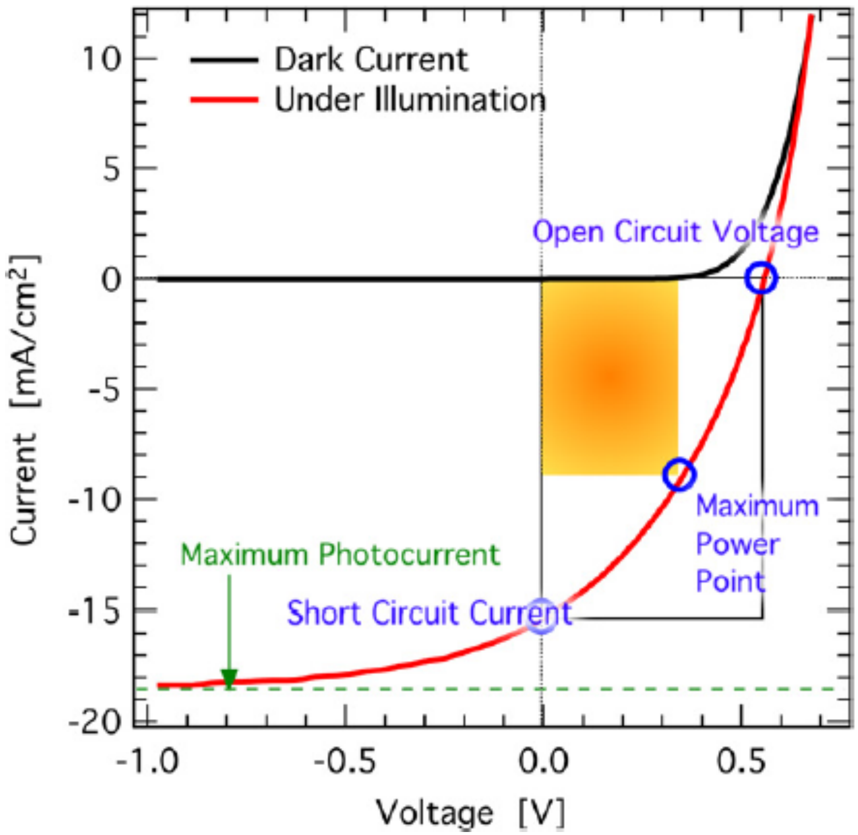
Solar Cell Parameters



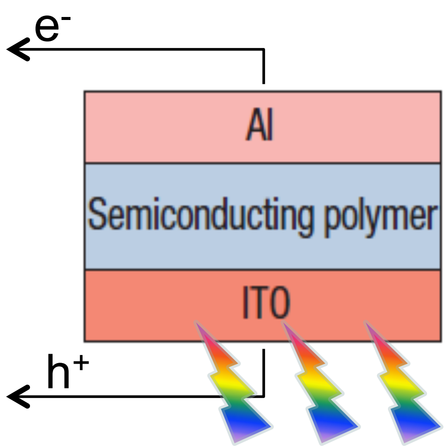
- J_{SC}: Short-circuit current density
- V_{OC}: Open-circuit voltage
- P_{max}: Maximum output power
- **FF**: Fill factor
- **Power conversion efficiency (PC**

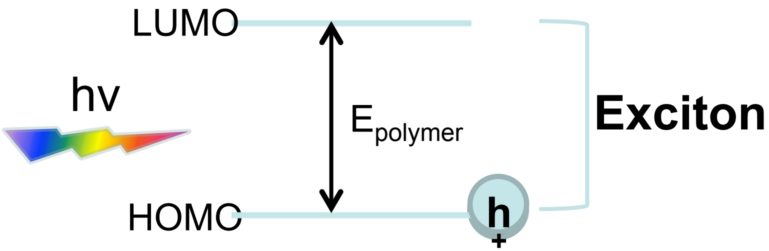
$$\eta = P_{max} / P_{in}$$

Picture source: Deibel and Dyakonov, Reports on Progress in Physics, 2010. **73**(9): p. 1-39

Polymer solar cells

Single-layer device





HOMO: Highest Occupied Molecular Orbital
LUMO: Lowest Unoccupied Molecular Orbital

- ~0.3 eV energy is needed to dissociate excitons
- An external voltage is required
- Recombination of free charge carriers

