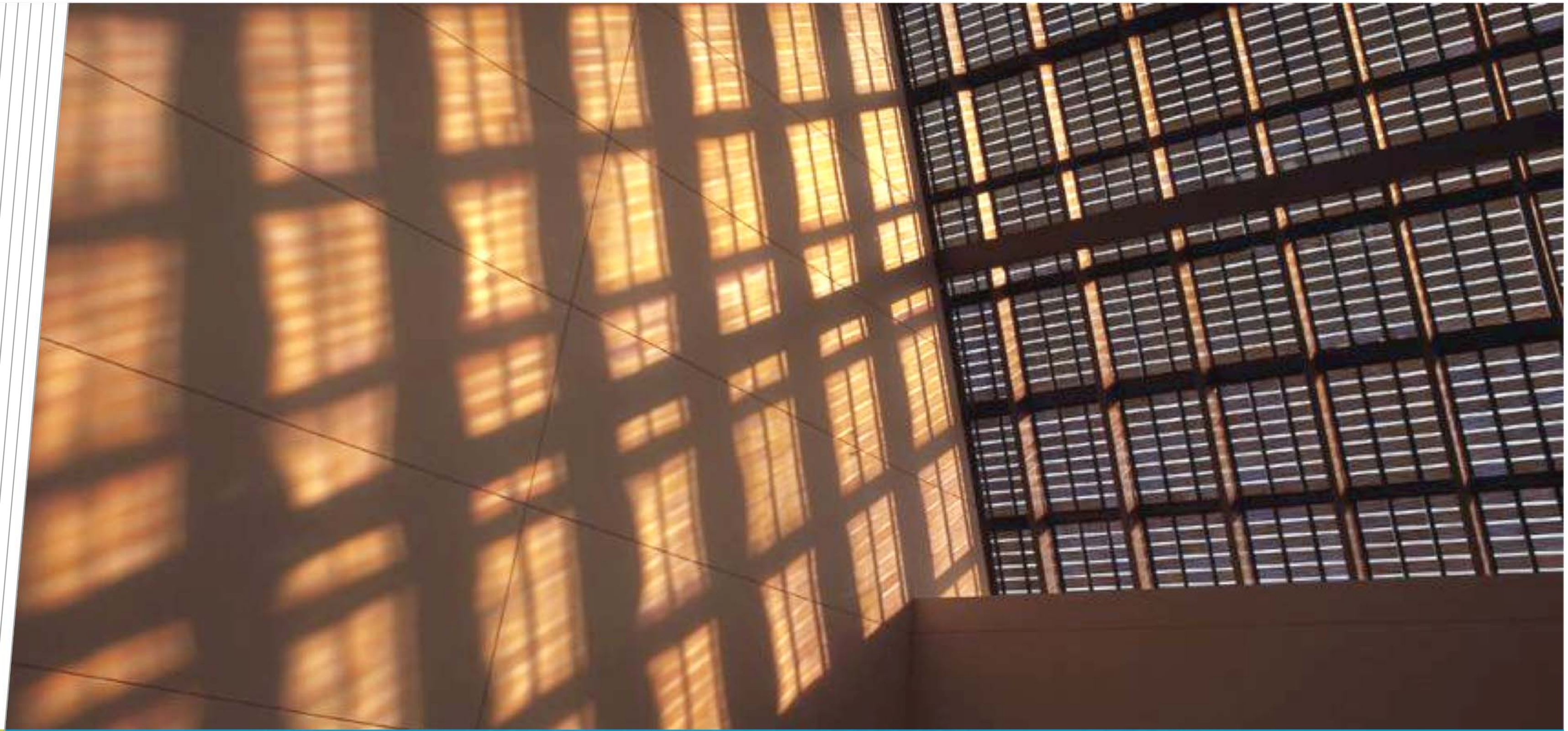


Introduction to Organic Solar Cells

Dr Chris Fell

Solar Group Leader

CSIRO Energy Technology, Newcastle, Australia

CSIRO

Organic semiconductors

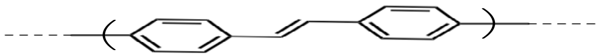
- Conductivity in polyacetylene – 1970s – Nobel Prize

Alan J. Heeger

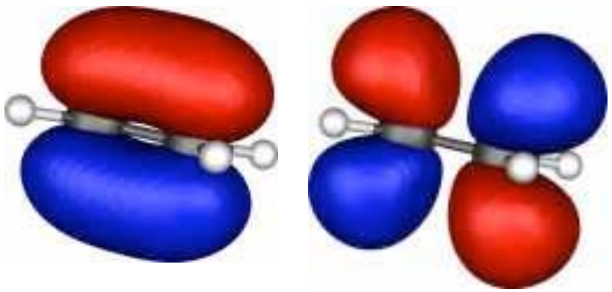
Alan G. MacDiarmid

Hideki Shirakawa

- Interacting P_z orbitals create chain of delocalised electron density



poly(phenylene vinylene) (PPV)



Why organic materials for solar cells ?

