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Nanostructures Improve Organic Photovoltaic Cells

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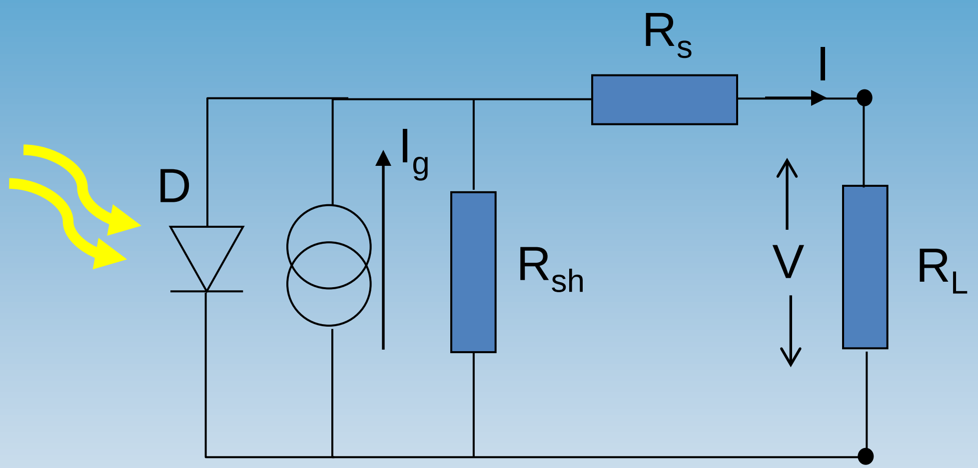
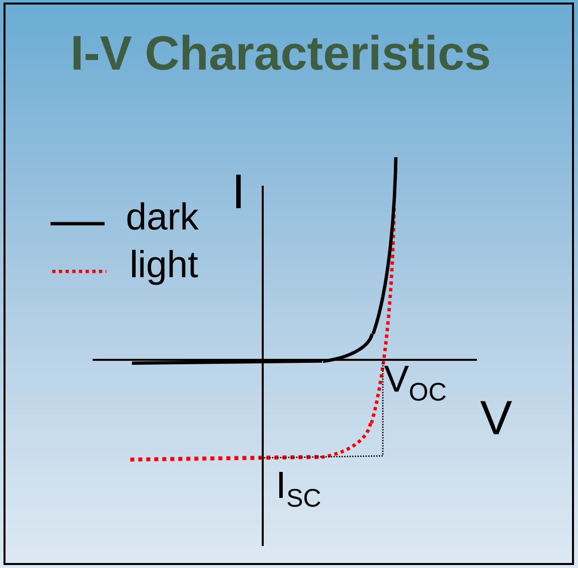
Green Photonics, Cardiff 19 Oct 2010