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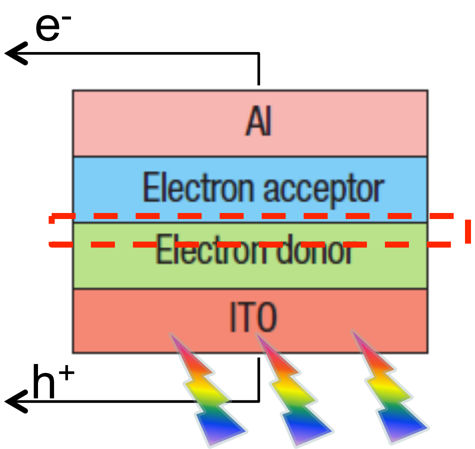
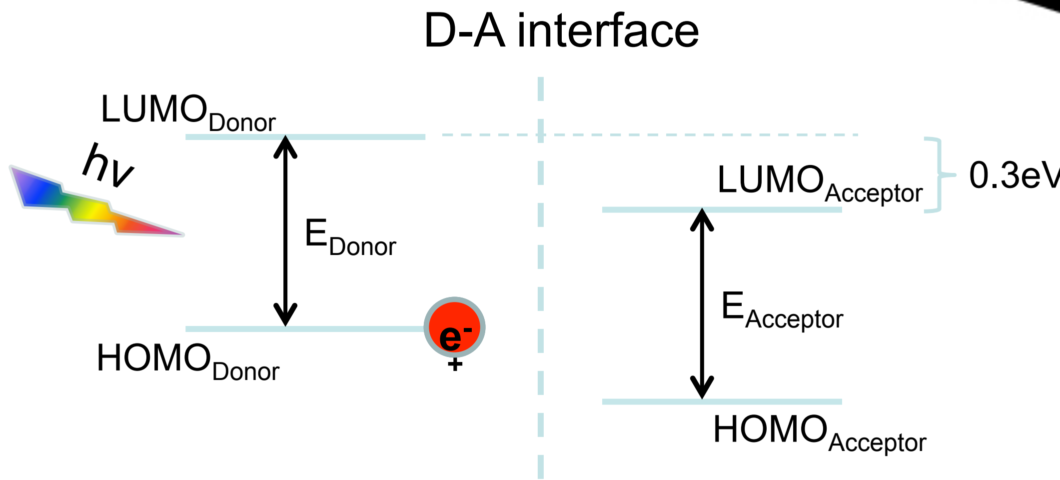
Bilayer Device





- D-A interface facilitates exciton dissociation
- Electron transfer from donor(semiconducting polymer) to acceptor
- Exciton dissociation is energetically favorable
- Exciton diffusion length(~10 nm)
- D-A interfacial area is limited by device geometry

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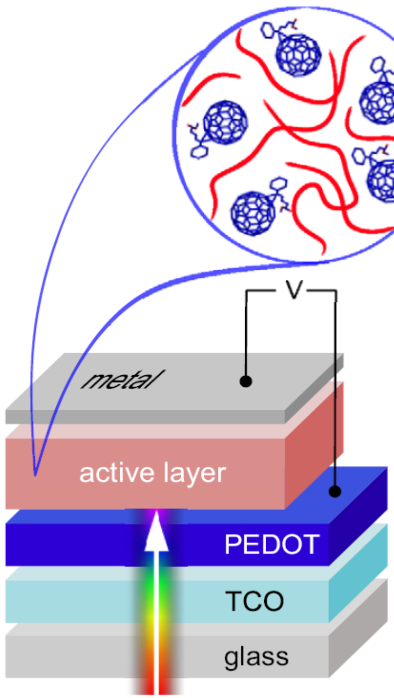
Bulk Heterojunction(BHJ) Solar Cells



- Nanoscale penetrating network
- D-A interface close to where exciton is generated
- Much increased D-A interfacial area
- Over 6% PCE for P3HT:PCBM BHJs*

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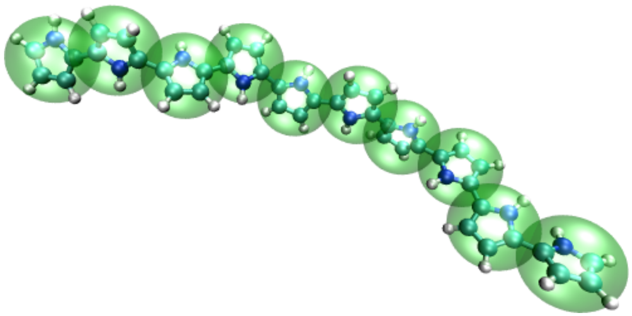
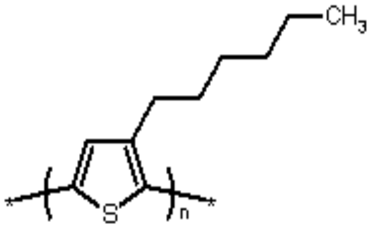
(Picture source: Deibel and Dyakonov, Reports on Progress in Physics, 2010. **73**(9): p. 1-39)
*Peet et al., Nature Materials, 2007. **6**(7) : p. 497-500.

