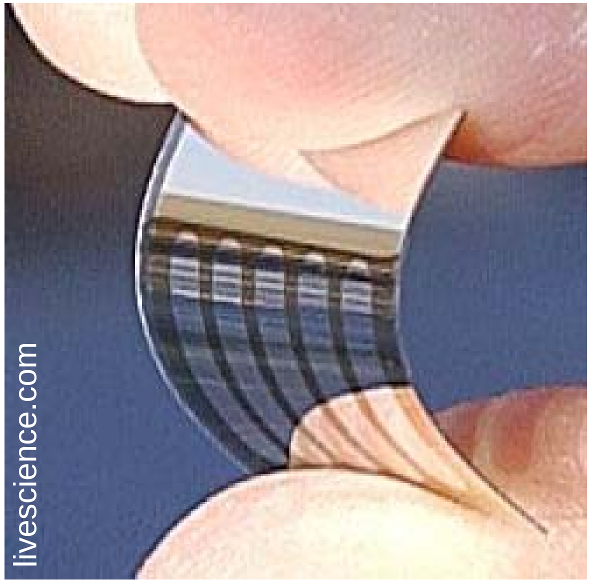
Organic Solar Cells:
Improving Performance by Controlling Nanoscale Structure and Morphology



Bryce Meredig
MSE 395
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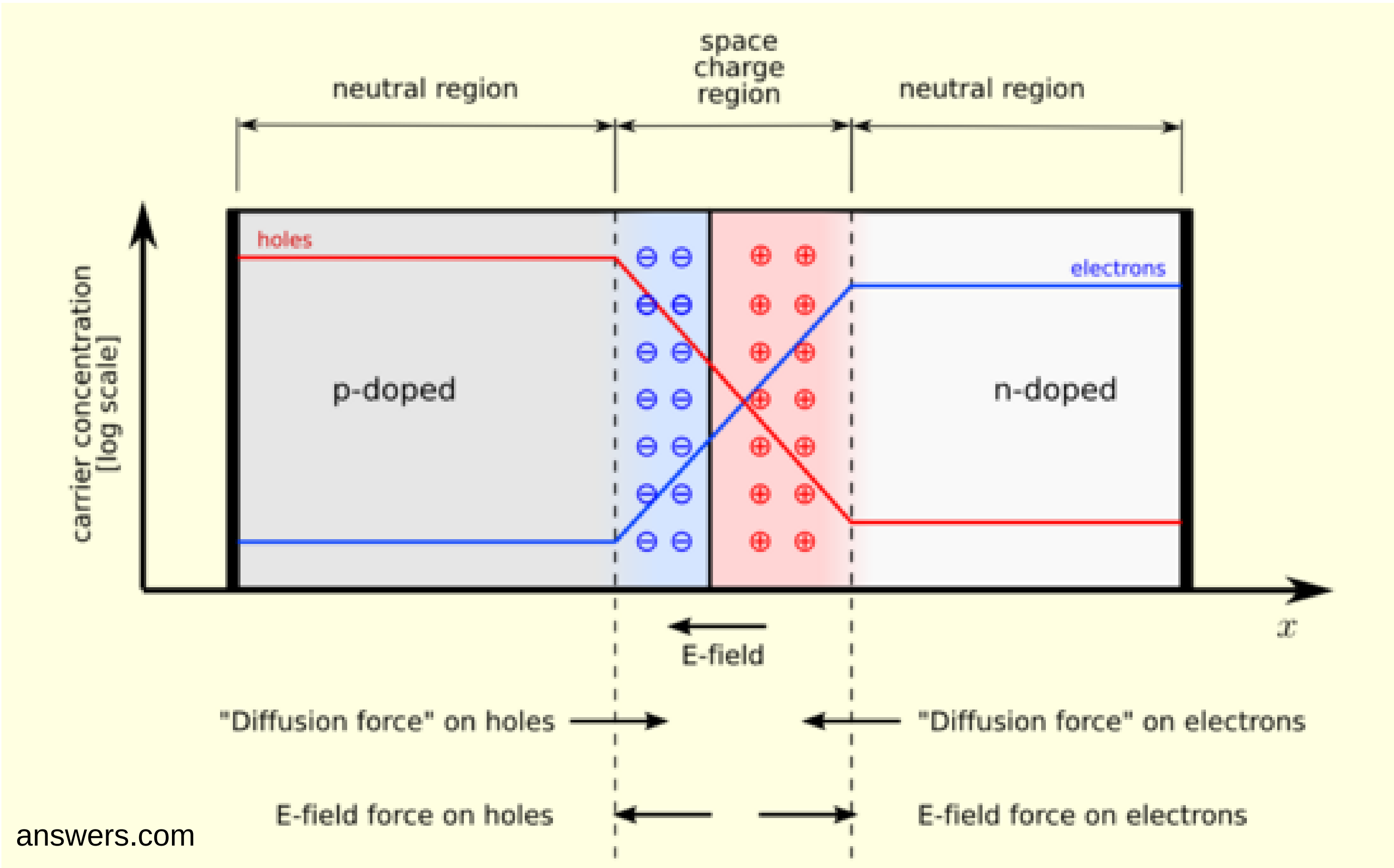
Solar Cell Fundamentals