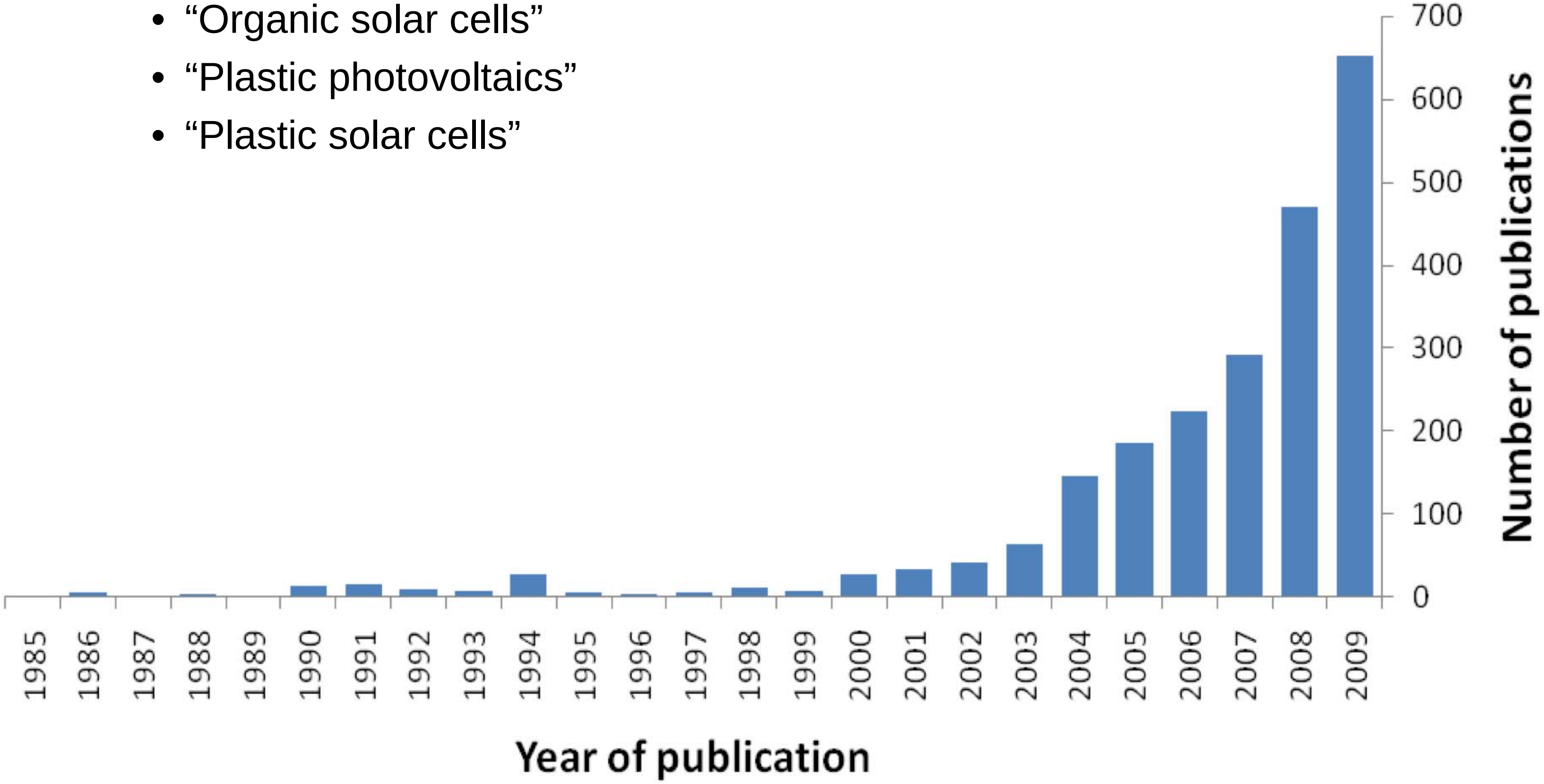
Room temperature

Ambient pressure

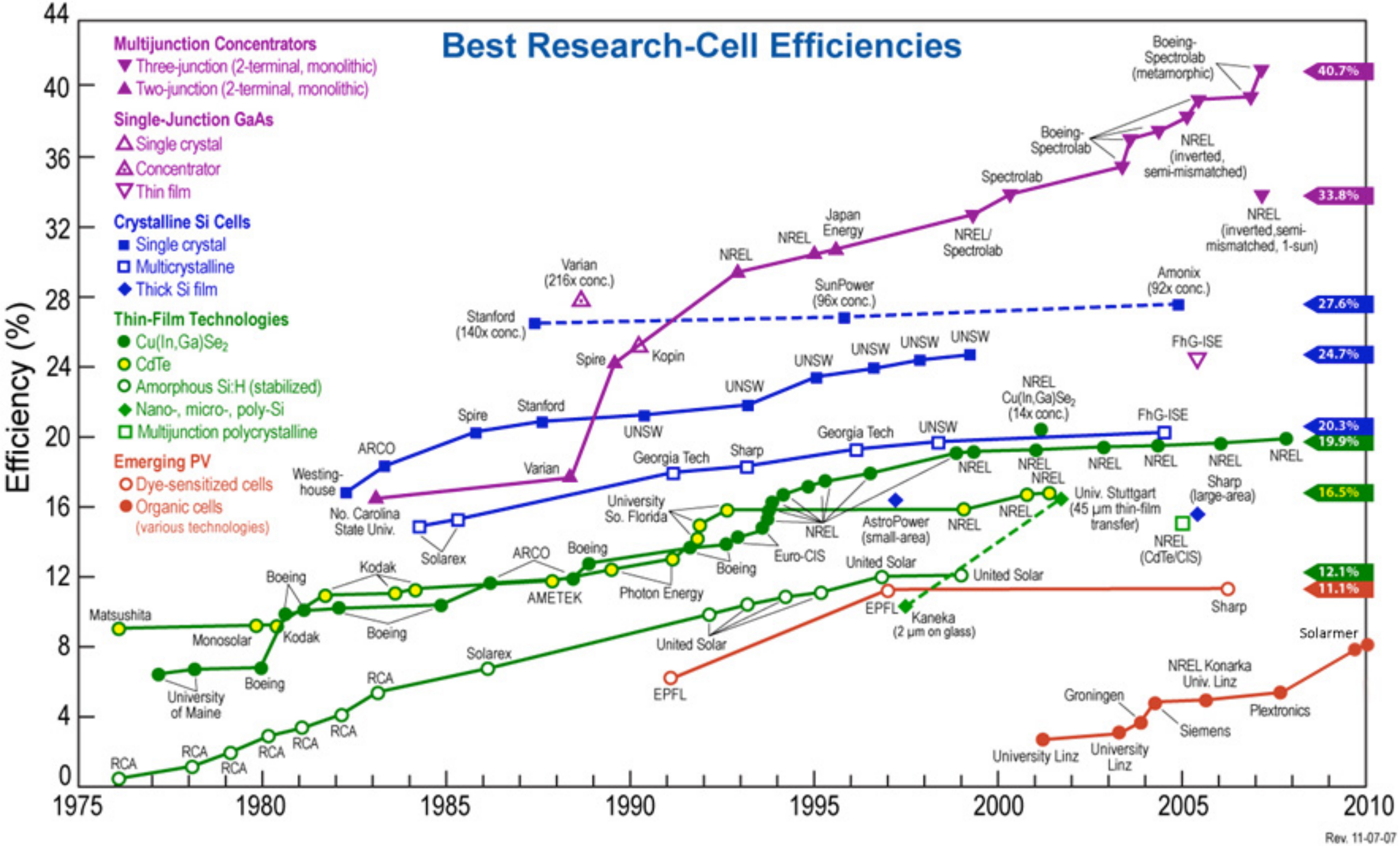
Solution-processing

Research activity in organic PV

- ISI - all databases
  - “Organic photovoltaics”
  - “Organic solar cells”
  - “Plastic photovoltaics”
  - “Plastic solar cells”



Progress in efficiency

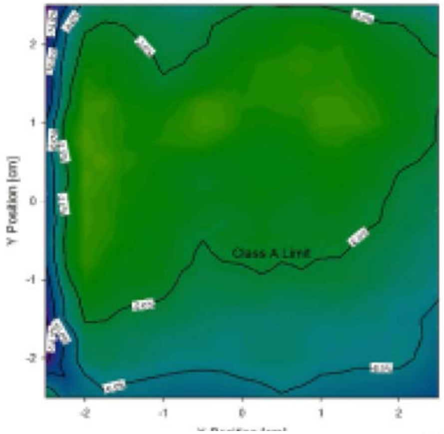


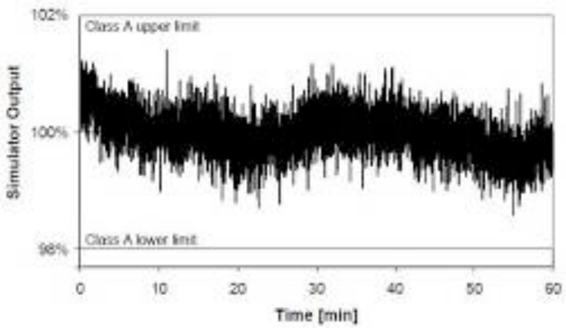
CSIRO organic PV – since 2005

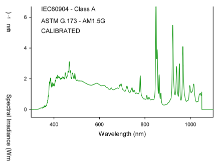
- Division of Energy Technology
  - National Solar Energy Centre – Newcastle
  - Axial device design (cell structures)
  - Lateral device design (modules)

