NANOTECHNOLOGY FOR IMPROVING THE ORGANIC SOLAR CELL ACTIVE LAYER FOR BETTER EFFICIENCIES

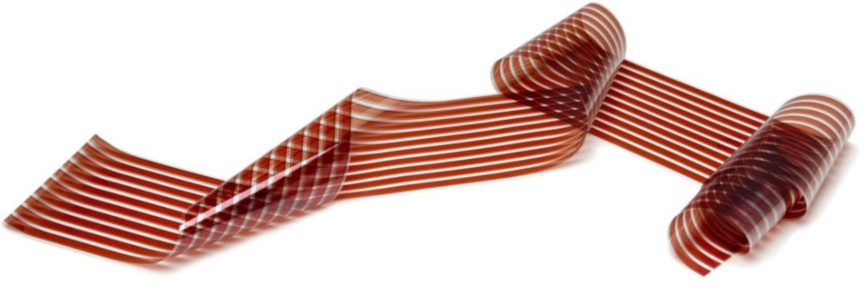
W.L. Abeygunasekara[1], B.G.L.T. Samaranayake[1], G. A. J. Amaratunga[2], V. V. Karunaratne[2]

[1]Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Peradeniya, 20400 Peradeniya.

[2]Sri Lanka Institute of Nanotechnology, Lot 14, Zone 1, Biyagama Export Processing Zone, Walgama, Malwana.

Why Organic Solar Cells?

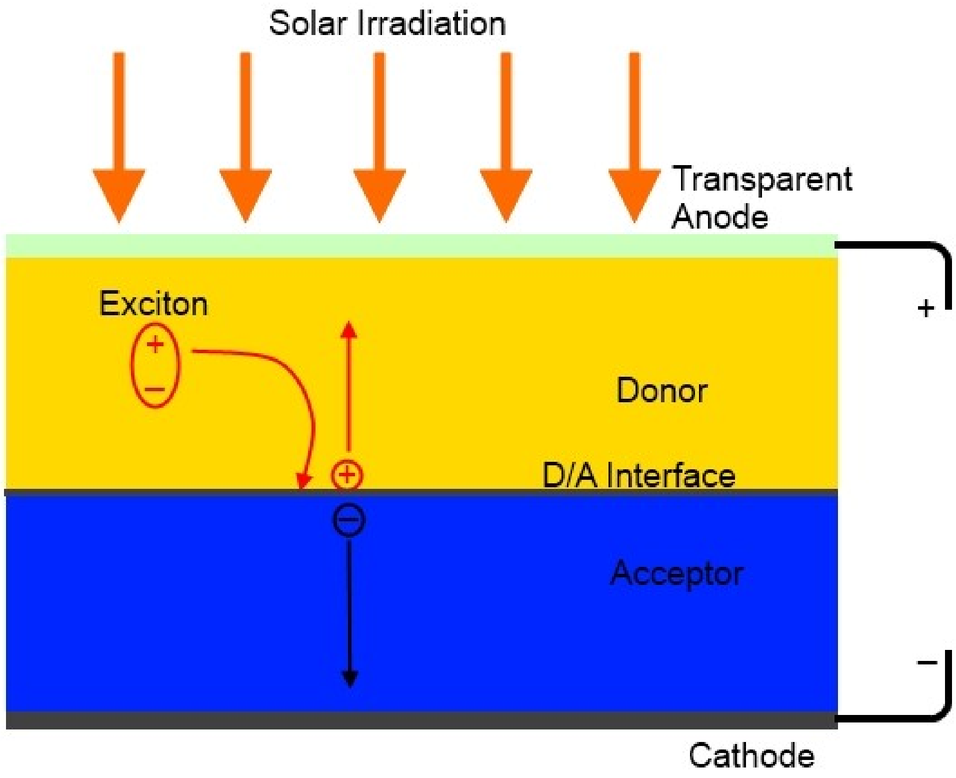
- Abundantly available raw material
- Low energy consuming fabrication techniques
- Environmental friendly
- Low cost
- Flexible
- Lightweight



