New Applications of Old Materials
From Paint to Solar Cells

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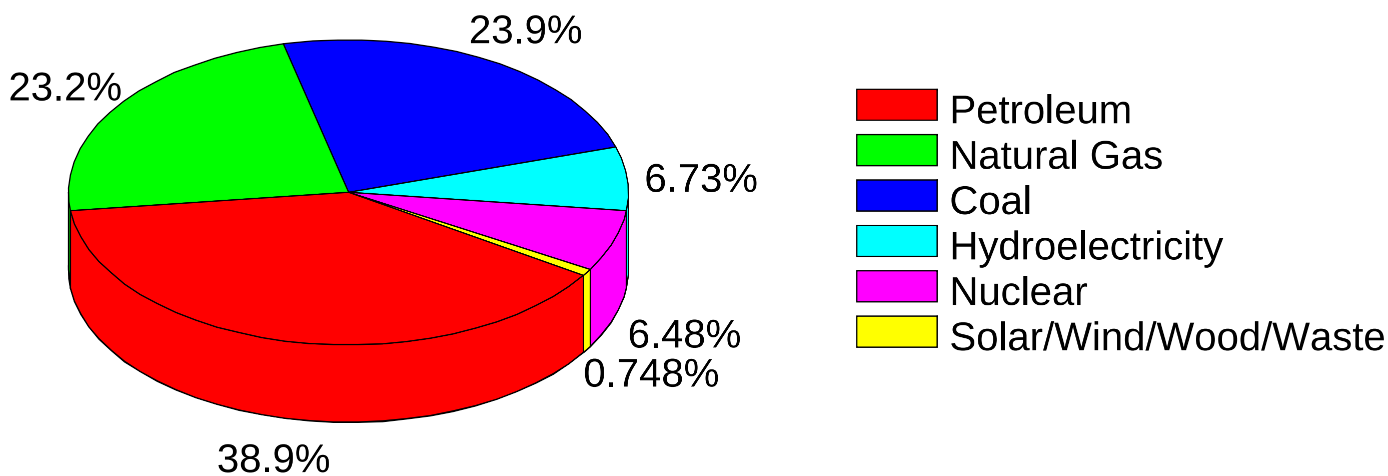
Sponsored by NSF

Solar Energy

At earth's surface average solar energy is ~ 4 x 10^{24} J / year

Global energy consumption (2001) was ~ 4 x 10^{20} J / year (increasing ~ 2% annually)



In US, average power requirement is 3.3 TW.

With 10% efficient cells we would need 1.7% of land area devoted to PV (~ area occupied by interstate highways)