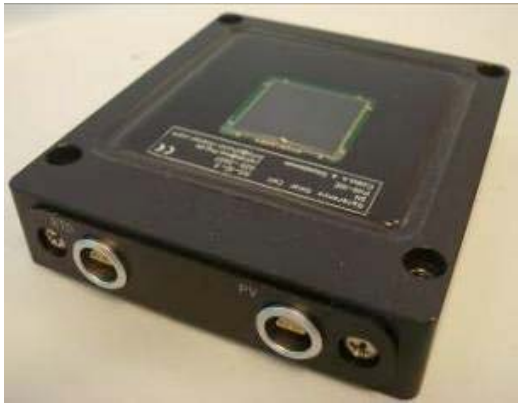
- Division of Molecular and Health Technologies – Melbourne
  - Long record of achievements in materials chemistry

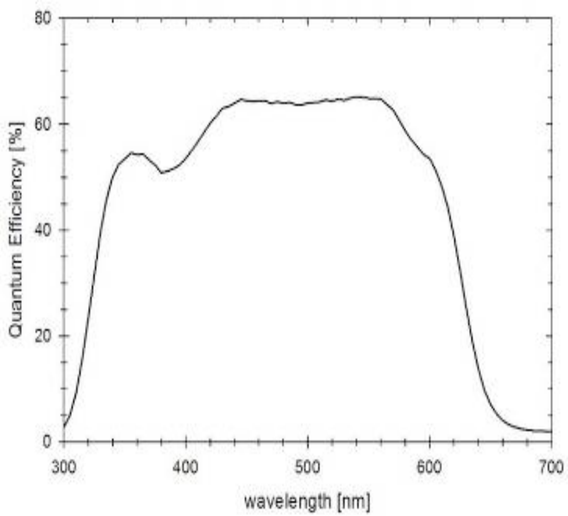
Measuring efficiency to IEC60904

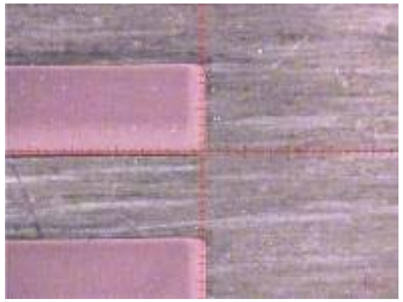


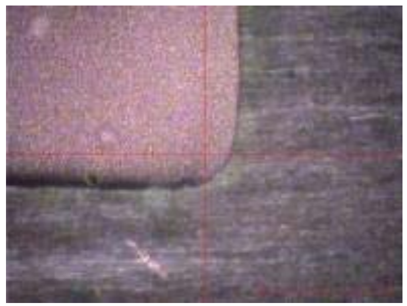




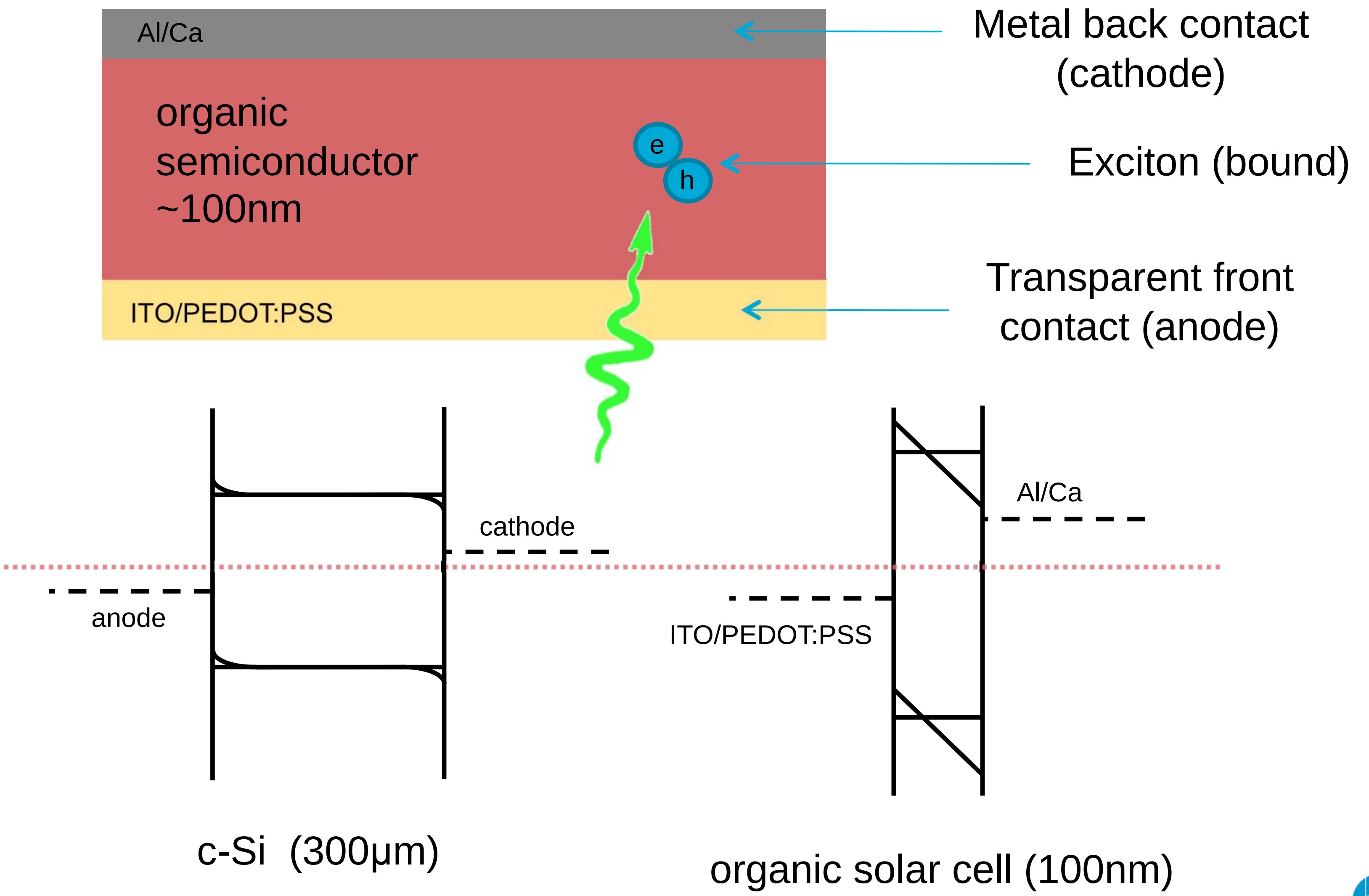




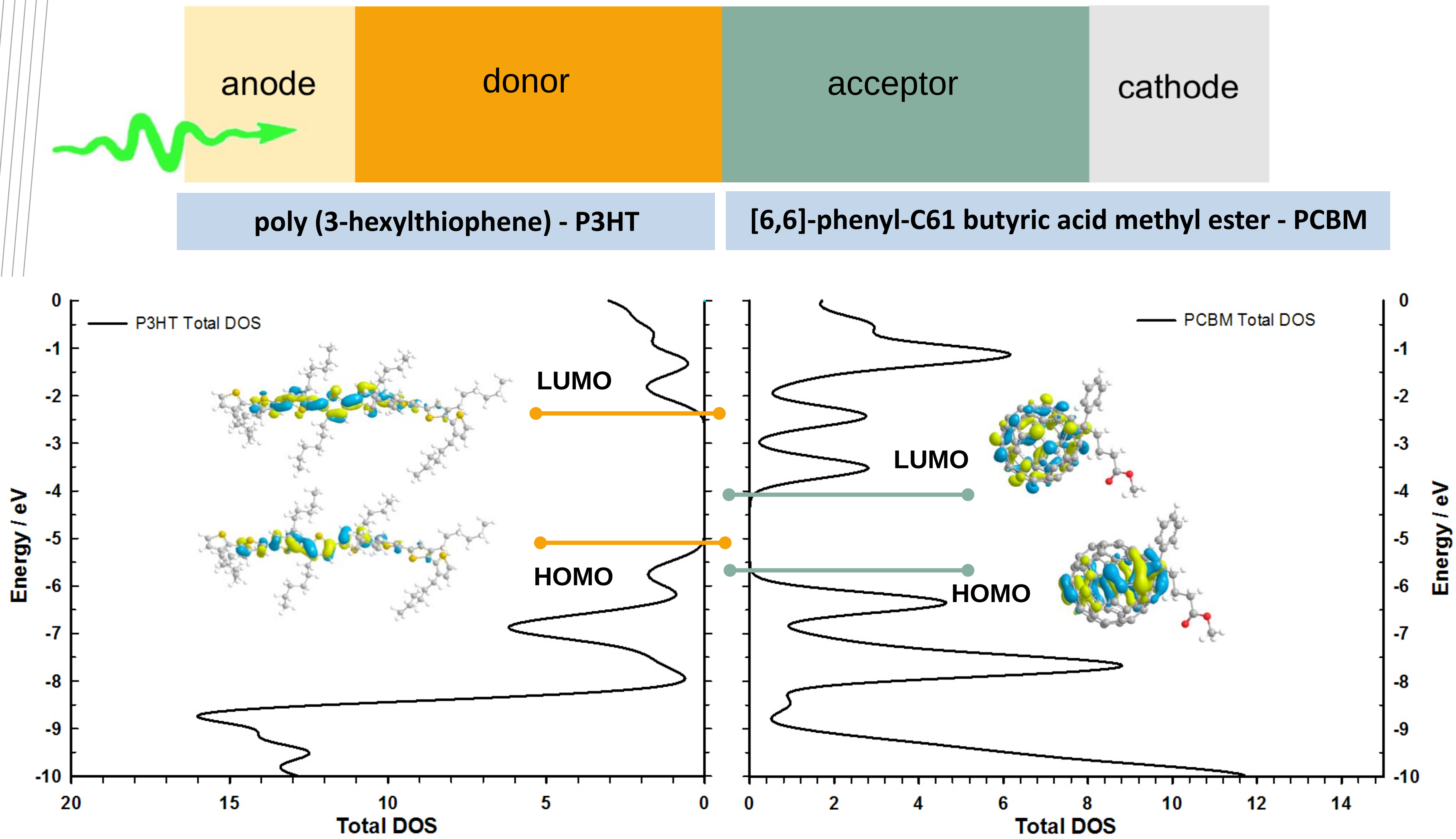