Equivalent Circuit of a Photovoltaic Device





D = Junction

I_g = Separation of photogenerated charges

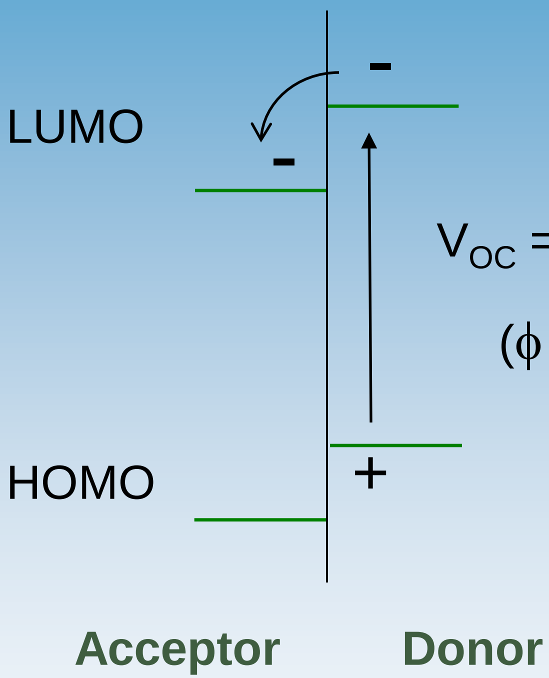
R_{sh}= Recombination

R_s = Series Resistance

R_L = Load Resistance

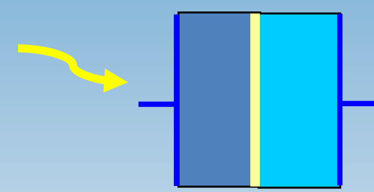
Organic Photovoltaics

In Organic materials excitons only diffuse ~20 nm

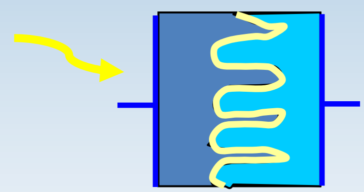


$$V_{OC} = E^{A}_{LUMO} - E^{D}_{HOMO} - \phi$$

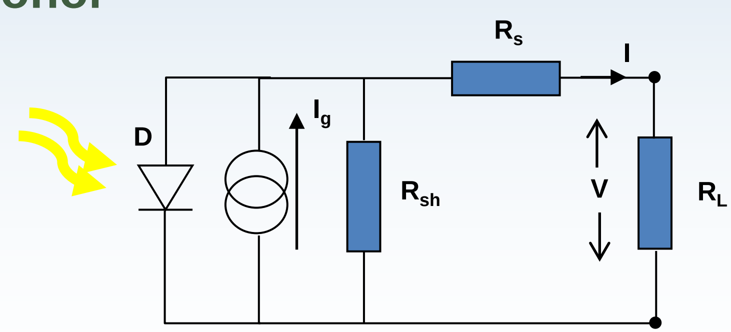
$(\phi \sim 0.5\ V)$



Planar Junction
– Small generation volume

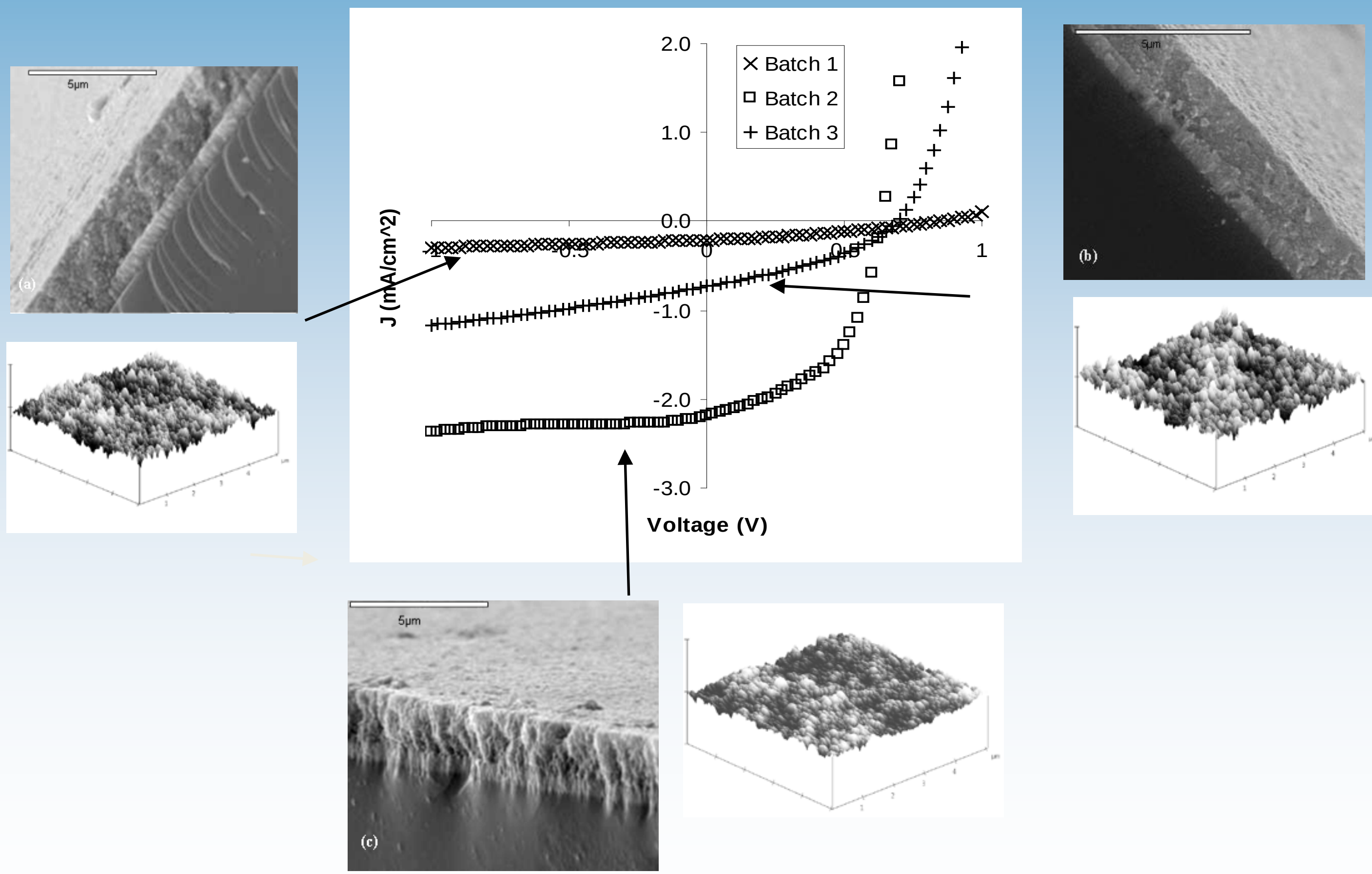


Interpenetrating junction
- High generation volume
- Must ensure continuity to electrodes.



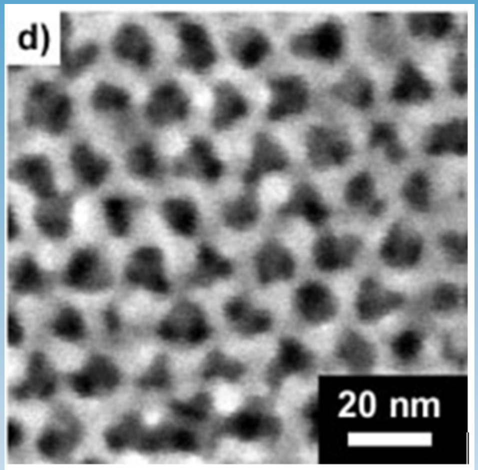
Oxide/Polymer Heterojunction Photovoltaics

nc-TiO_2/Ru-dye/P3HT



Al-Dmour et al, 2007, J. Phys D: Appl. Phys., **40** 5034-5038

Nanostructuring Titania by Directed Assembly and Nanoimprinting

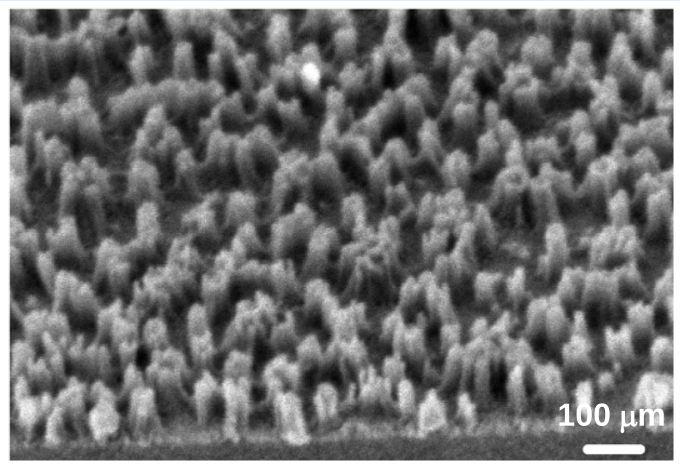


Coakley et al, Adv Funct. Mater **13**, 301 (2003)