Source: DOE

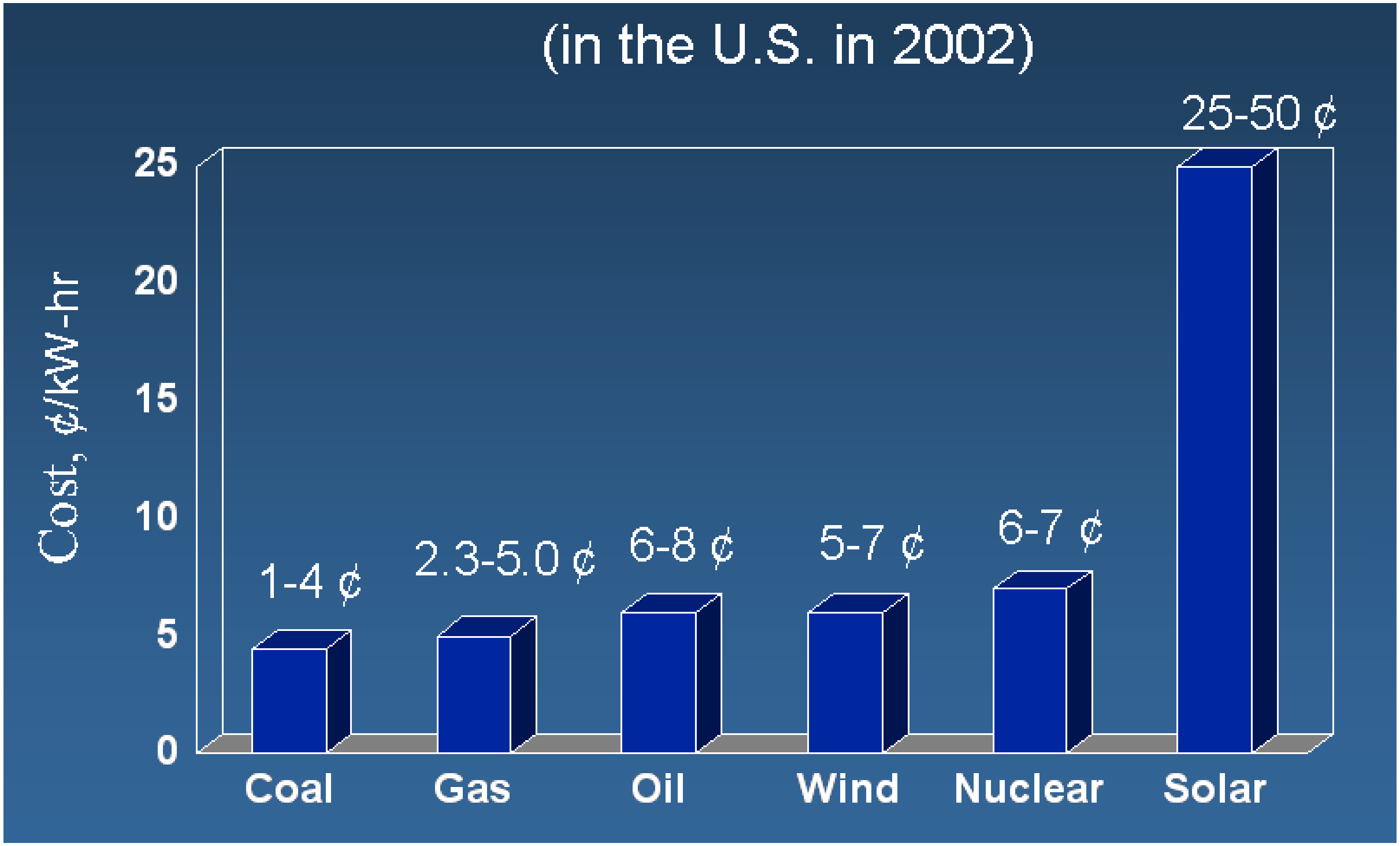
Solar Energy Land Requirements