The single semiconductor device



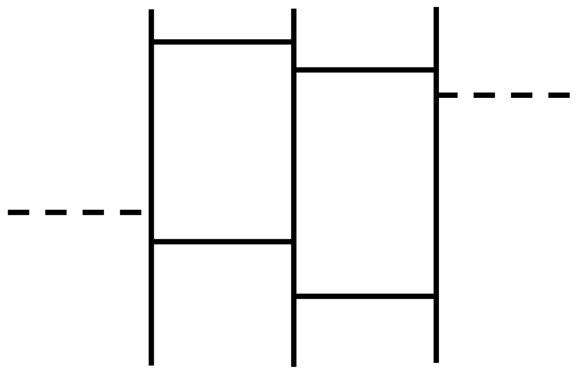
Splitting excitons: The planar heterojunction



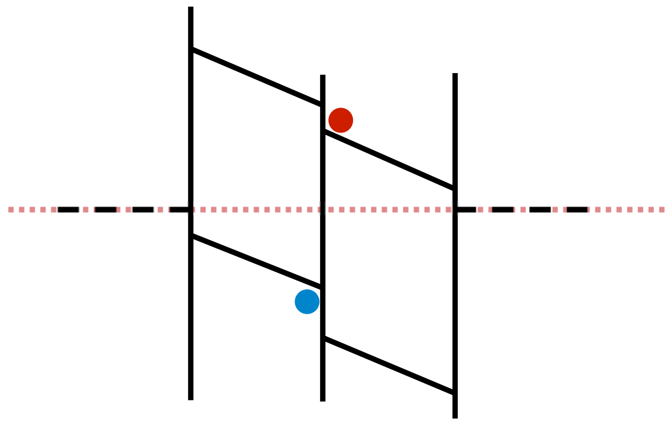
Understanding open-circuit voltage

- Heterojunction – voltage can go beyond flat-band

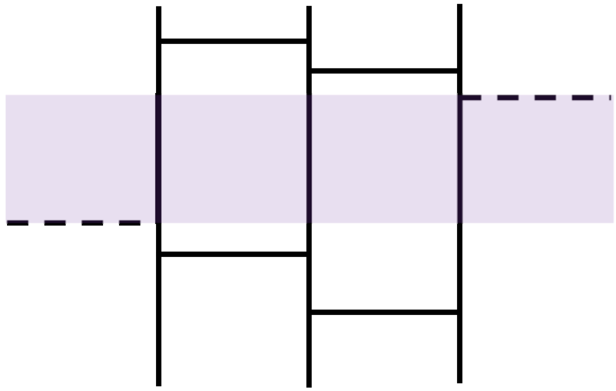
1. Bands prior to assembly



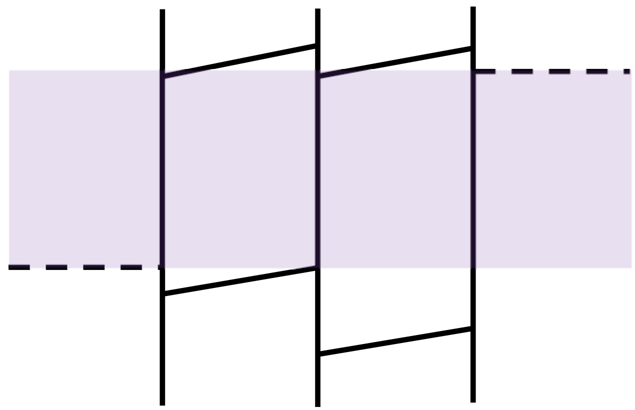
2. Assembled device (planar heterojunction)