- Traditionally based on semiconductor *p-n* junctions
- Photocurrent results from generation of charge carriers in the space charge region



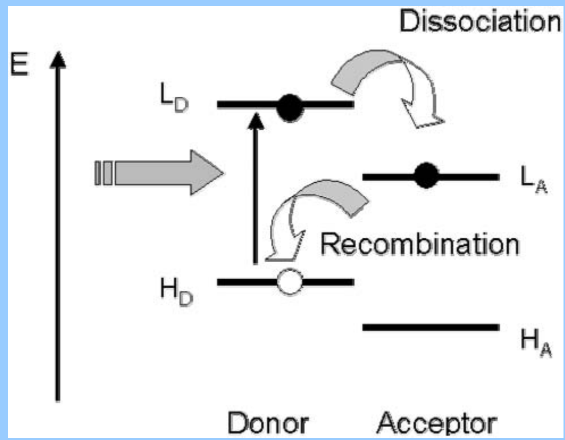
Why Organic Materials?

- *Not* because they have higher efficiency—they don't!
- Easier (and hence cheaper) to manufacture than crystalline inorganic semiconductors (e.g., Si-based)
- Could be produced in large quantities and used for off-grid applications, such as in the developing world
- Can be deposited on flexible substrates: “plastic” solar cells
- Solution processing means they can be printed onto a substrate rather than requiring lithography

Organic Photovoltaics

Energy Levels | **Device Design**

Organic solar cells



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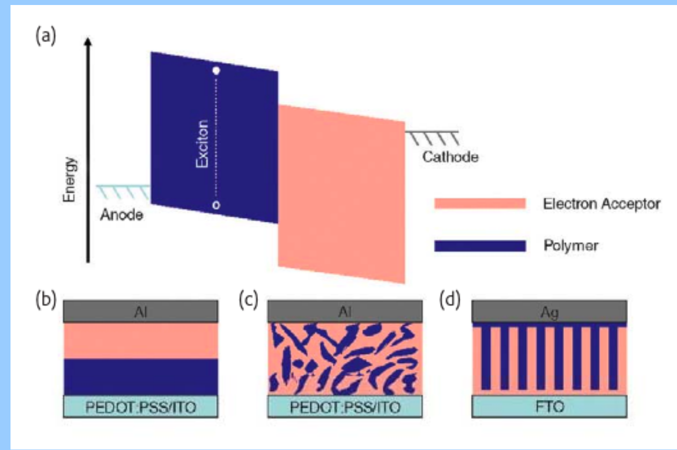
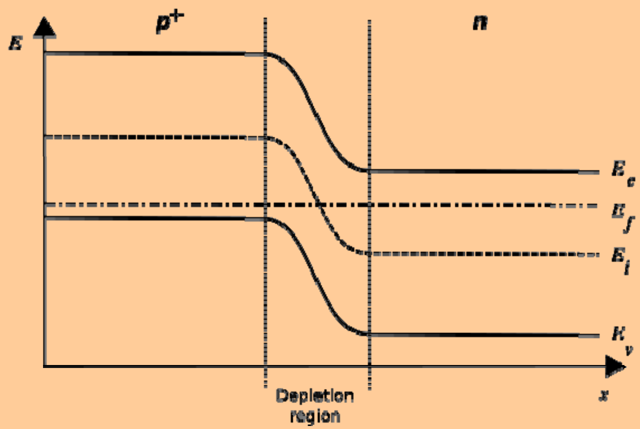