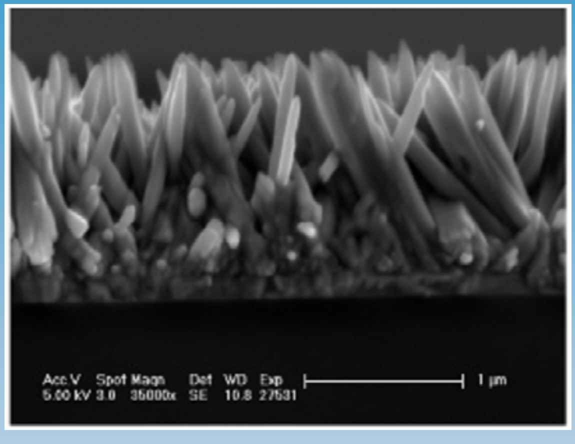
- Dip coating in a solution of titania sol-gel and a structure directing block co-polymer.
- Pores too small P3HT unable to π-stack so mobility low.

Williams et al Chem Mater **20,** 5229 (2008)

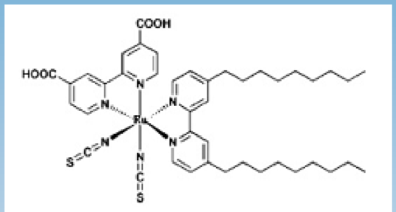
Anatase titania nanostructure replicated using PRINT from the silicon master.

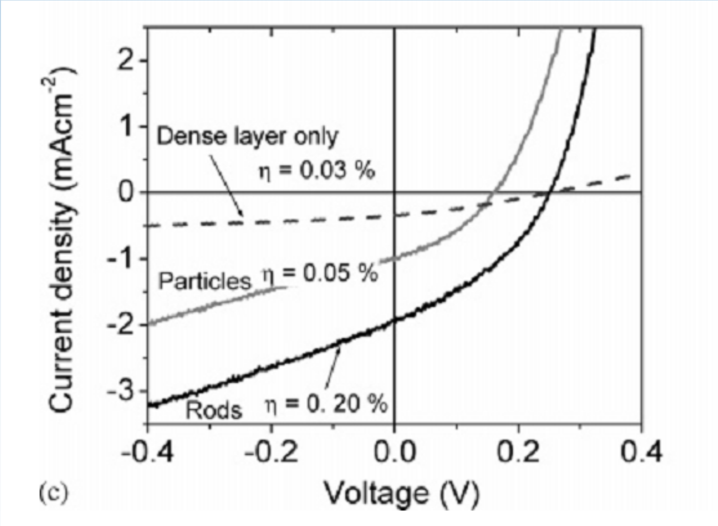


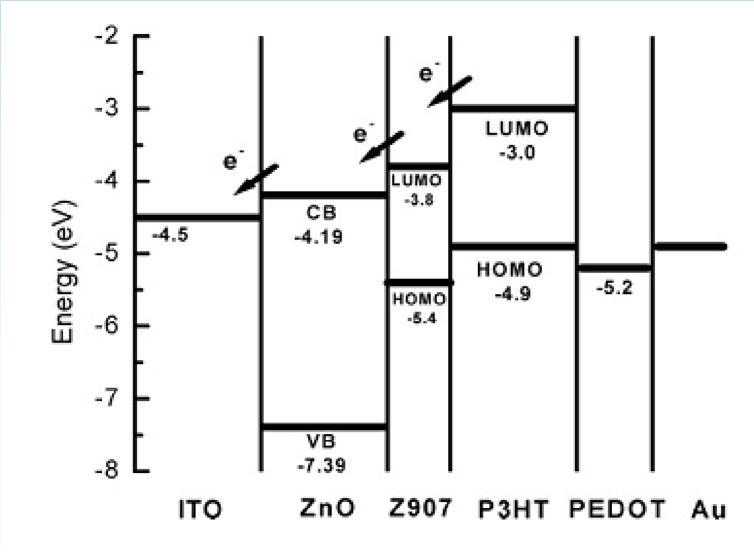
ZnO Nanorods



Grown on a dense ZnO layer by heating an aqueous solution of $ZnSO_4.7H_2O$ and NH_4Cl at 60ºCfor 3-6 hours.