Power plastic , Konarka

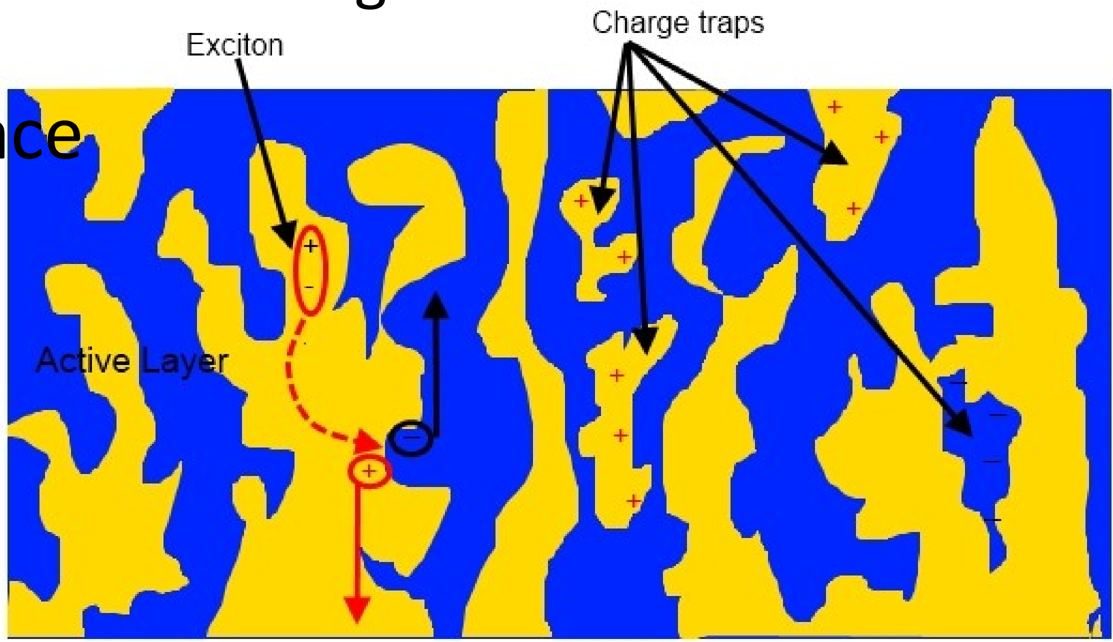
Basic Operation

- Organic semiconductors
  - Low exciton diffusion lengths (10-20 nm)
  - Poor charge mobilities
- Very thin active layers
  - about 100 nm
- High charge recombination rates
- Low device efficiencies
  - 7-8% in best performing research cells
  - Less than 5% in actual cells