Mayer et al., *Mat. Today* (2007)

Inorganic semiconductor solar cells



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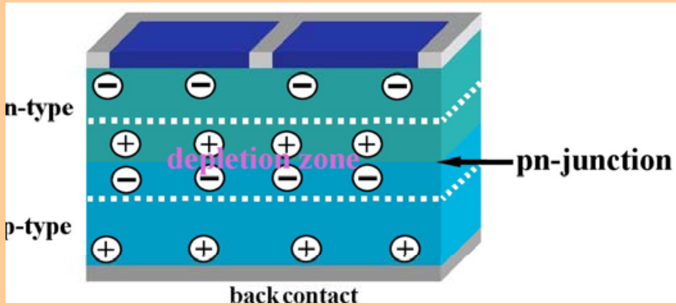
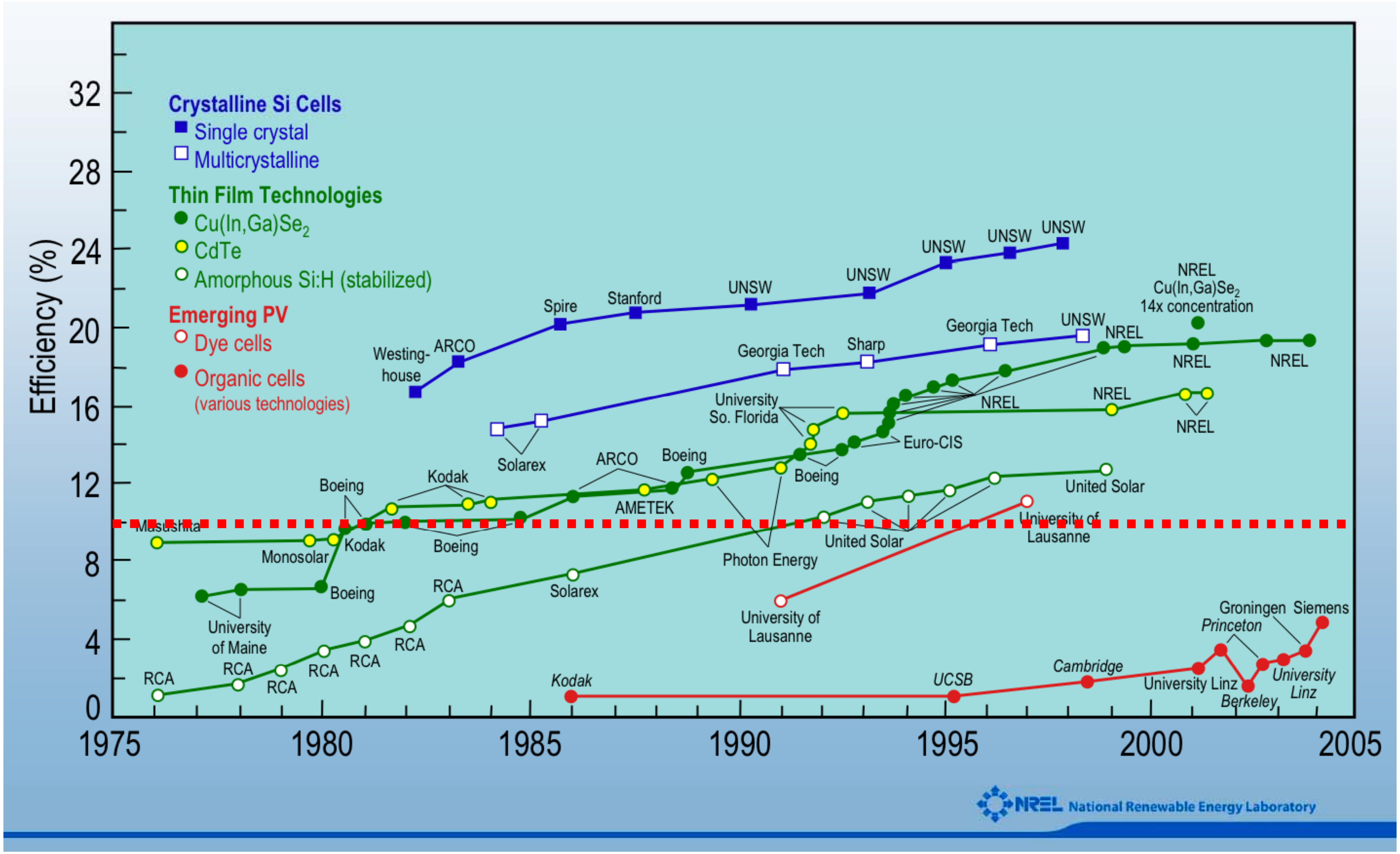