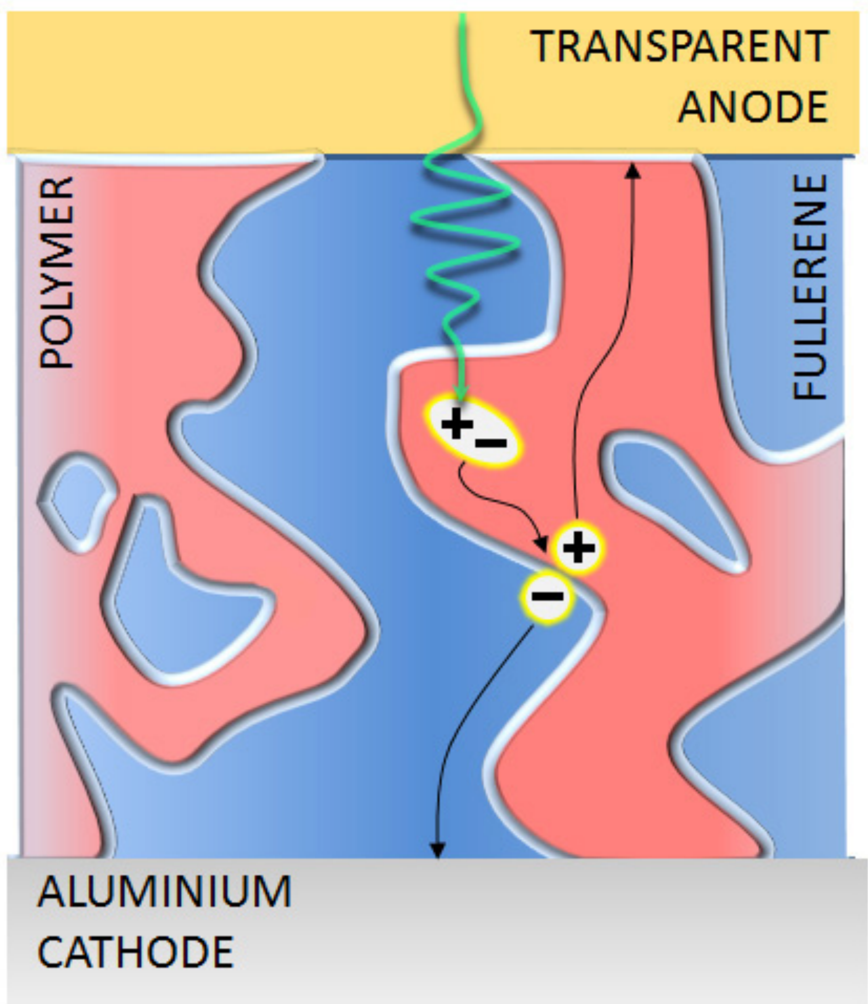
3. Illuminated to flat-band voltage



4. Illuminated beyond flat-band voltage

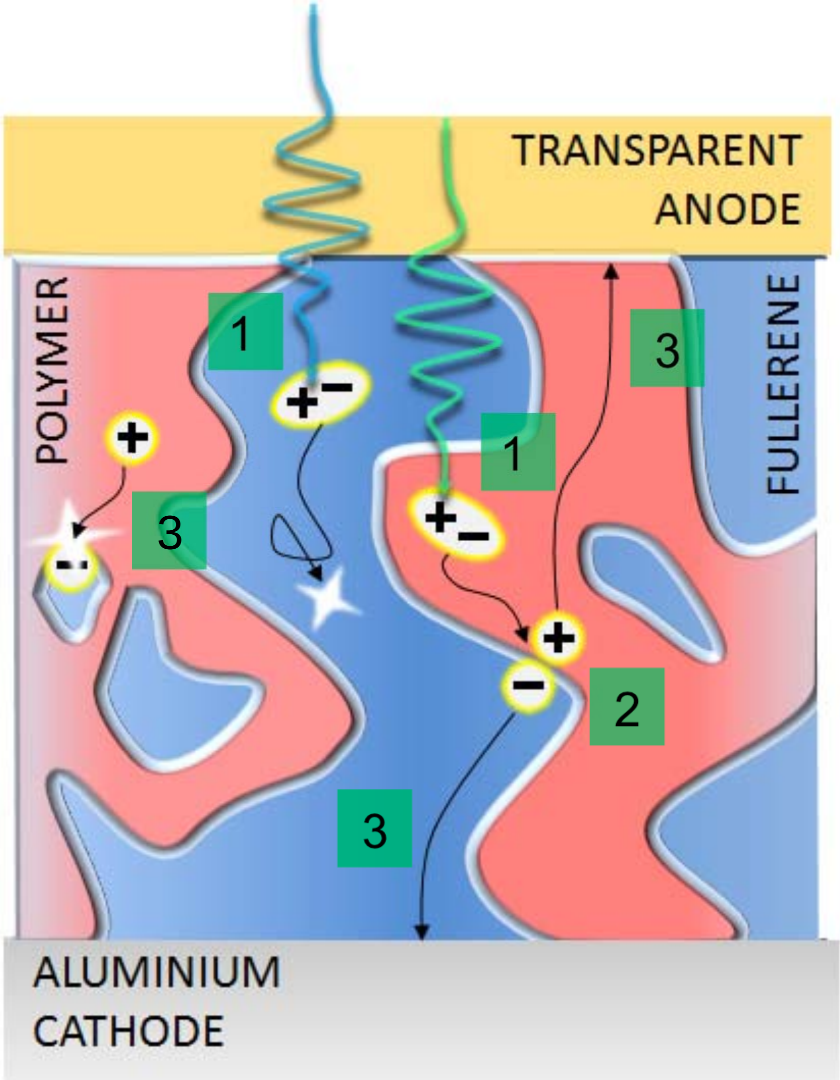


The bulk heterojunction device



- Mix donor and acceptor into one blend
- Greatly increases interface area for exciton dissociation
- Nanomorphology now critical
  - Choice of solvent
  - Annealing
- Penalties in voltage and transport