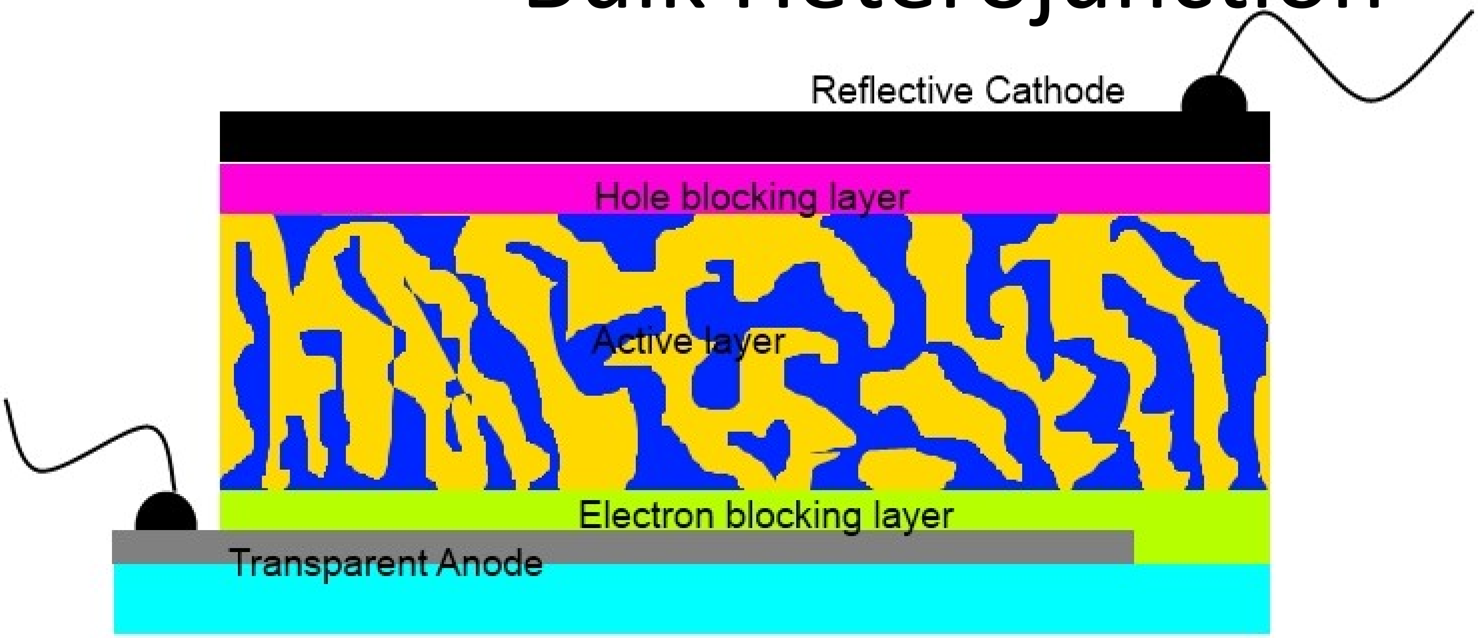


Bulk Heterojunction (BHJ)

- Intermixed donor and acceptor polymers
  - Ideally phases should be same length scale as exciton diffusion length
- Increased D/A interface
  - Better exciton dissociation
  - Increased active layer thickness
- Poor charge mobility
  - Discontinuous donor and acceptor networks
  - Poor crystallinity within individual material phases



Bulk Heterojunction



- Active layer
  - Photogeneration
- Interface layers
  - Charge blocking
  - Reduce recombinations at end electrodes
- End electrodes
  - Charge extraction