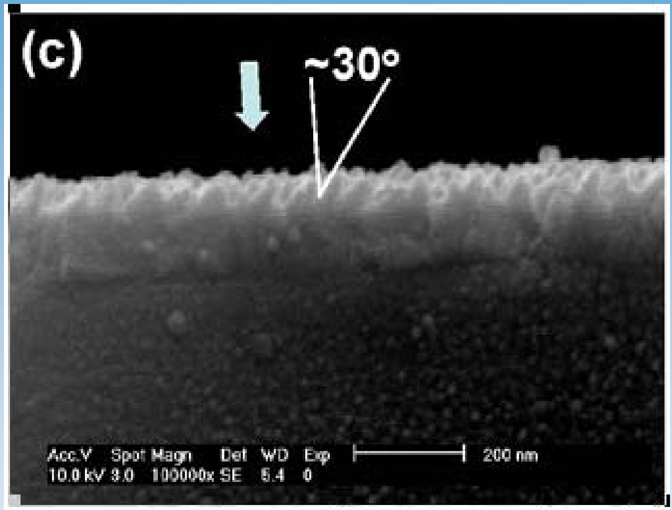




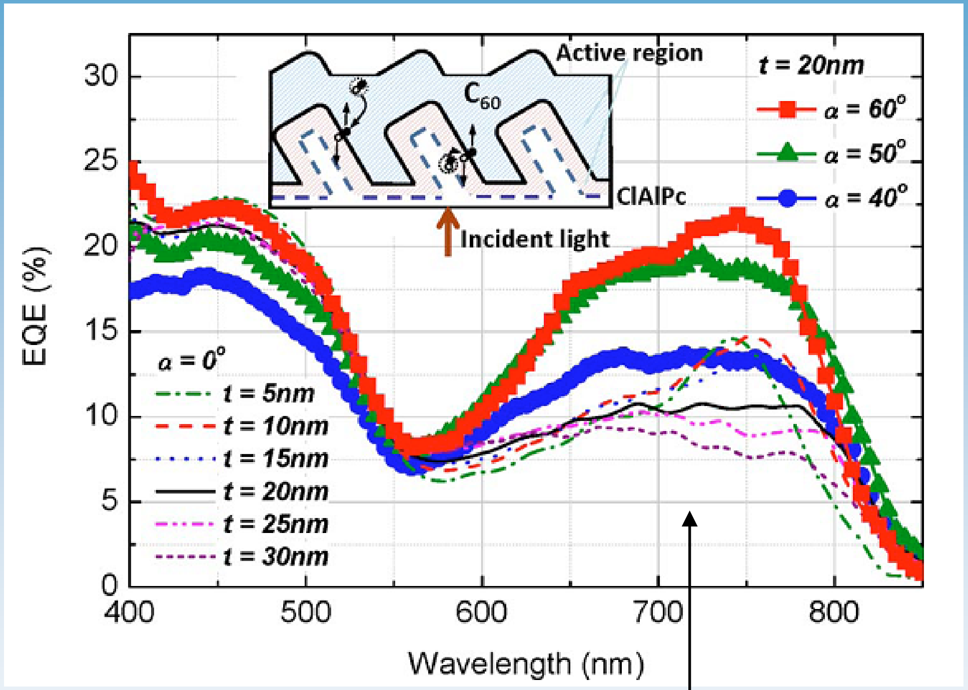


Ravirajan et al J. Phys. Chem. B **110**, 7635 (2006)