specmat.com

Target: 10% Efficiency



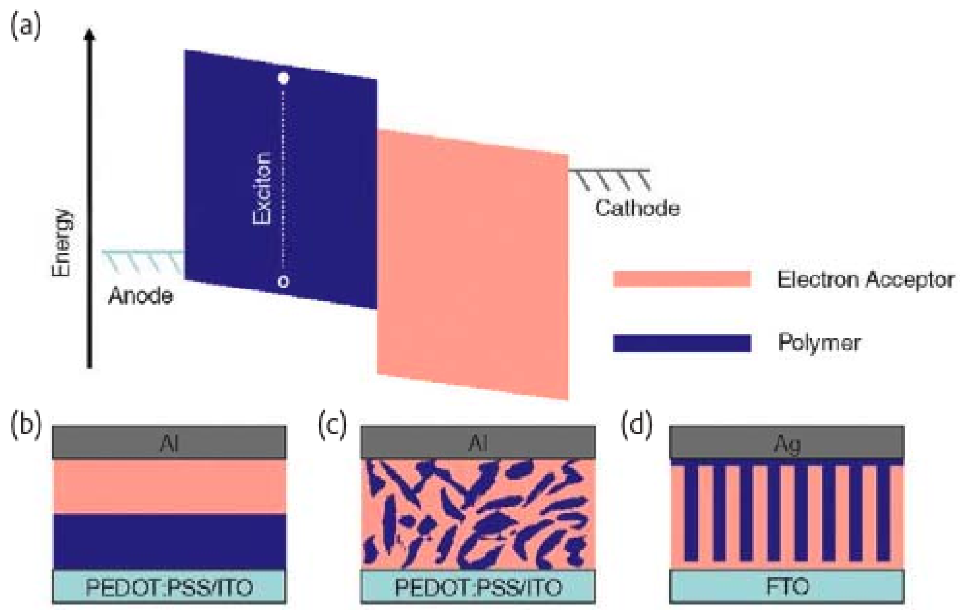
Sarah Kurtz, World Renewable Energy Conference (2004)