Active Layer Thickness

- Exciton diffusion length
- Charge carrier mobilites

} Decrease thickness

- Optimal absorption of Solar energy

} Increase thickness

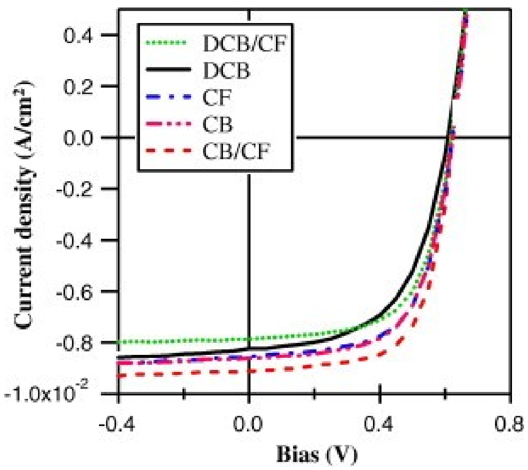
- Optimal solar cell performance

→ Compromise between optimal absorption and optimal charge transport

Active Layer Morphology

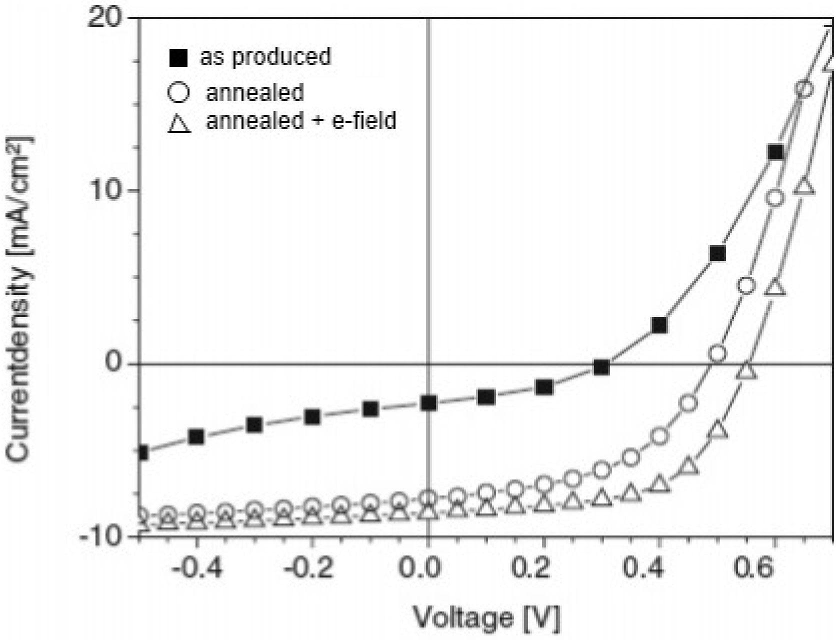
- Ideal BHJ
  - Continuous percolation pathways for both donor and acceptor polymers
  - Donor and acceptor phases with same size scale as exciton diffusion length
- BHJ morphology would depend on
  - Polymer blend
  - Solvent
  - Substrate
  - Fabrication technique/conditions
  - Post fabrication processing
  - Additives
  - Other external influences