Nanostructuring by Oblique Evaporation



SEM cross-section of evaporated ClAlPc

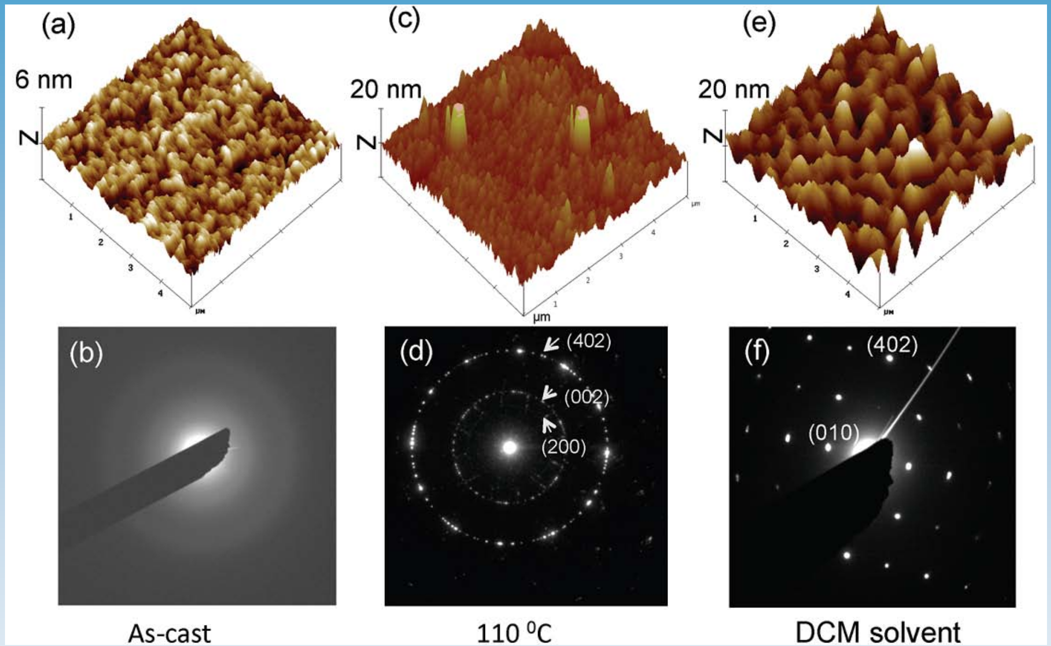


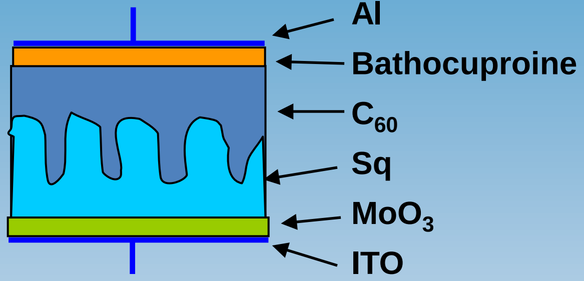
Enhance EQE in region of interest

$\eta_P \sim 2.6\%$

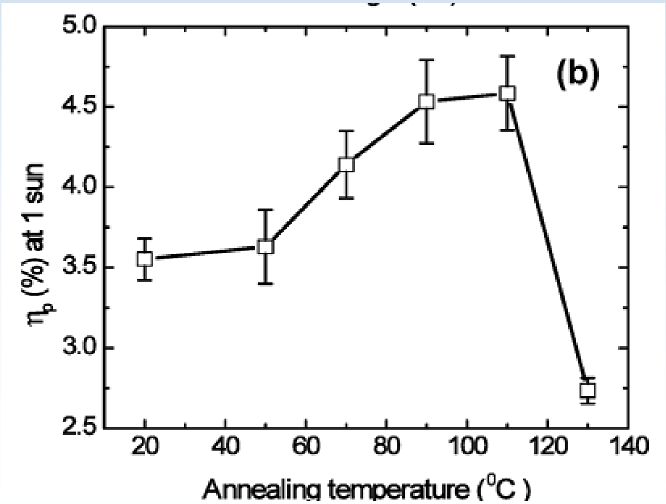
N Li and S R Forrest, APL **95** 123309 (2009)

Nanostructuring of Squaraine by Thermal and Solvent Annealing



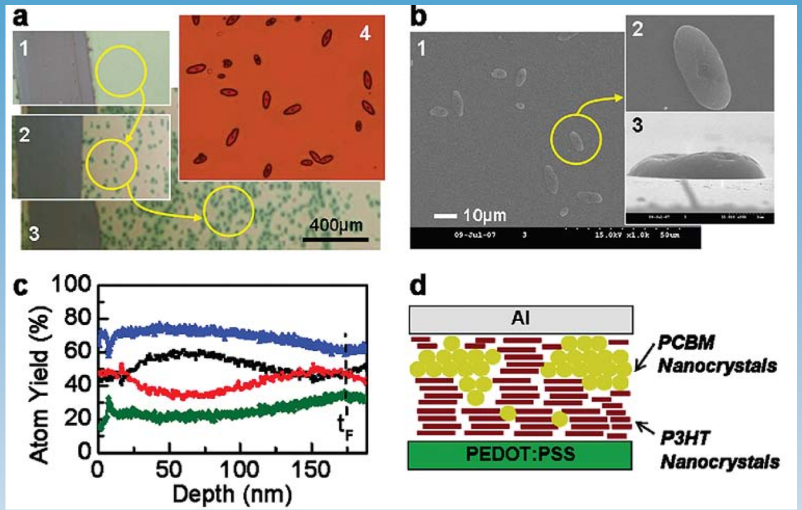


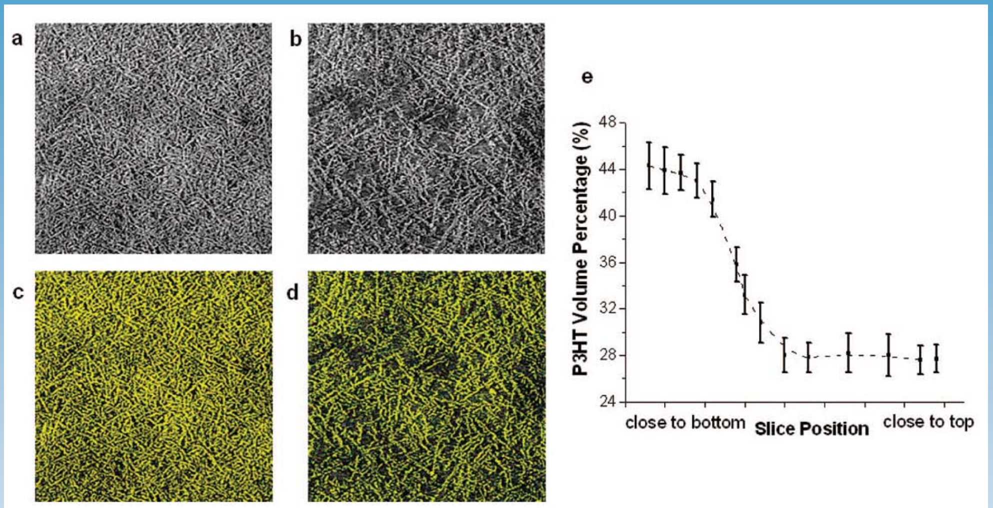
- Thermal annealing improves crystallinity and surface roughness
- η_P increases until 'holes' down to the MoO_3 layer appear above110^{o}C
- Solvent annealing increases exciton diffusion length by a factor 3 but η_P = 1.5 to 2.1% though



Wei et al, Nano Lett **10**, 3555 (2010)

Controlled Phase Separation by Thermal Annealing





'Vertical' phase separation of PCBM and P3HT blend

$\eta_P \sim 4.4\%$

Kim et al, ACS Nano **3**¸ 2557 (2009)