230x230 mile^2 @ 10% ~ 3TW

DOE

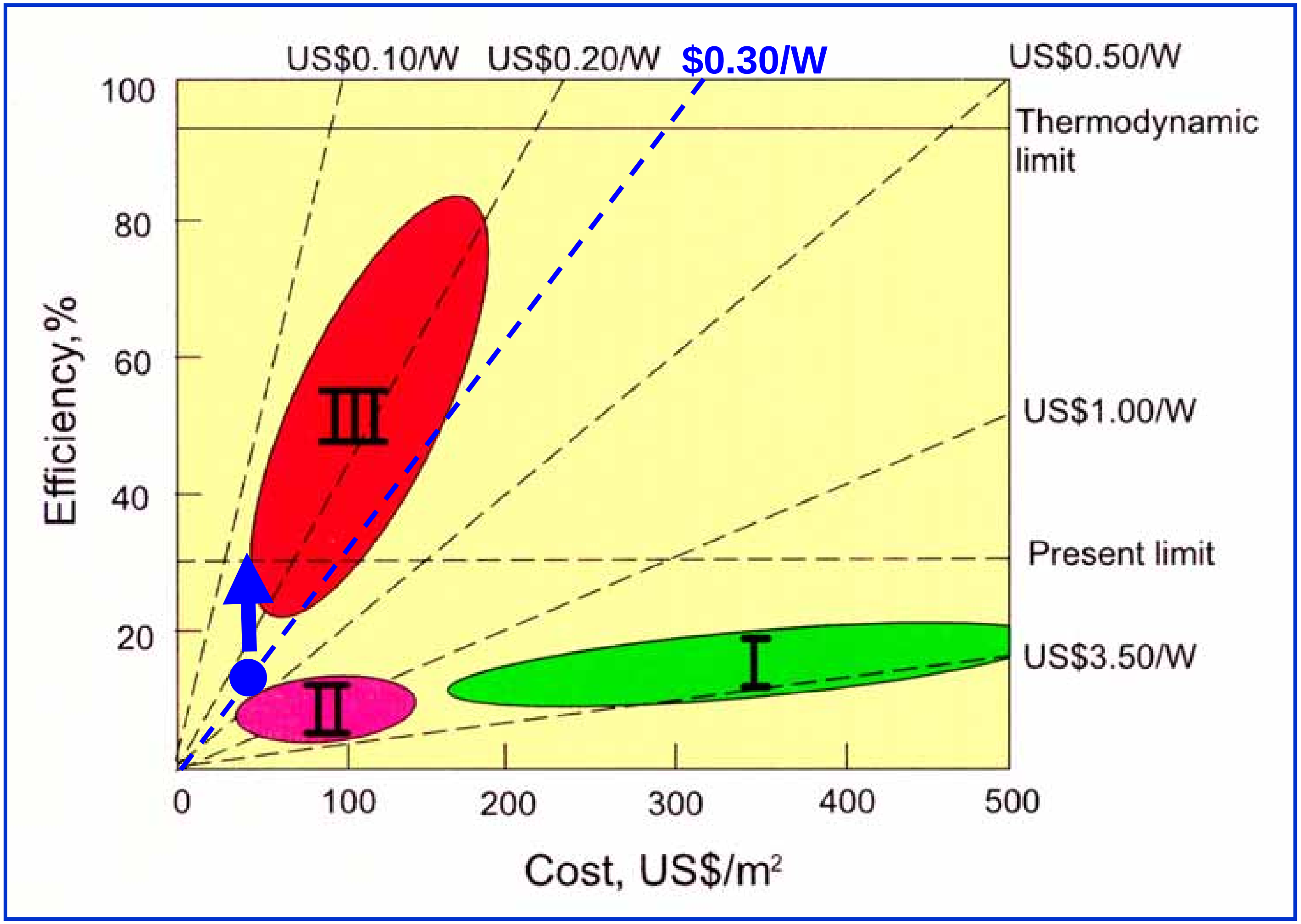
N. Lewis (Caltech)