Improving the BHJ



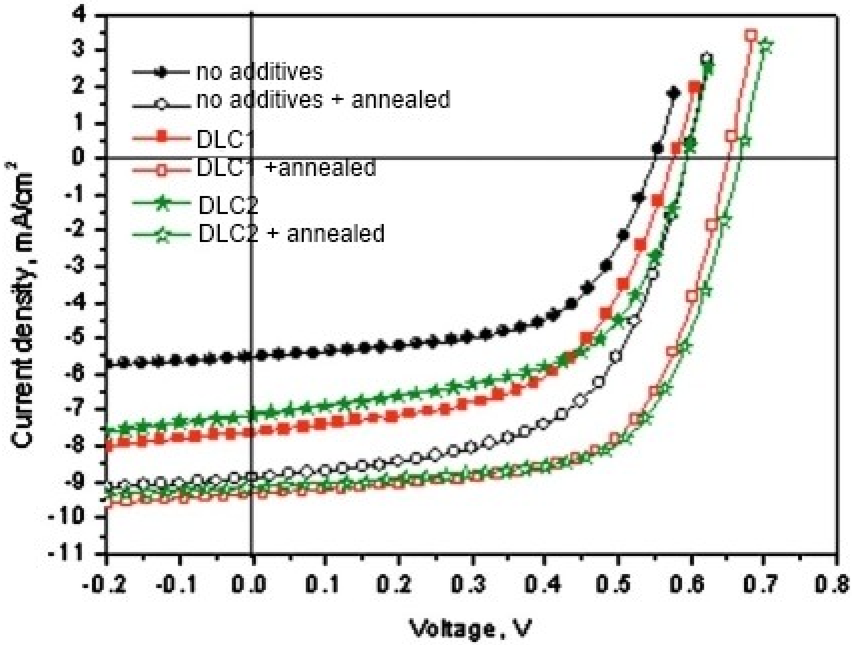
Effect of solvent used

Bagui & Iyer,



Post fabrication annealing

Ebadian et al,



Liquid crystal additive

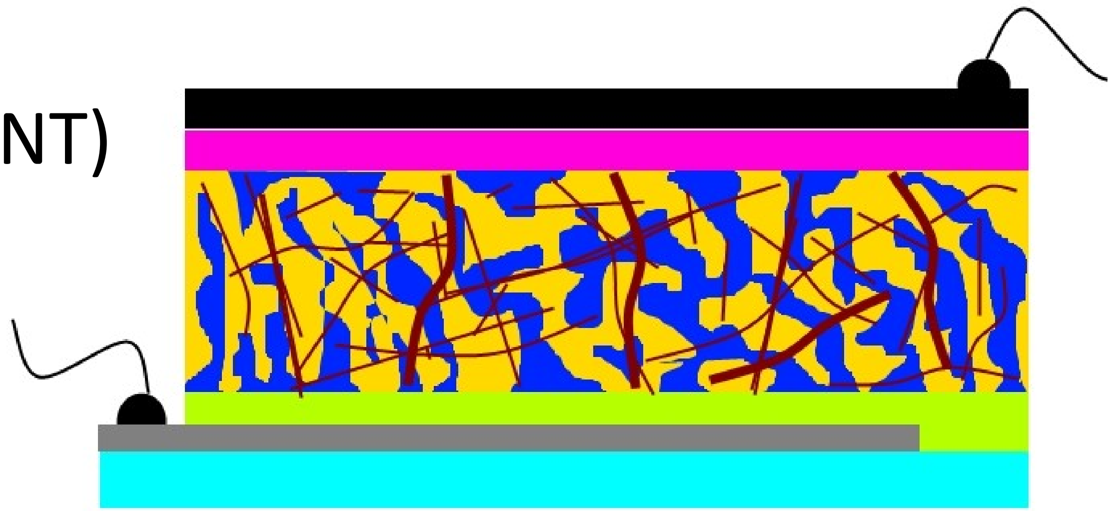
Jeong et al,

Improving the BHJ

- The effect of solvent
  - Slow drying of active layer create better morphology in spin cast BHJs
  - Solvents with higher evaporation temperatures are better
- Heat treatment
  - Post fabrication annealing of the active layer
  - In the case of semi crystalline polymers better morphology and performance after annealing
  - No improvements for amorphous materials
- Liquid crystals/ e-field treatment
  - Better active layer morphology

Active Layer Charge Mobility

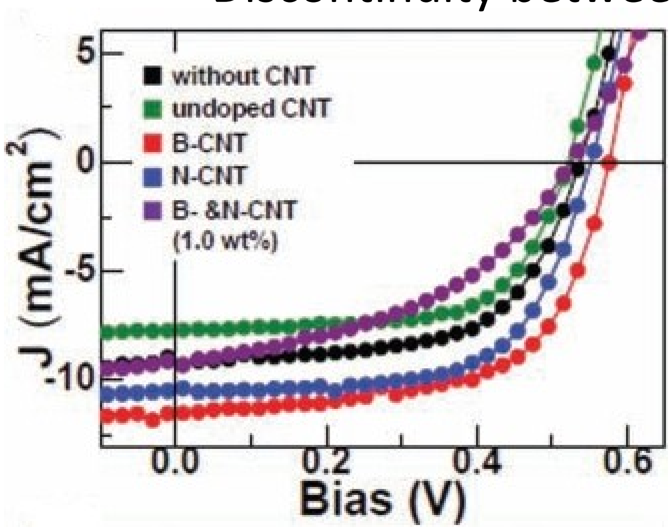
- Incorporate 1D nano conductors within the active layer
- Carbon nanotubes (CNT)
  - Carrier mobility
  - Mechanical flexibility
  - Compatibility with solution processing

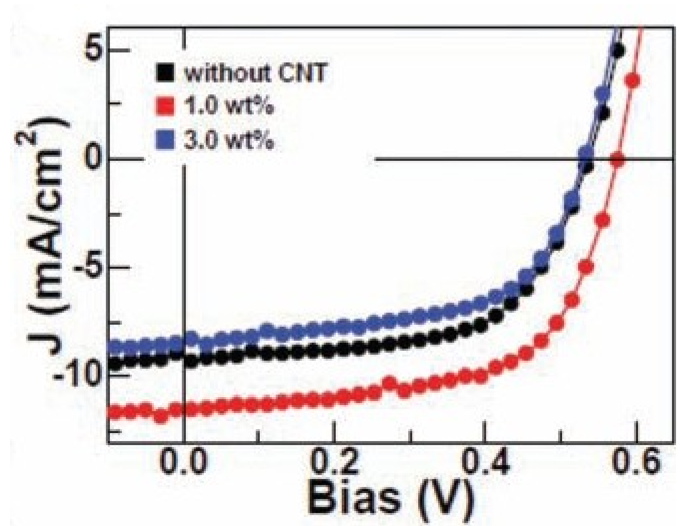


- Random dispersion within active layer
  - SWNT/MWNT
  - Functionalized/pristine
    - Electron / hole selectivity
    - Uniform dispersion