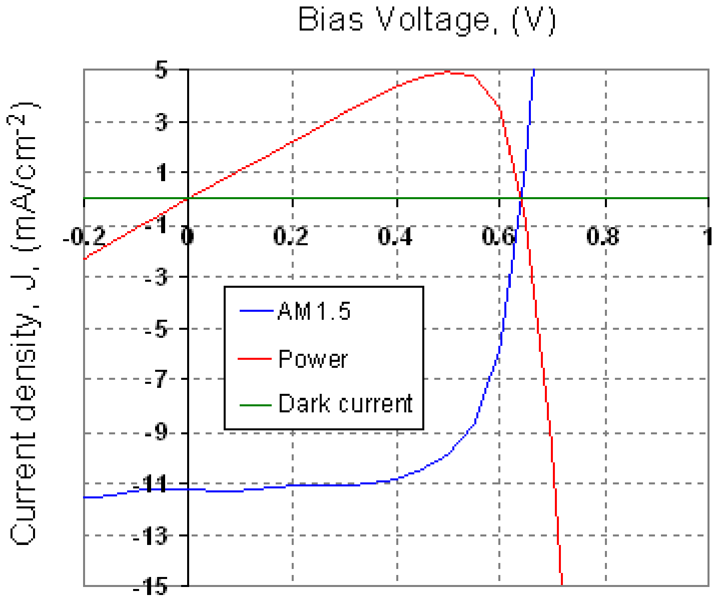
Confirmed by TEM tomography

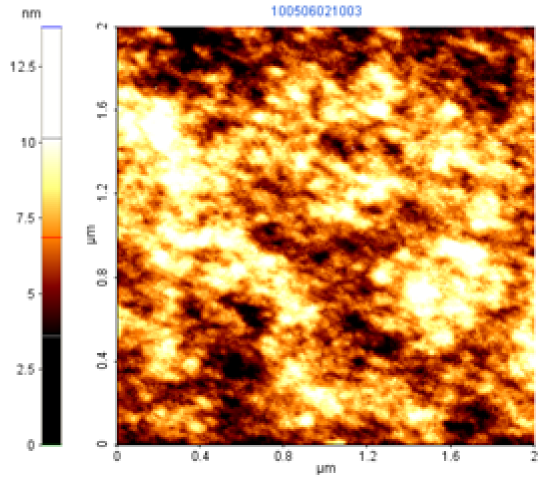
$\eta_P \sim 3.8\%$

Bavel et al, Nano Letters **9,** 507 (2009)

The University of Manchester

OPV Material evaluation: P3HT





Ra = 1.47nm, Rz= 7.05 nm

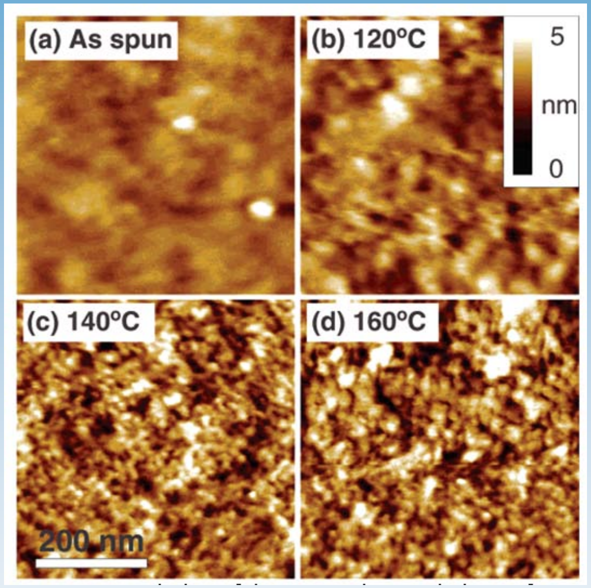
PEDOT, 2krpm for 30 secs, baked for 15 mins @ 120°C, Blend concentration (P3HT:PCBM) = 1:0.7, Spin speed = 1500rpm. LiF (3nm) and Al (80nm) contacts added. Annealing temperature (after contact evaporation) = 140 ° C. Measured performance at 1 Sun AM1.5

	V_{OC}	J_{SC} (mA/cm^{-2})	FF (%)	PCE (%)
P3HT:PC[C61]BM (1:0.7) (6 devices)	0.66	-11.27	65	4.75

Research report

Slide courtesy of Dr Jeff Kettle

Controlled Phase Separation by Thermal Annealing



McNeill et al, J Phys Chem C **111**, 19153 (2007)

Evolution of the nanoscale morphology of a spin-coated PFB:F8BT blend by thermal annealing.

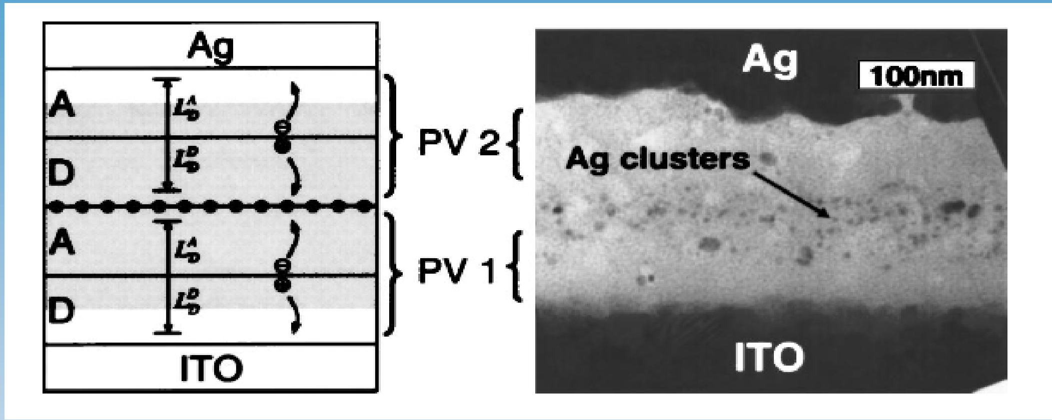
Geminate recombination believed to result in low efficiency.