Understanding photocurrent



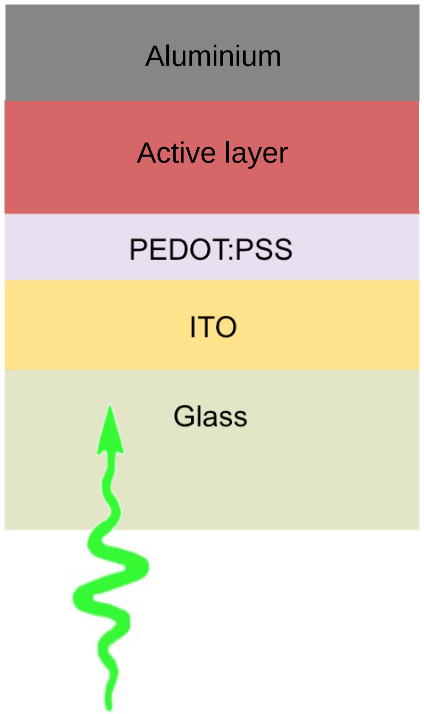
1: Exciton generation

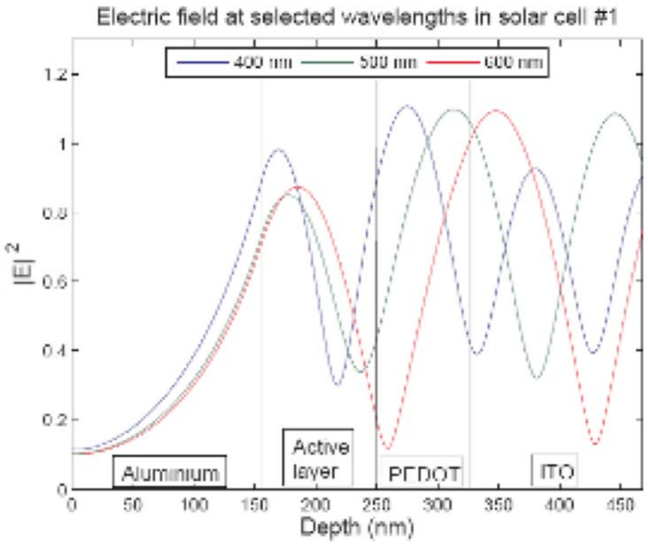
2: Exciton dissociation

3: Charge transport

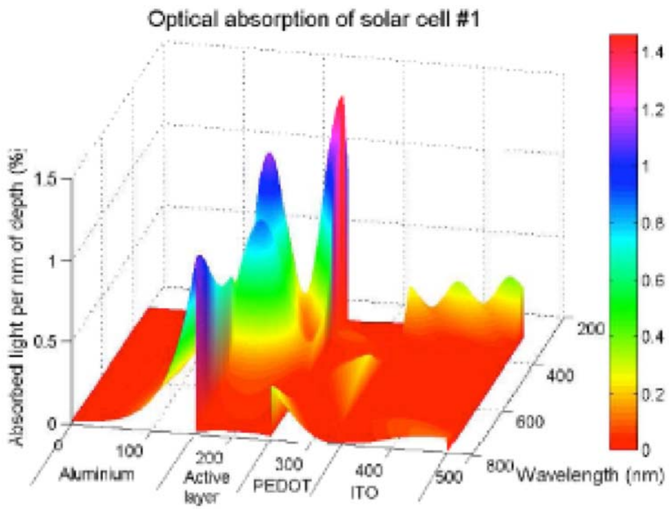
1: Exciton generation (optical excitation)

- How much light is coupled into the active layer ?
  - Measure the optical properties of each layer, n(λ) and κ(λ)
  - Use Fresnel equations to model multi-layer interference



