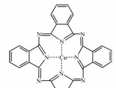
Small Molecular Weight Organic Solar Cells

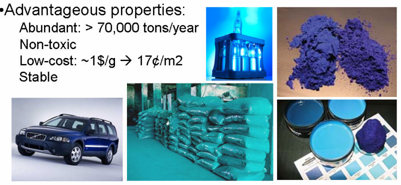
Shanbin Zhao, Albert Liu, Seung Rim, Whitney Gaynor and Peter Peumans
Stanford Organic Electronics Lab
Department of Electrical Engineering, Stanford University

Why Pigments?

Pigments

- Pigments = Small molecular weight absorbers in the UV/Visible/NIR wavelength range
- Mature industry/market
- Advantageous properties:
  - Abundant: > 70,000 tons/year
  - Non-toxic
  - Low-cost: ~1\$/g → 17¢/m2
  - Stable





Low-Cost

Roll-to-roll vacuum coating

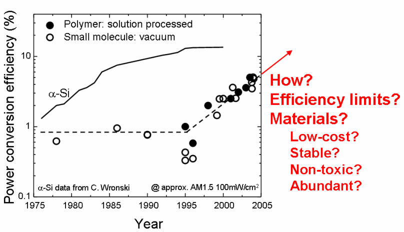
Methods
- Thermal evaporation (Al, organics, plasma assisted)
- E-beam evaporation (ceramics, SiO_x)
- Sputtering (ITO)
- PECVD (ceramics)

Applications
- Food Packaging
  - 50nm Al, 1000m/min, 4m wide → 80,000m²/hr
  - 100 machines would need 2 years to make all the PV cells we need @ 10%
- Barrier Layers
- OLEDs/OPV

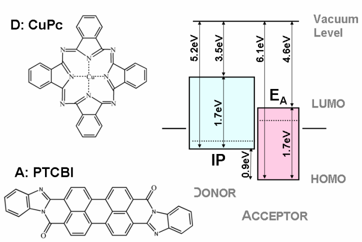
http://www.appliedfilms.com/

R. Ludwig, R. Kukla, and E. Josephson, *Proceedings of the IEEE* **93**, 1483 (2005).

Efficiencies

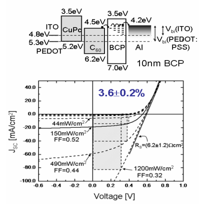


Organic Solar Cell Operation



Cell Architectures

Exciton Diffusion



Exciton Blocking Layer
- Reduced damage to active organic layer
- Optimization of optical interference
- Blocks excitons

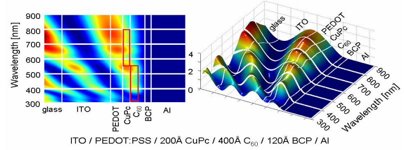
Yoo, Domercq and Kippelen, Appl. Phys. Lett. **85**, 5427 (2004).

Chu, Shrotriya and Yang, *Appl. Phys. Lett.* **86**, 243506 (2005).

P. Peumans, et al., *J. Appl. Phys.* **93**, 3693 (2003).

Optical Interference

- Optical interference effects can be optimized
  - "Focus" optical intensity in absorbing layers
  - Wavelength dependent

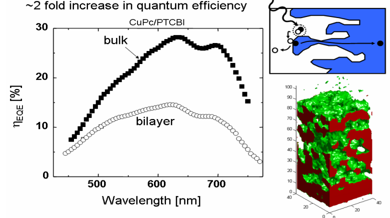


ITO / PEDOT:PSS / 200Å CuPc / 400Å C_{60} / 120Å BCP / Al

P. Peumans, et al., *J. Appl. Phys.* **93**, 3693 (2003).

Nanostructured Interfaces

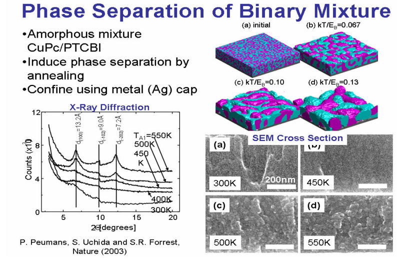
~2 fold increase in quantum efficiency



P. Peumans, S. Uchida and S.R. Forrest, Nature (2003)

Phase Separation of Binary Mixture

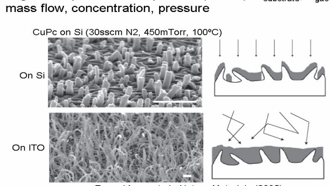
- Amorphous mixture CuPc/PTCBI
- Induce phase separation by annealing
- Confine using metal (Ag) cap



P. Peumans, S. Uchida and S.R. Forrest, Nature (2003)

Ordered Nanostructures by Growth

Organic Vapor Phase Deposition (OVPD): $T_{substrate}$, T_{gas}, mass flow, concentration, pressure

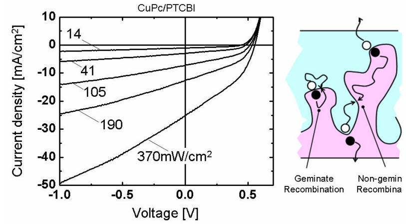


From: Yang, et al., Nature Materials (2005).