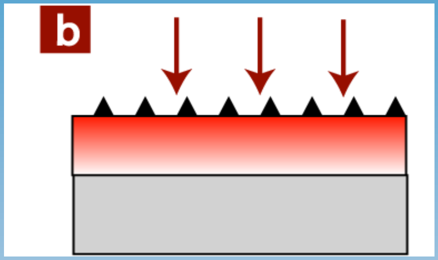
$\eta_P < 4\%$

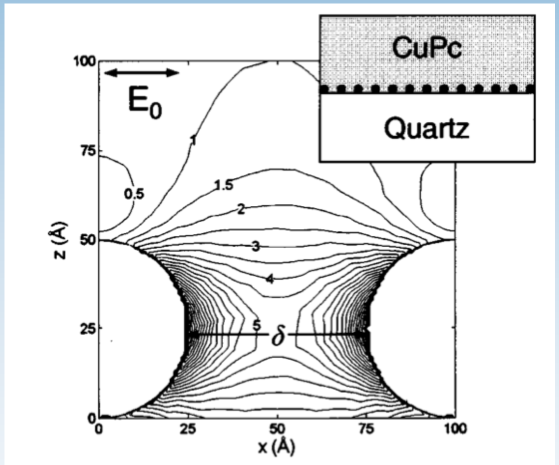
Plasmonic Field Enhancement

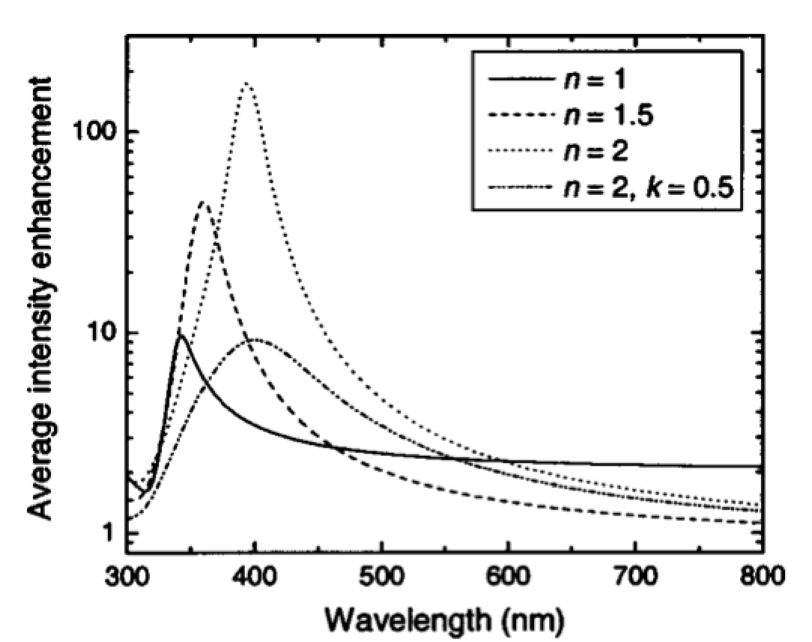
Slide courtesy of Dr Ned Ekins-Daukes, Imperial College

CuPc Organic Tandem PV device





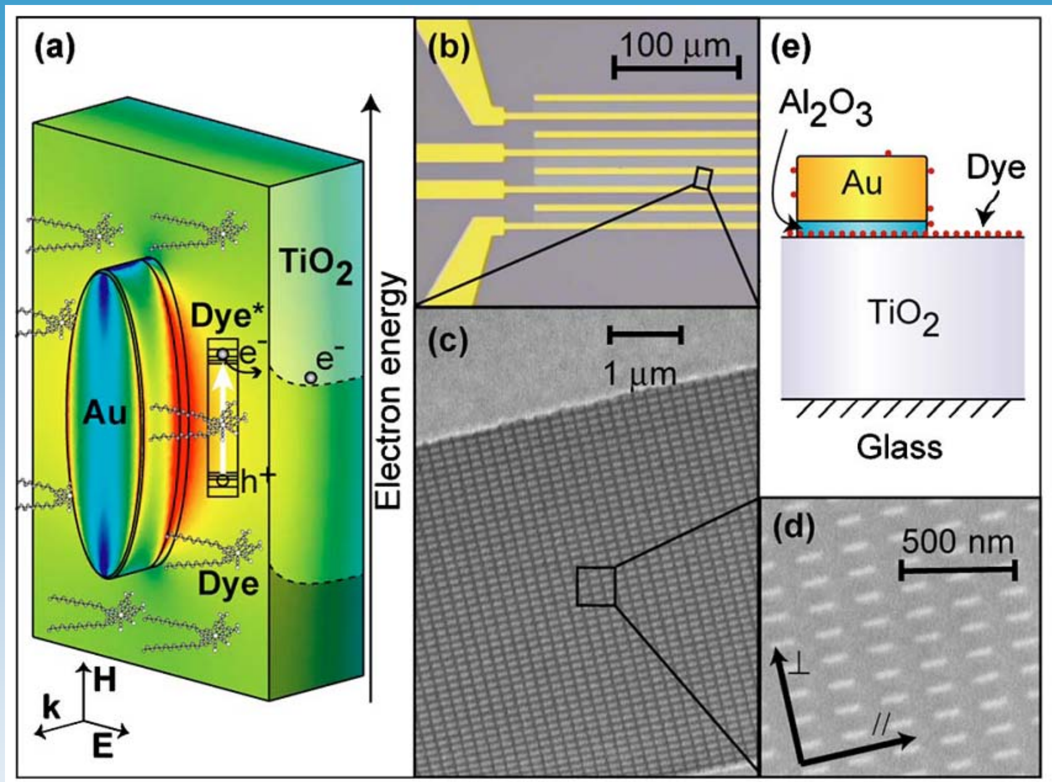




Simulation confirms that extra efficiency over a standard tandem cell is due to increased absorption arising from the surface plasmons excited in the silver particles