Donor

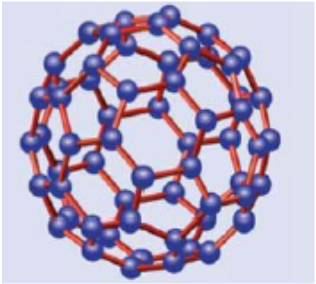


Conjugated polymer

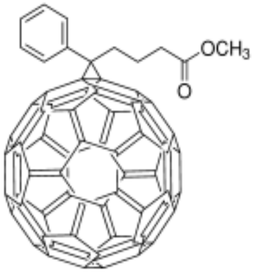


P3HT

Acceptor



Fullerene(C_{60})



PCBM

Picture source: http://www.mpip-mainz.mpg.de/~andrienk/conferences/DPG_2009/

Castro Neto et al., Reviews of Modern Physics, 2009. **81**(1): p. 109-162

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Factors Affecting BHJ Performance

- **Choice of donor and acceptor materials**: band gap and miscibility
- **Choice of solvent**: polymer chain packing
- **Donor-acceptor ratio**: domain size
- **Annealing conditions**: reorganize polymer chains, crystallization
- **Other post-production treatments**: DC voltage during annealing for ordered structure *

Morphology → Performance

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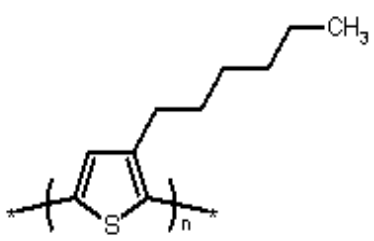
Pictures source: Dennler, Scharber and Brabec, Adv. Mater. 2009, **21**(13): p. 1323-1338.
* Padinger, Rittberger and Sariciftci, Adv. Funct. Mater., 2003. **13**(1): p. 85-88.

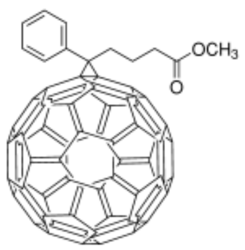
BHJ features

Polymer:Fullerene BHJ device

- High interfacial area for exciton dissociation
- Bicontinuous network for charge transport
- 50:50 w/w P3HT:PCBM for optimum performance
- Increase P3HT ratio to capture more solar energy



P3HT



PCBM

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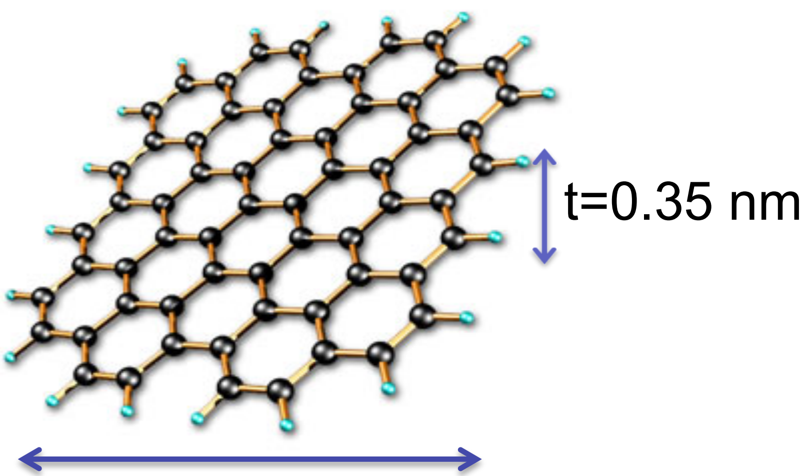
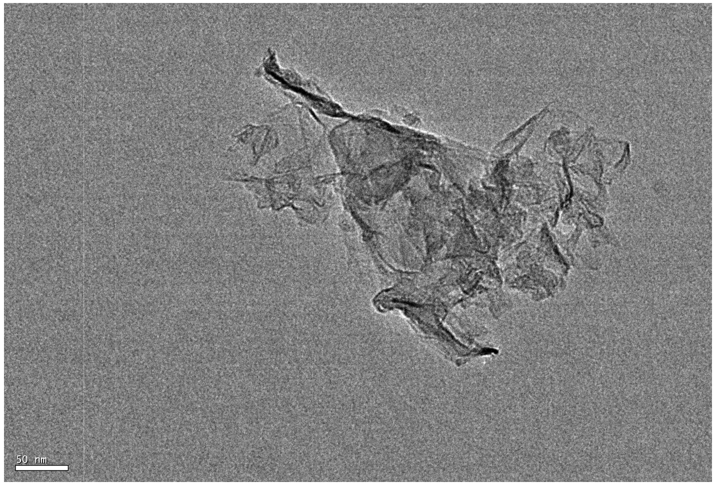
Pristine Graphene

- OPVs with chemically modified graphenes were reported*
- Excellent conductivity and high aspect ratio
- Percolation paths at very low fraction