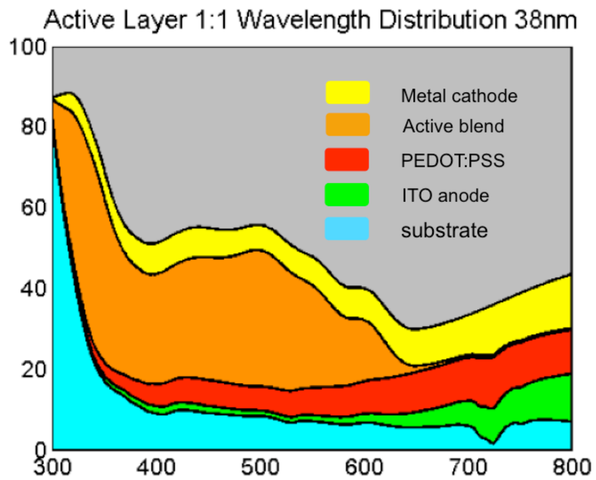


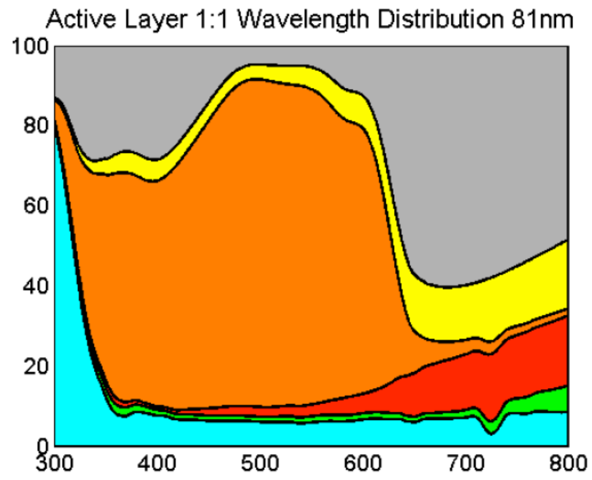
Optical field

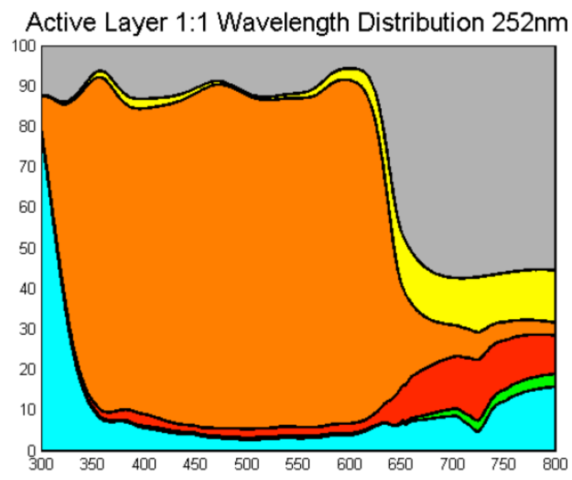


Absorbed energy

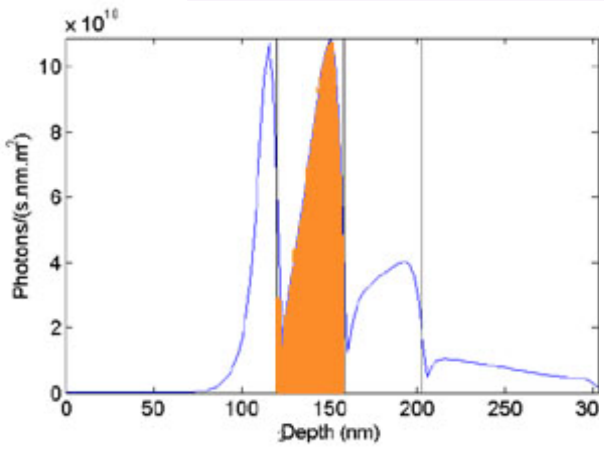
Photon accounting



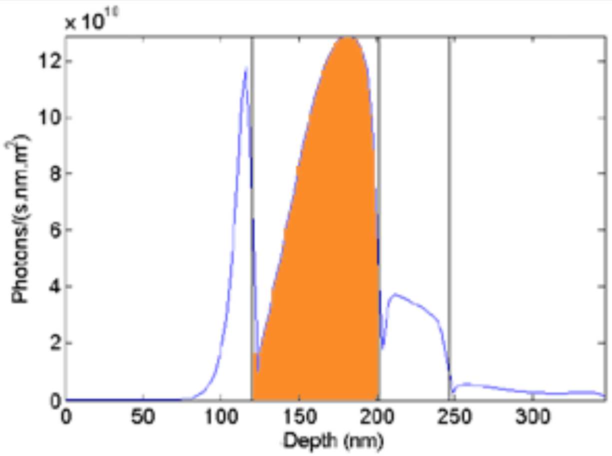




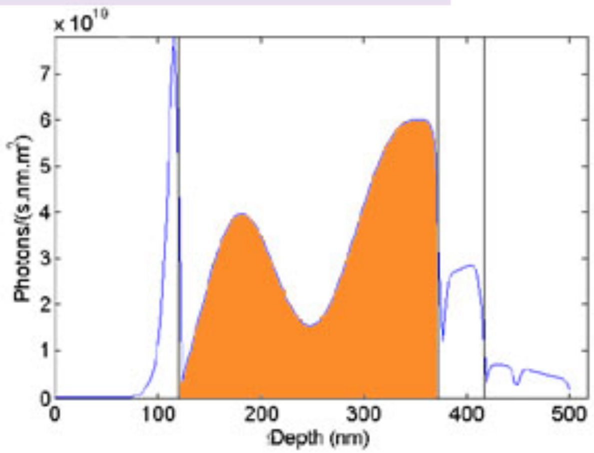
↑ ENERGY ↑ ↓ EXCITONS ↓



38nm active layer



81nm active layer



252nm active layer

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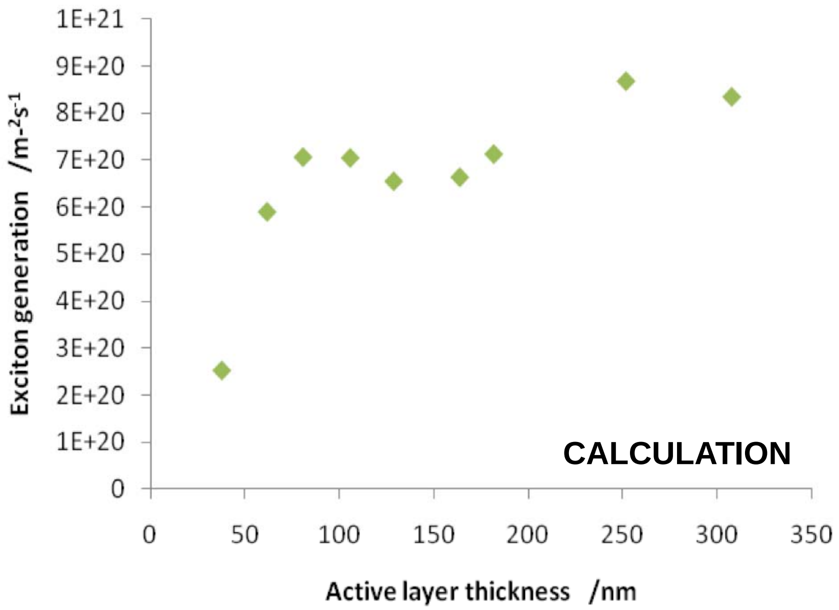
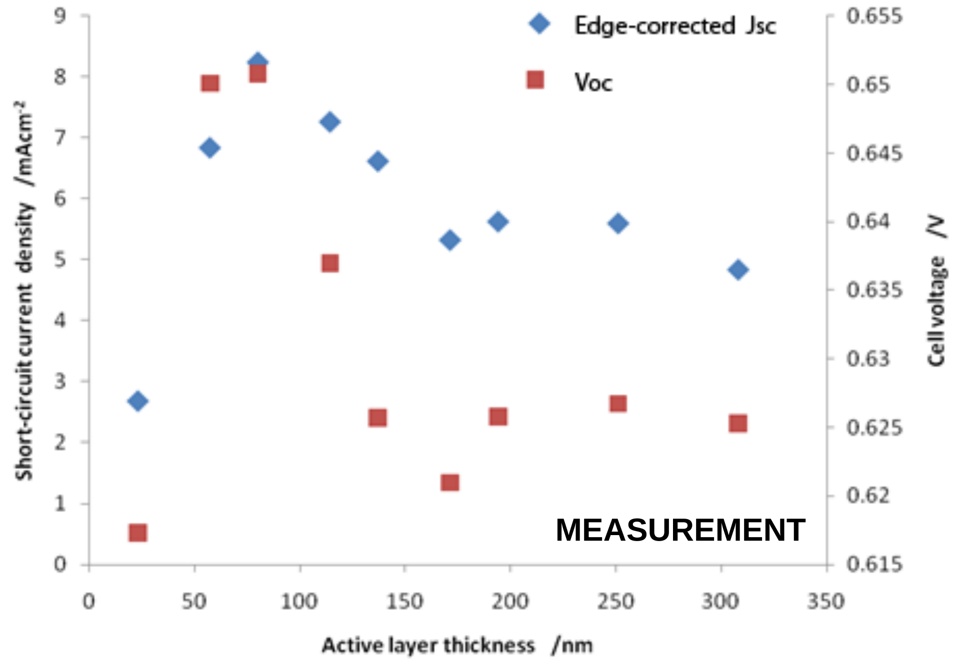
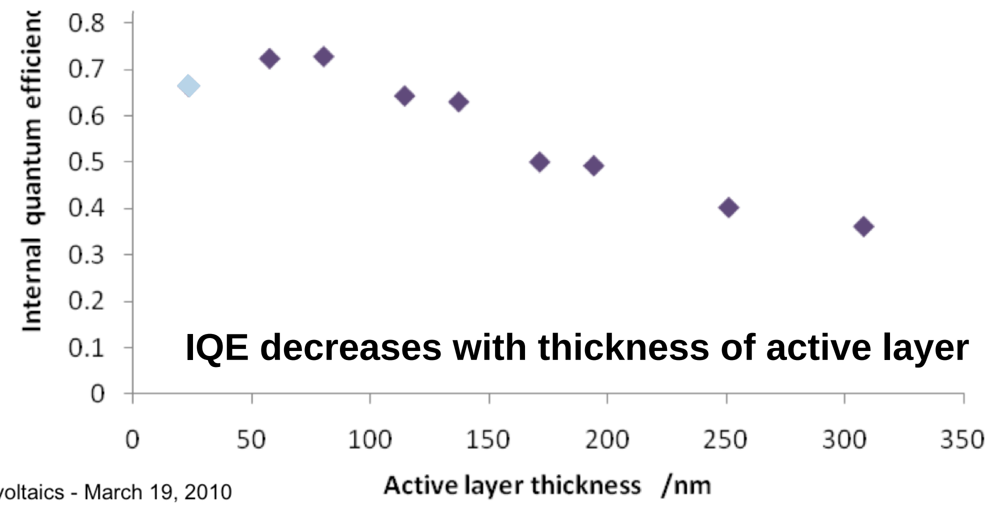
Internal quantum efficiency