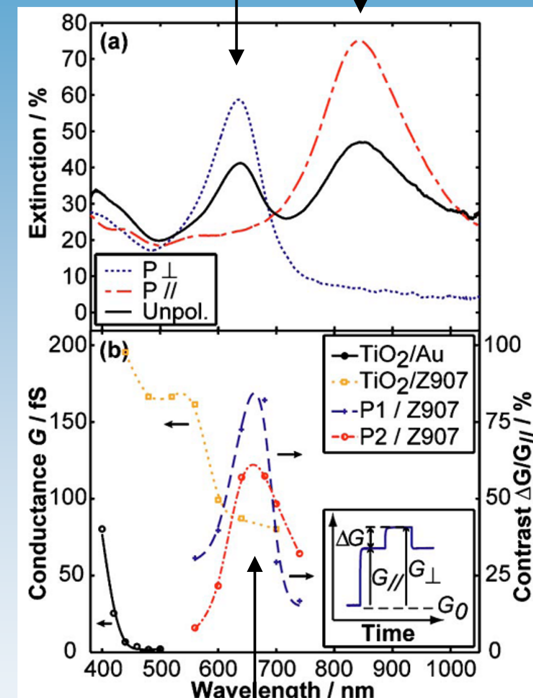
Rand et al, J. of Appl Phys **96,**7519 (2004)

Plasmonic Field Enhancement



Evanescent field of Localised Surface Plasmon Resonance (LSPR) amplifies excitations of the dye

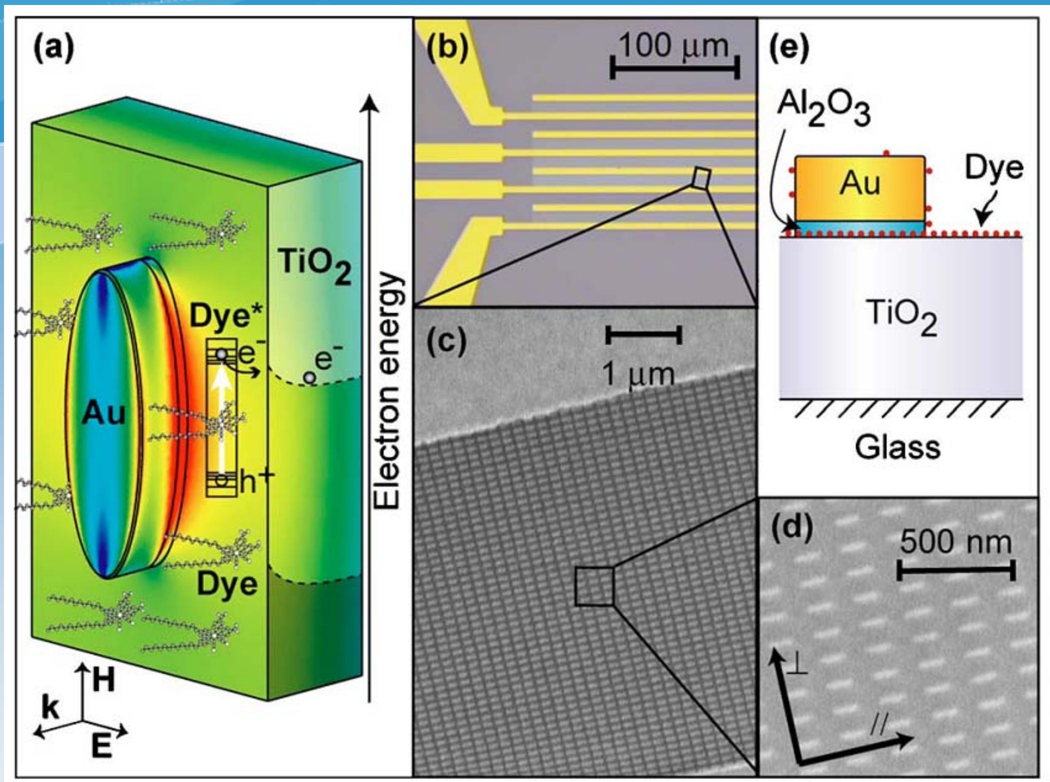
Spectral differences arise from elliptical gold dots



Differences in photoconduction arising from orientation of gold dots relative to polarization of incident light

Hägglund et al, APL **92**, 013113 (2008)

Plasmonic Field Enhancement

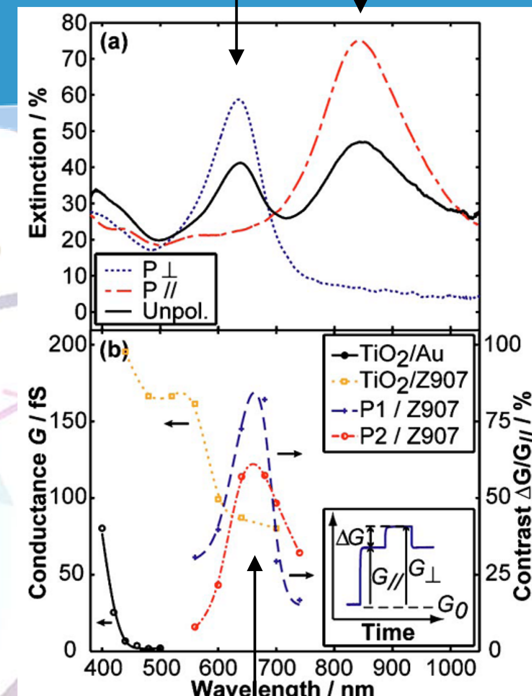


Evanescent field of Localised Surface Plasmon Resonance (LSPR) amplifies excitations of the dye

Problem – Exciton quenching near metal surface

– encapsulate in thin insulating layer!

Spectral differences arise from elliptical gold dots



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Conclusions

- **Major efforts worldwide to improve PV efficiency by nanostructuring**
- **Polymer/PCBM blends making excellent progress**
- **Nano-imprinting of structures showing promise**
- **Plasmonics offers major step forward if exciton quenching can be overcome**

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Acknowledgements

HEFCW

EPSRC

Welsh Assembly A4B Programme