Dia.~550nm

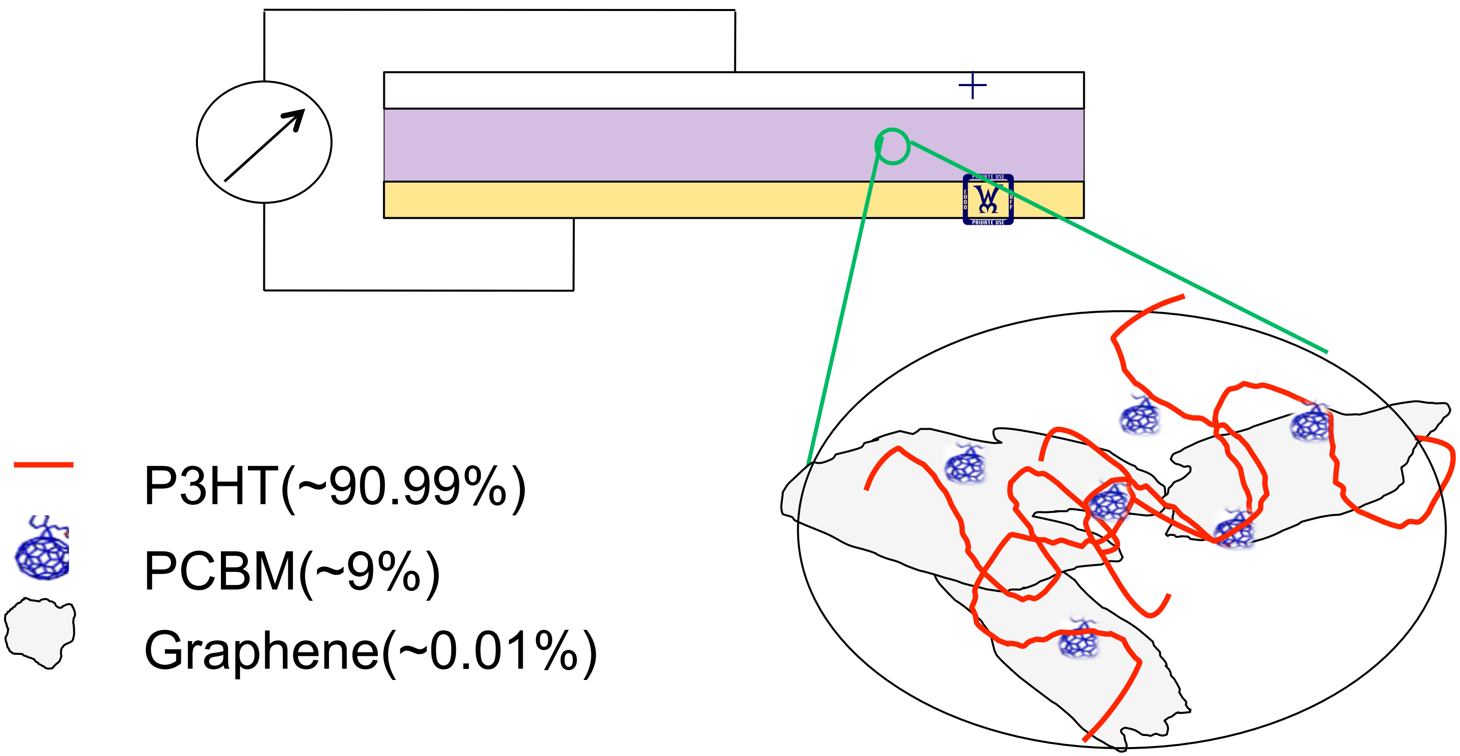
TEM image of pristine graphene flake



Scale bar=50nm

*Liu, Z. *et al.*, Adv. Mater., 2008. **20**(20),
Yu, D. *et al.*, ACS Nano, 2010. **4**(10), Yu, D. *et al.*, J. Phys. Chem. Lett., 2011. **2**(10).