Nanoscale Exciton and Carrier Transport

Carrier Recombination Losses

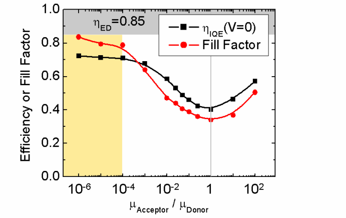
Usually attributed to low mobilities



P. Peumans, *et al.*, *Nature* **425**, 158 (200

Effect of Charge Carrier Mobilities

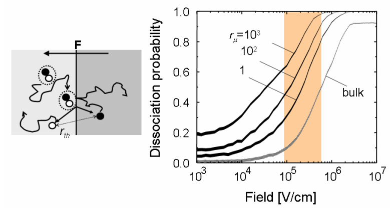
Strong Coulomb attraction → Charge mobility ratio is important



Zhao and Peumans

Carrier Recombination Dynamics

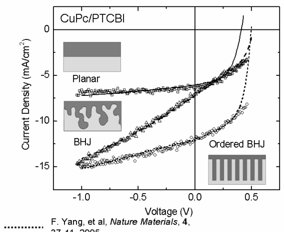
- Model explains why charges separate
- Large ratio of mobilities → increased separation probability



Peumans and Forrest, *Chem. Phys. Lett.* (200

Model Fits Experimental Data

- Same parameters – different geometries
- Geometry is an important route for optimization

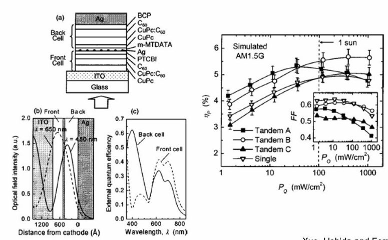


F. Yang, et al, *Nature Materials*, **4**, 37-41, 2005

Zhao and Peumans

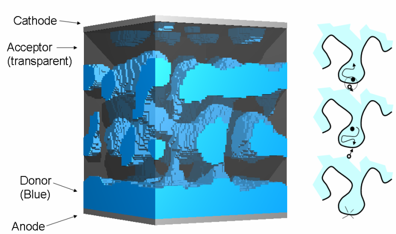
Complex Designs

Today's best cells: multijunction + nanostructured



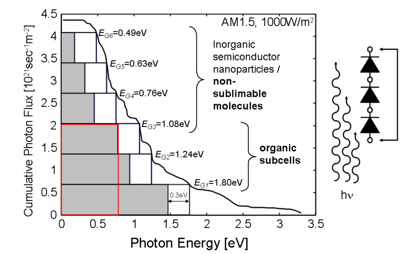
Xue, Uchida and Forrest

Nanostructured Solar Cell Model

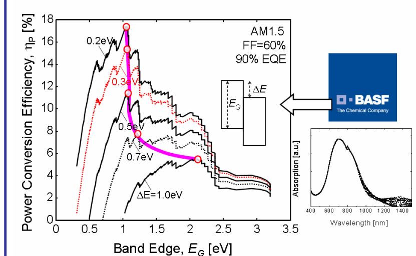


3rd Generation Cells

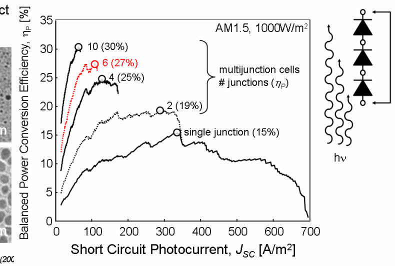
Material Requirements



Single Junction Efficiency Limits

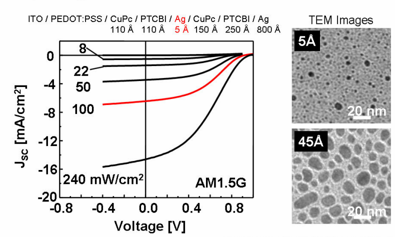


What's Next? Multijunction Cells



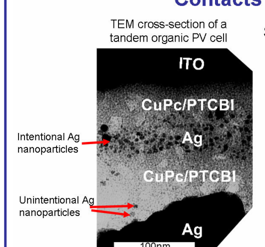
Multijunction Cells

Layer of Ag nanoclusters between cells acts as ohmic contact

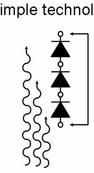


P. Peumans, et al., J. Appl. Phys. 93, 3693 (200

Transparent, Ohmic Metal Nanoparticle Contacts



Simple technology!



Case for Small Molecule OPV

- Small molecular weight materials
  - Stable, non-toxic, abundant, low-cost
- Best cells today: 5-6%
- Path toward >20%
  - Multijunction
  - Low bandgap/high bandgap
  - Decreased ΔE
  - Contacts and doping
  - Nanostructured interfaces
  - Metal nanostructures
- Manufacturing technology
  - Aerosol/OVPD
  - OPV on fiber