Random dispersion of CNT in active layer

- Only a small amount of CNT possible (less than 1%)
- Negative effects
  - Charge recombination (due to metallic nanotubes)
  - Shunting of the device (due to bundles of tubes)
  - Non optimal CNT alignment
  - Discontinuity between CNT network and end electrodes



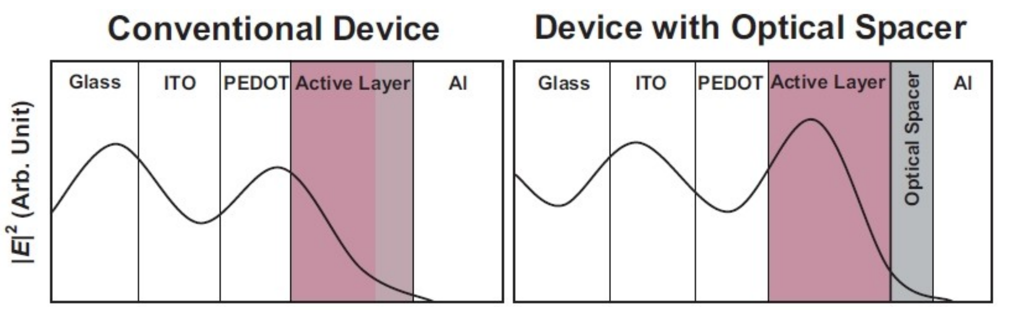


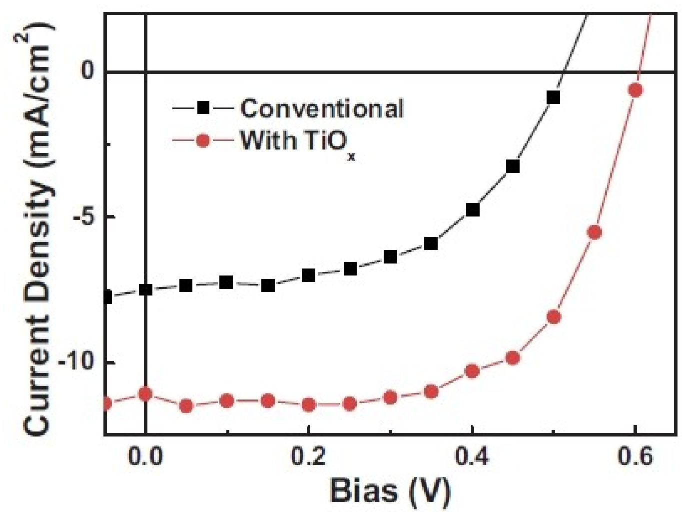
Lee et al,

Optical Enhancers

Increase the effective optical thickness of the active layer while keeping the electrical thickness low

- TiO_2 optical spacer
  - Transparent oxide layer
  - Keep the active layer away from low light intensity area near back electrode
  - Electron extraction/ hole blocking layer
  - Increase series resistance