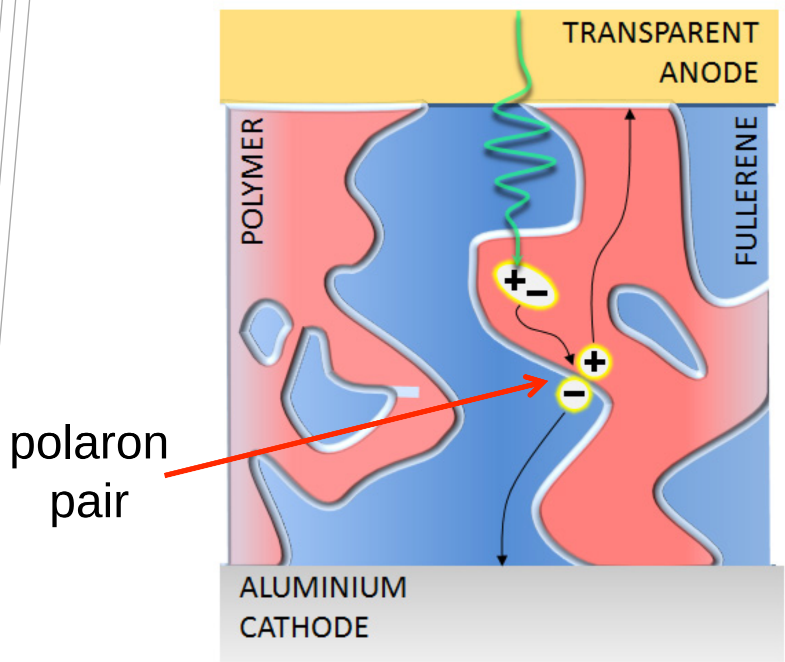


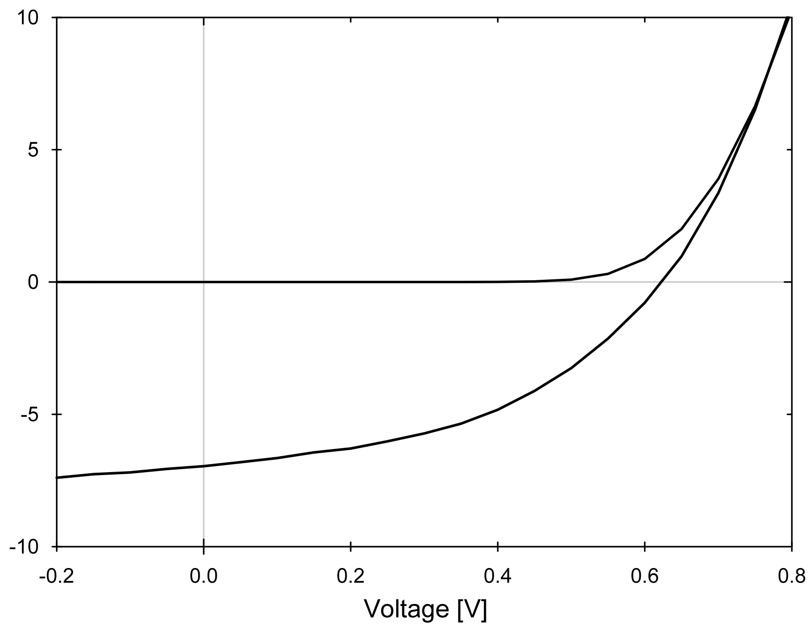




2: Exciton dissociation

- Two-stage process
  - Rapid dissociation to polaron pair
  - Polaron pair separation efficiency – FIELD DEPENDENT





- Photocurrent is voltage-dependent!

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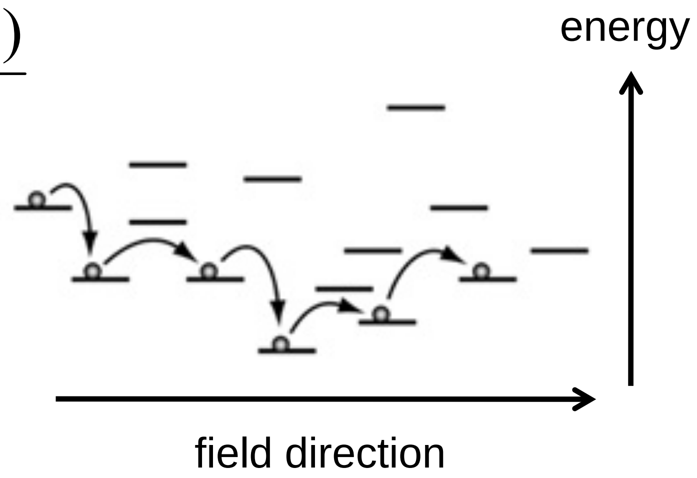
3: Charge transport - hopping

- Space charge contribution to the electric field

$$\frac{dE(x)}{dx} = \frac{e}{\varepsilon\varepsilon_0}\left[p(x) - n(x)\right]$$

- Transport equation for electrons

$$J_e(x) = e\mu_e(E,T)n(x)E(x) + D(\mu,T)\frac{dn(x)}{dx}$$



- Continuity equation for electrons

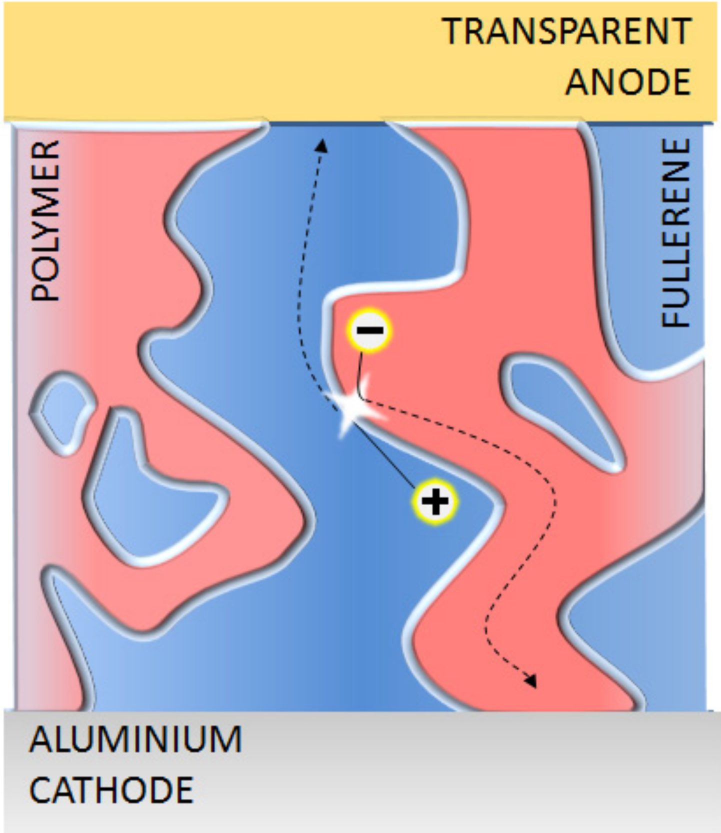
$$\frac{dn(x)}{dt} = \frac{1}{e}\frac{dJ_e(x)}{dx} + k_d S(x) - R(x)$$

Bi-molecular recombination

- Hopping transport
  - Band-band (intrinsic) recombination rate not important
- Bi-molecular recombination rate dominated by the time it takes for carriers to meet
- Langevin-type recombination

$$R(x) = \frac{q}{\varepsilon\varepsilon_0} min\{\mu_e, \mu_h\} n(x) p(x)$$

- Higher mobility means greater recombination!



Opportunities to increase performance

- Improving absorption
  - Narrow spectral bandwidth limits capture of AM1.5
- Optimise band structure
  - Adjusting heterojunction band offsets to minimise energy loss whilst still splitting exciton
- Improving mobility
  - Higher mobility materials
  - Interdigitated donor-acceptor designs for simpler carrier pathways
- Optimising optical interference
  - Maximise light-trapping in the active layer
- Reducing exciton binding energy
  - The biggest single obstacle to reaching the Shockley-Queisser limit

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Thank you

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