The Active layer



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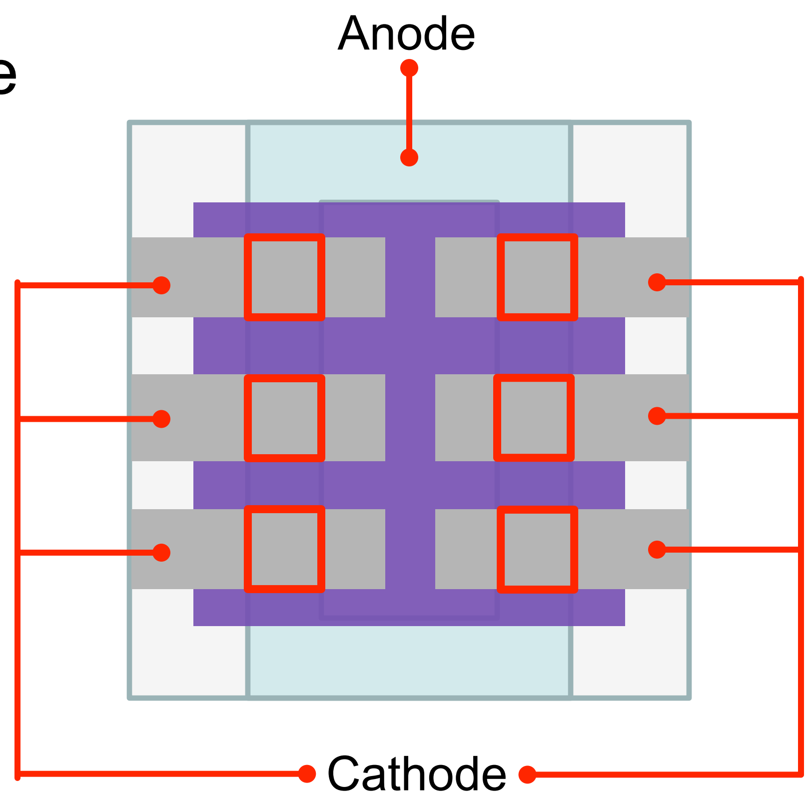
Device Fabrication

- Patterned ITO as bottom electrode
- PEDOT:PSS by spin coating
- 10:1 P3HT:PCBM(w/w) with graphene by spin coating
- LiF and Aluminum
- Fabricated and annealed in N_2



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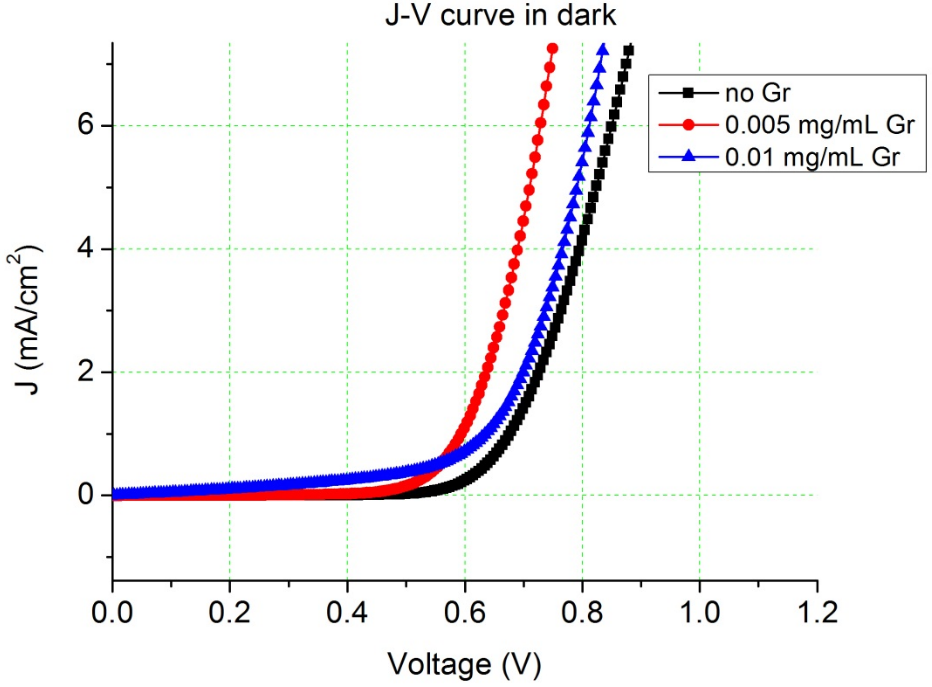
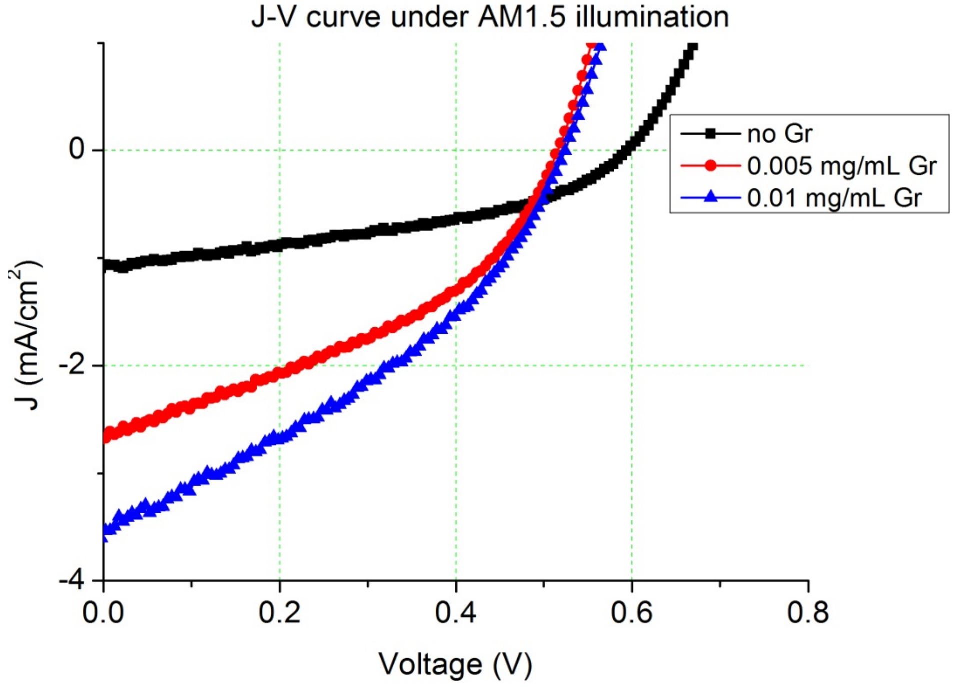
Device Characterization