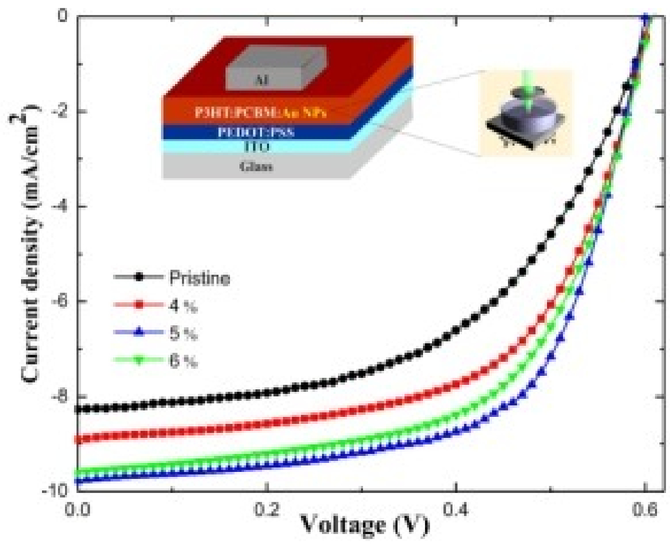




Kim et al,

Optical Enhancers

- Nanoparticles as light scatterers
  - Random dispersion within active layer
  - Increase the active layer absorbance
    - Trap the light waves within active layer
    - Size dependent performance
  - Undesirable effects
    - Charge recombination sites
    - Shunting of the device



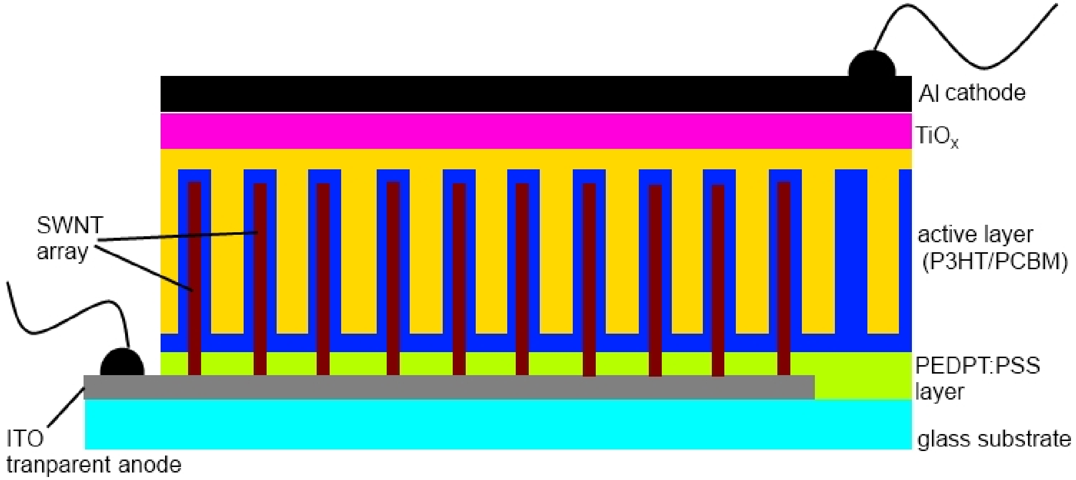
Spyropolous et al,

Future Directives

Interpenetrating electrode array

- Directional alignment of CNTs
- Better connectivity to the end electrode
- Minimal shunting

Orderly bulk heterojunction



- Optimal morphology
- No charge traps

References

[1] J. Nakamura, K. Murata and K. Takahashi, "Relation between carrier mobility and cell performance in bulk heterojunction solar cells consisting of soluble polythiophene and fullerene derivatives", *Applied Physics Letters*, vol. 87, 2005, pp. 132105-3.

[2] S. Cook, R. Katoh and A. Furube, "Ultrafast Studies of Charge Generation in PCBM:P3HT Blend Films following Excitation of the Fullerene PCBM", *The Journal of Physical Chemistry C*, vol. 113, 2009, pp. 2547-2552.

[3] S. Barrau, V. Andersson, F. Zhang, S. Masich, J. Bijleveld, M.R. Andersson and O. InganaÌ?s, "Nanomorphology of Bulk Heterojunction Organic Solar Cells in 2D and 3D Correlated to Photovoltaic Performance", M*acromolecules,* vol. 42, 2009, pp. 4646-4650.

[4] Y.S. Kim, Y. Lee, K. Kim, E. Seo, E. Lee, W. Lee, S. Han and S. Lee, "Effect of solvents on the performance and morphology of polymer photovoltaic devices", C*urrent Applied Physics,* vol. 10, 2010, pp. 985-989.

[5] J. Sakai, T. Taima, T. Yamanari and K. Saito, "Annealing effect in the sexithiophene:C70 small molecule bulk heterojunction organic photovoltaic cells", S*olar Energy Materials and Solar Cells,* vol. 93, 2009, pp. 1149-1153.