Materials and Device Designs

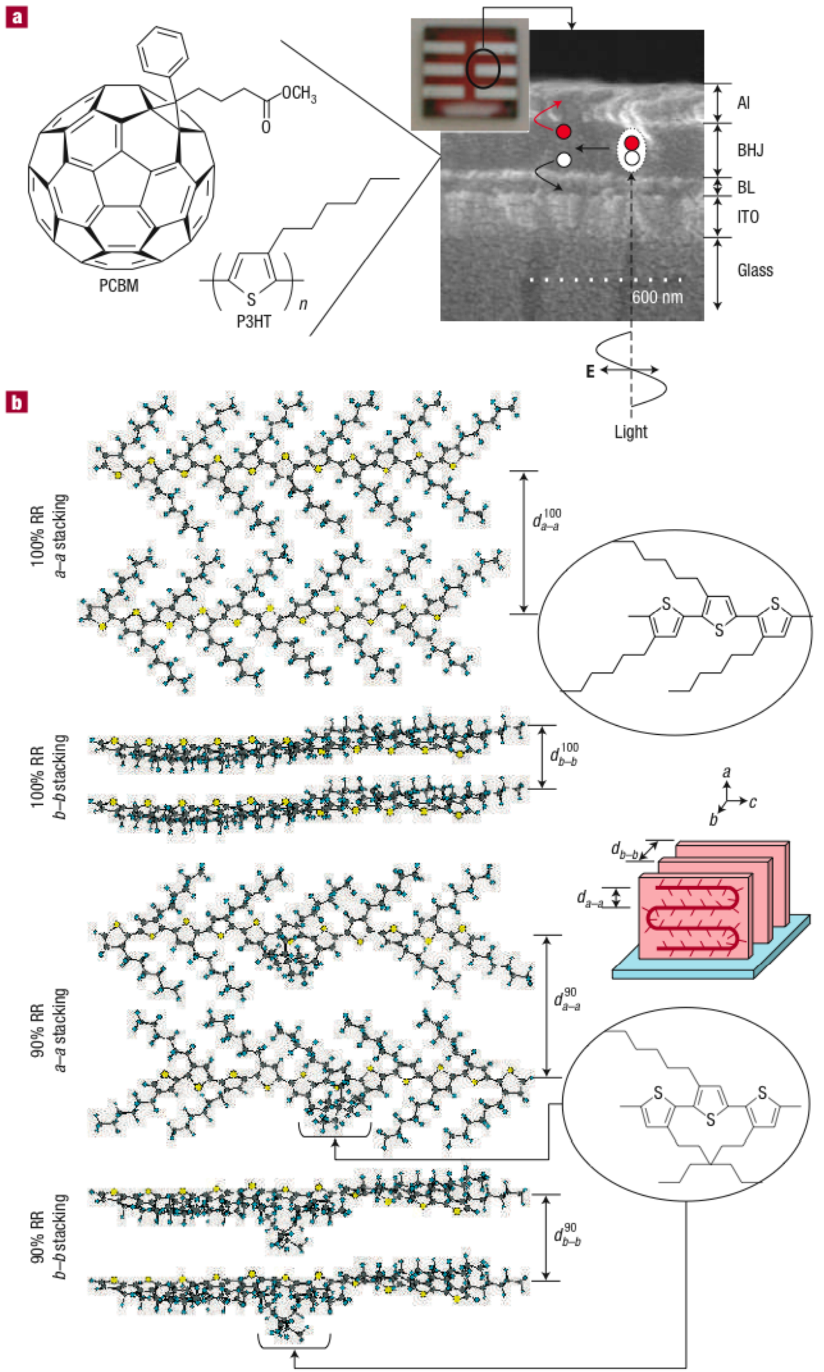
- Two key questions:

> 1) *What are the optimum active polymer and electron acceptor materials?*
> 2) *How should they be fabricated (structure and morphology) to yield the best performance?*

- (b) is a planar heterojunction (HJ); (c) is a bulk HJ; and (d) is an ordered HJ



Mayer et al., *Mat. Today* (2007)