- J-V characteristics





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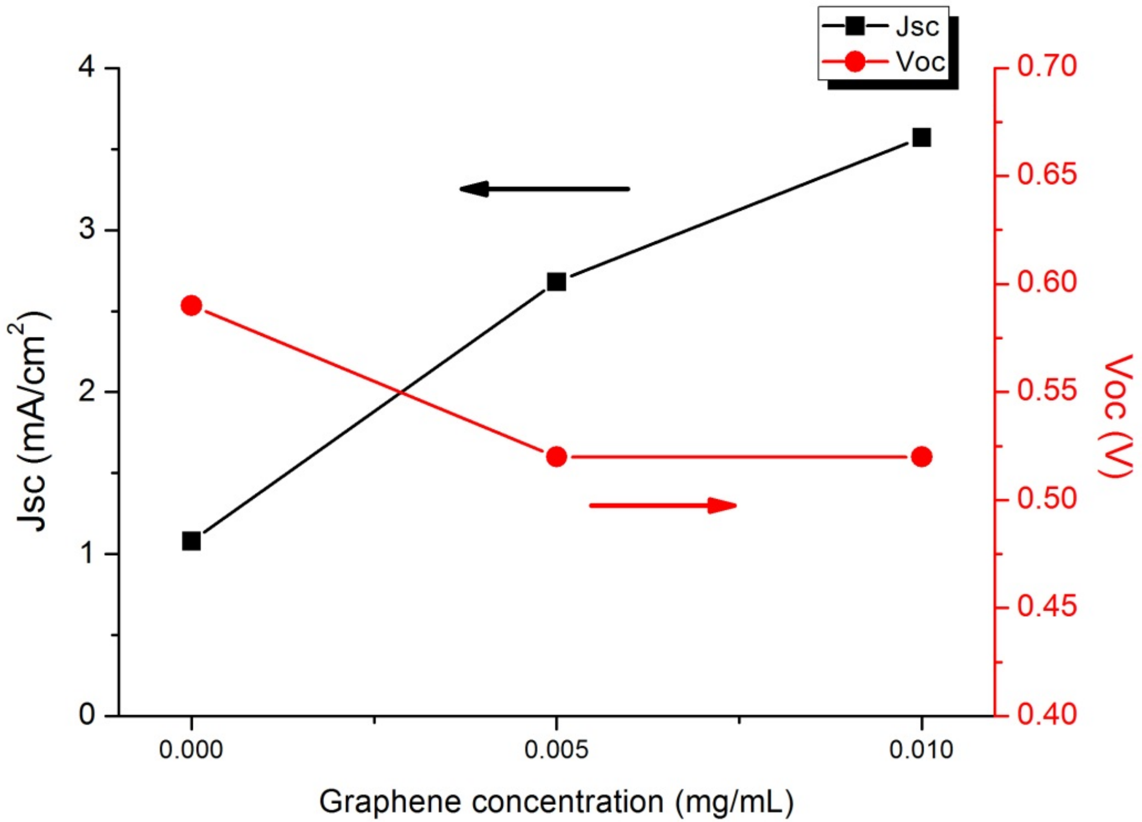
➢ Cell performance summary