[6] S. Ebadian, B. Gholamkhass, S. Shambayati, S. Holdcroft and P. Servati, "Effects of annealing and degradation on regioregular polythiophene-based bulk heterojunction organic photovoltaic devices", S*olar Energy Materials and Solar Cells,* vol. 94, 2010, pp. 2258-2264.

[7] S. Jeong, Y. Kwon, B. Choi, H. Ade and S. Han, "Improved efficiency of bulk heterojunction poly(3-hexylthiophene):[6,6]-phenyl-C[sub 61]-butyric acid methyl ester photovoltaic devices using discotic liquid crystal additives", A*pplied Physics Letters,* vol. 96, 2010, pp. 183305-3.

[8] A. Bagui and S.S.K. Iyer, "Effect of Solvent Annealing in the Presence of Electric Field on P3HT:PCBM Films Used in Organic Solar Cells", E*lectron Devices, IEEE Transactions on,* vol. 58, 2011, pp. 4061-4066.

[9] C. Nam, Q. Wu, D. Su, C. Chiu, N.J. Tremblay, C. Nuckolls and C.T. Black, "Nanostructured electrodes for organic bulk heterojunction solar cells: Model study using carbon nanotube dispersed polythiophene-fullerene blend devices", J*ournal of Applied Physics,* vol. 110, 2011, pp. 064307-7.

[10] E. Kymakis and G.A.J. Amaratunga, "Photovoltaic cells based on dye-sensitisation of single-wall carbon nanotubes in a polymer matrix", S*olar Energy Materials and Solar Cells,* vol. 80, 2003, pp. 465-472.

[11] A.J. Miller, R.A. Hatton and R.S.P. Silva, "Water-soluble multiwall-carbon-nanotube-polythiophene composite for bilayer photovoltaics", A*pplied Physics Letters,* vol. 89, 2006, pp. 123115-3.

[12] M. Lee, S. Park, H. Lee, H. Kim, S. Yoo and O. Kim, "Selective Electron- or Hole-Transport Enhancement in Bulk-Heterojunction Organic Solar Cells with N- or B-Doped Carbon Nanotubes", A*dvanced Materials,* vol. 23, 2011, pp. 629-633.

[13] T. Mallajosyula, K.S. Iyer and B. Mazhari, "Increasing the efficiency of charge extraction limited poly-(3-hexylthiophene):[6,6] phenyl C61 butyric acid methyl ester solar cells using single walled carbon nanotubes with metallic characteristics", J*ournal of Applied Physics,* vol. 109, 2011, pp. 124908-10.

[14] H. Borchert, F. Witt, A. Chanaewa, F. Werner, J. Dorn, T. Dufaux, M. Kruszynska, A. Jandke, M. HÃ¶ltig, T. Alfere, J. BÃ¶ttcher, C. Gimmler and C. Klinke, "Vertically Oriented Carbon Nanostructures and Their Application Potential for Polymer-Based Solar Cells", The J*ournal of Physical Chemistry C, vo*l. 116, 2011, pp. 412-419.

[15] R. Radbeh, E. Parbaile, M. Chakaroun, B. Ratier, M. Aldissi and A. Moliton, "Enhanced efficiency of polymeric solar cells via alignment of carbon nanotubes", Polym*er International, vo*l. 59, 2010, pp. 1514-1519.

[16] G.D. Spyropoulos, M.M. Stylianakis, E. Stratakis and E. Kymakis, "Organic bulk heterojunction photovoltaic devices with surfactant-free Au nanoparticles embedded in the active layer", Appli*ed Physics Letters, vo*l. 100, 2012, pp. 213904-5.

[17] M. Kang, J. Park, H. Ahn, T. Xu and L.J. Guo, "Toward Low-Cost, High-Efficiency, and Scalable Organic Solar Cells with Transparent Metal Electrode and Improved Domain Morphology", Selec*ted Topics in Quantum Electronics, IEEE Journal of, vo*l. 16, 2011, pp. 1807-1820.