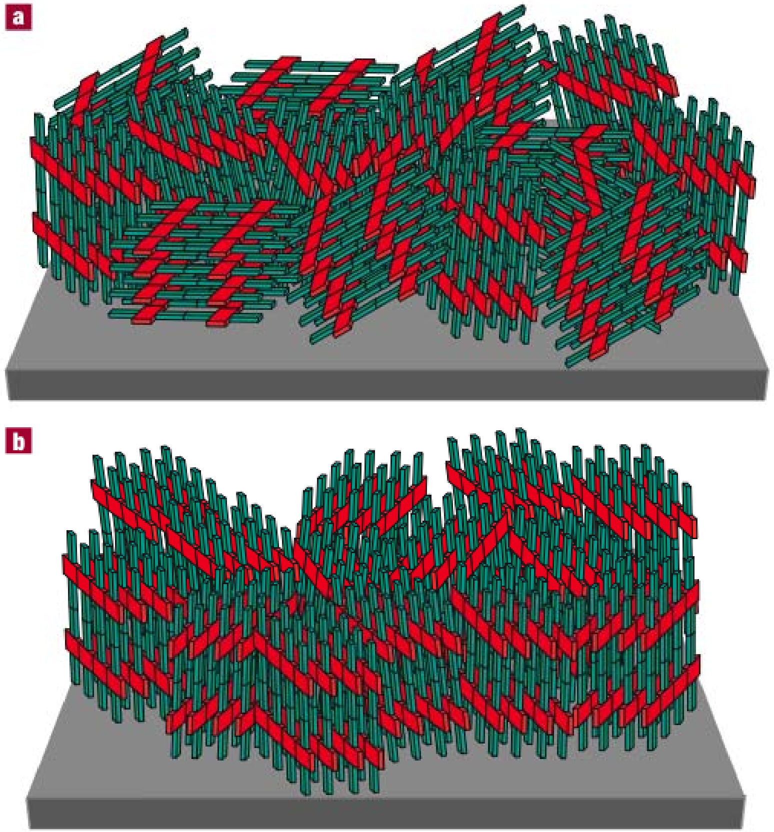
Kim *et al.*, *Nat. Mater.* (2006)

Materials Requirements

- Polymer (active region)
  - Should absorb light near peak of solar power output
  - Should transmit charge carriers effectively
- Electron acceptor
  - Can be inorganic (e.g. titania) or organic (e.g. fullerenes)
  - Must provide potential energy decrease for electrons relative to the polymer
  - Should have high electron mobility

The Role of Morphology

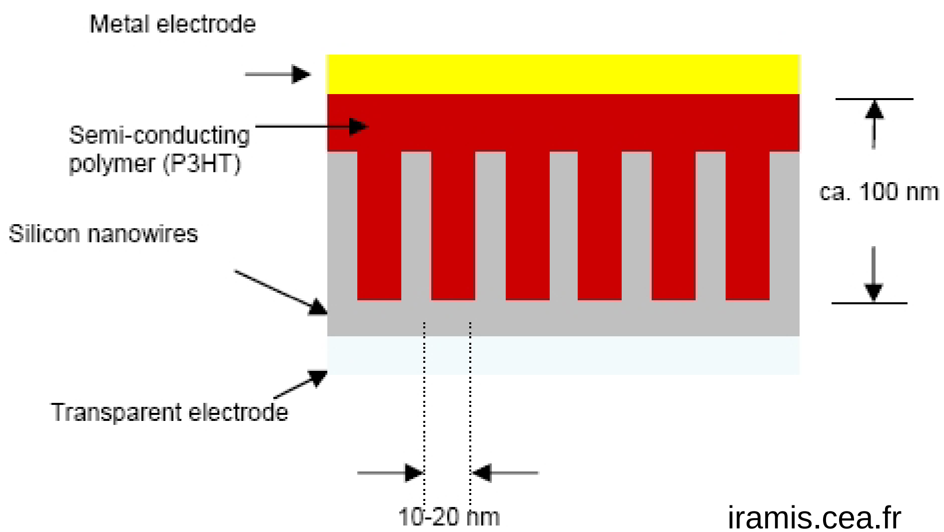
- Not all polymer films are created equal
- Differences in morphology can change critical parameters like charge carrier mobility by orders of magnitude
- A wide variety of experimental parameters influence morphology



Kline *et al*., *Nat. Mater.* (2006)

Structures on the Nanoscale

- Challenge: Want thick films to absorb as much light as possible, but thin films to allow charge carrier diffusion to contacts
- Solution: Design nanostructures (bulk or ordered heterojunctions) optimized for typical diffusion lengths in the polymer



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Remaining Challenges

- Experiments can be difficult to repeat due to the enormous number of variables involved
- Optimizing structures and interfaces for charge transport
- Mechanisms governing morphology are poorly understood
- Organics are often not stable in air over long periods

Future Prospects

- Self-organizing and self-assembling systems
- New interface chemistries
- Tailored molecule synthesis for target energy levels and other properties
- Single-crystal organics