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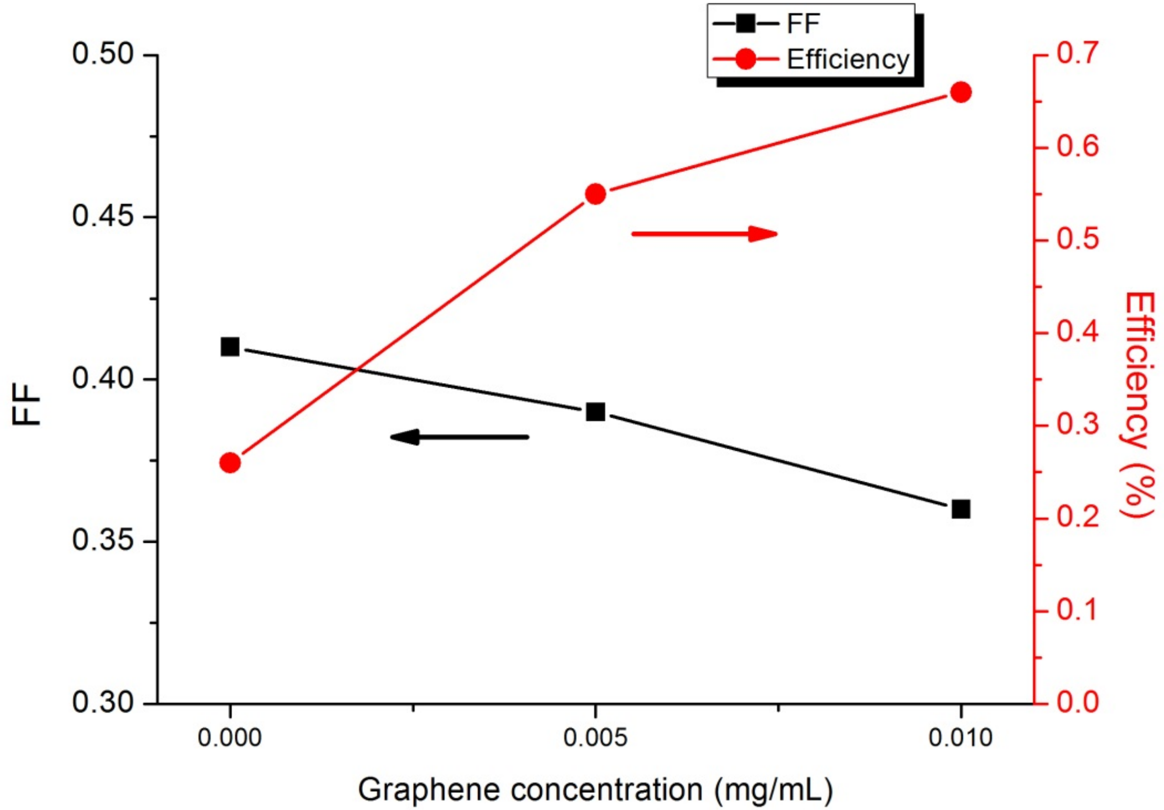
➢ Cell performance summary(cont.)



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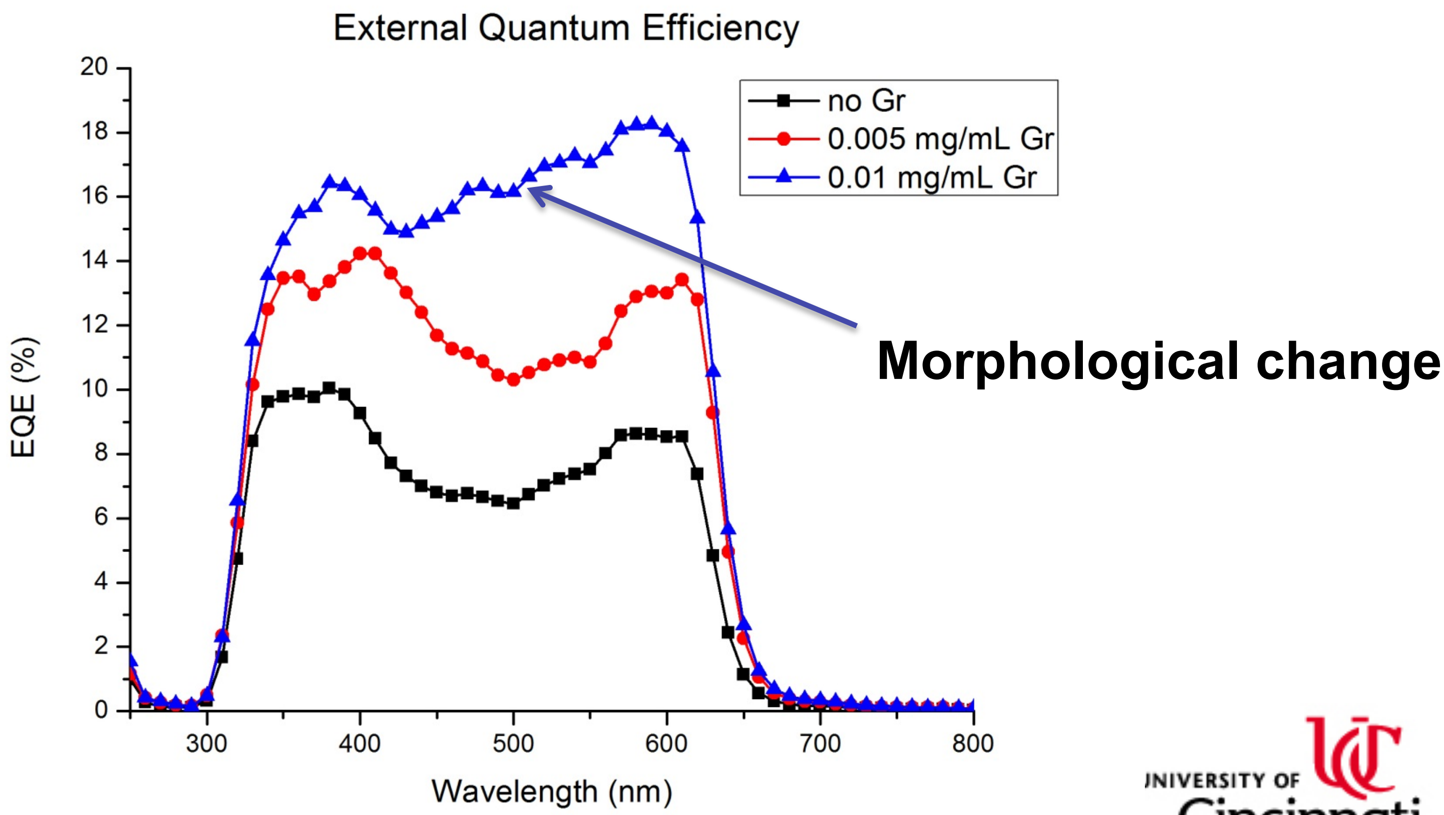
Device Characterization(cont.)

- External Quantum Efficiency(EQE)*



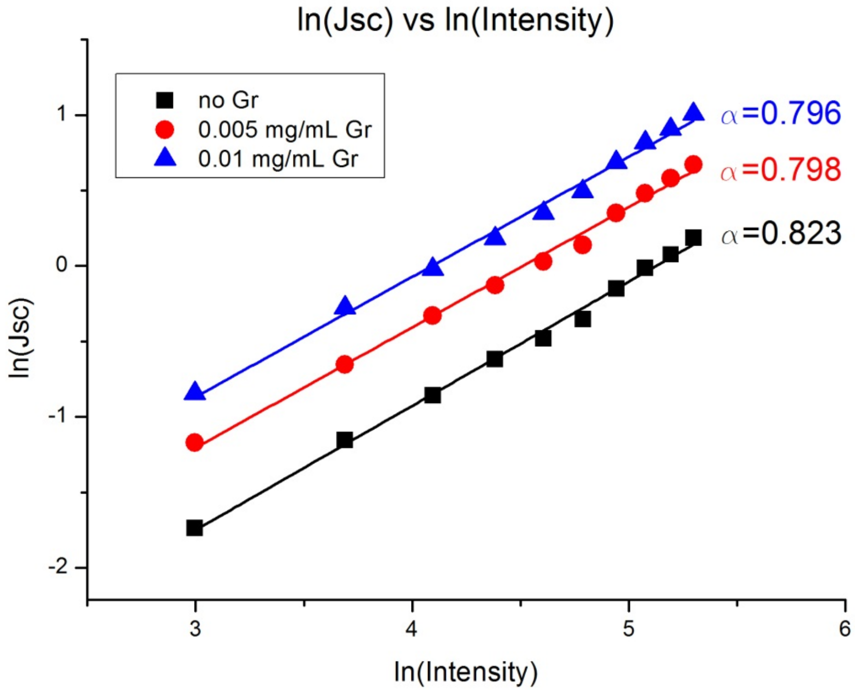
*Yu and Kuppa, App. Phy. Lett. (submitted)

Device Characterization(cont.)

- Recombination mechanism

$$J_{SC} \sim P_{In}^{\alpha}$$

α=1: monomolecular(geminate) recombination
α=0.5: bimolecular(non-geminate) recombination



greater bimolecular recombination

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* Pientka, M. *et al.*, Nanotechnology, 2004. **15**(1): p. 163-170.

Conclusions

- Adding small fraction of graphene greatly enhances charge transport and leads to much better J_{sc} and [illegible]

- Cells with more than 90% P3HT are viable

- Introduction of graphene in active layer leads to change of morphology

- Device physics change with increasing graphene fraction

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*Yu and Kuppa, App. Phy. Lett. (submitted)

Future Work

- Better dispersed and oriented graphene via morphological control
- Increase FF by reducing interfacial roughness
- Stability and device encapsulation

FY and VKK thank UC and the URC for funding and support

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Thank you!

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