Electrical Energy Production Cost



N. Lewis (Caltech)

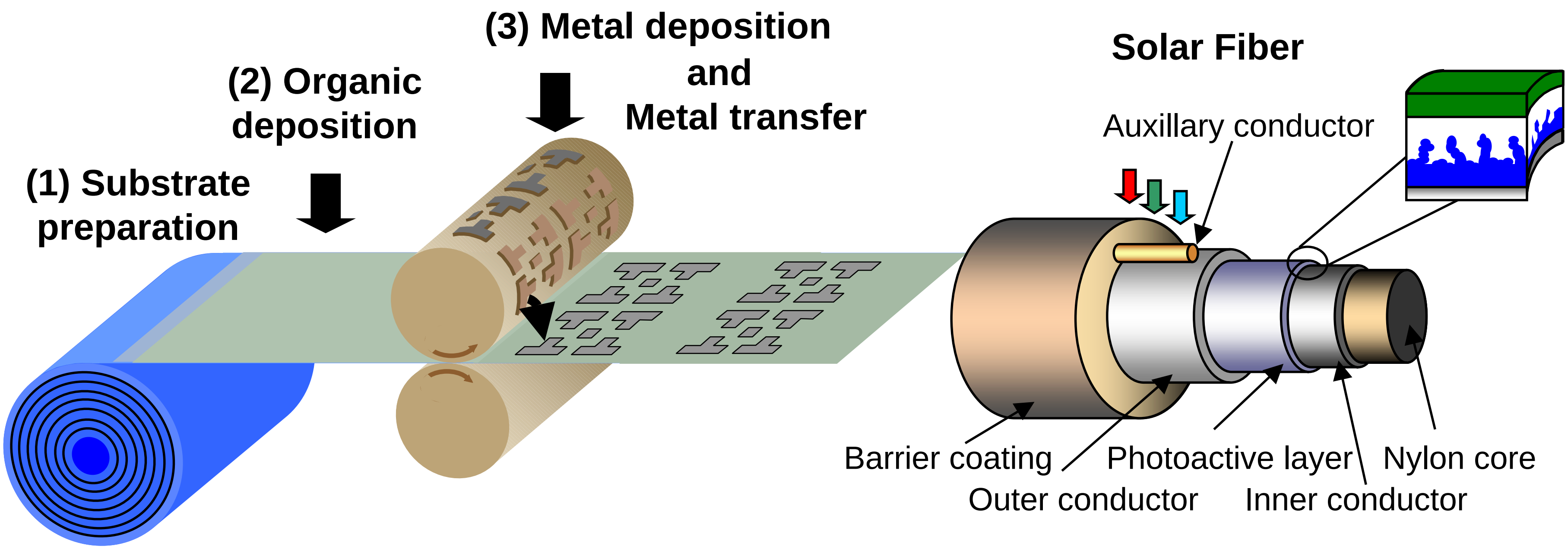
Cost/Efficiency of Photovoltaic Technology



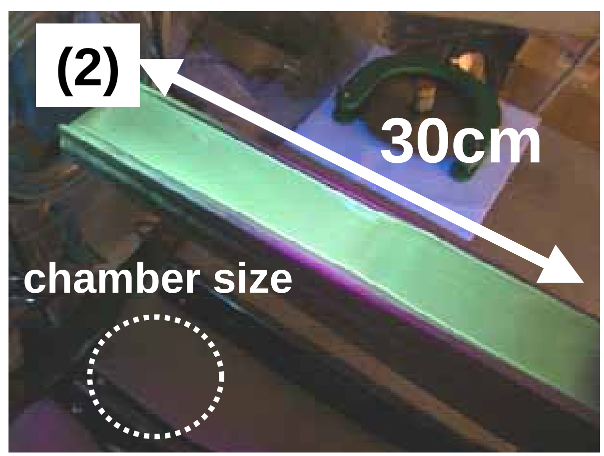
Costs are modules per peak W; installed is $5-10/W; $0.35-$1.5/kW-hr

M. Green (UNSW)

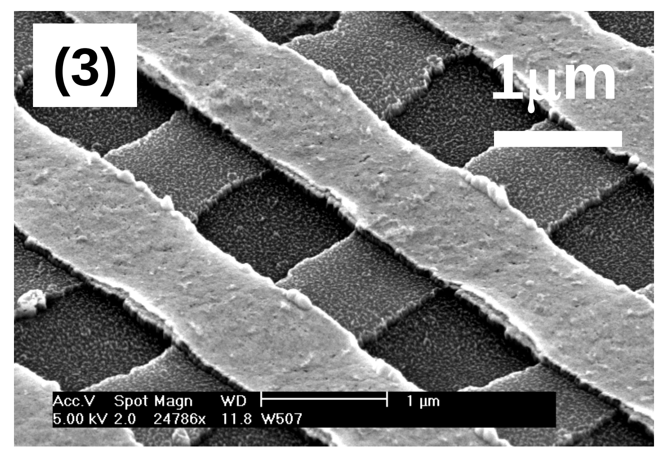
Cheap: Roll-to-Roll Processing



Roll-to-roll coater
(Applied Films)

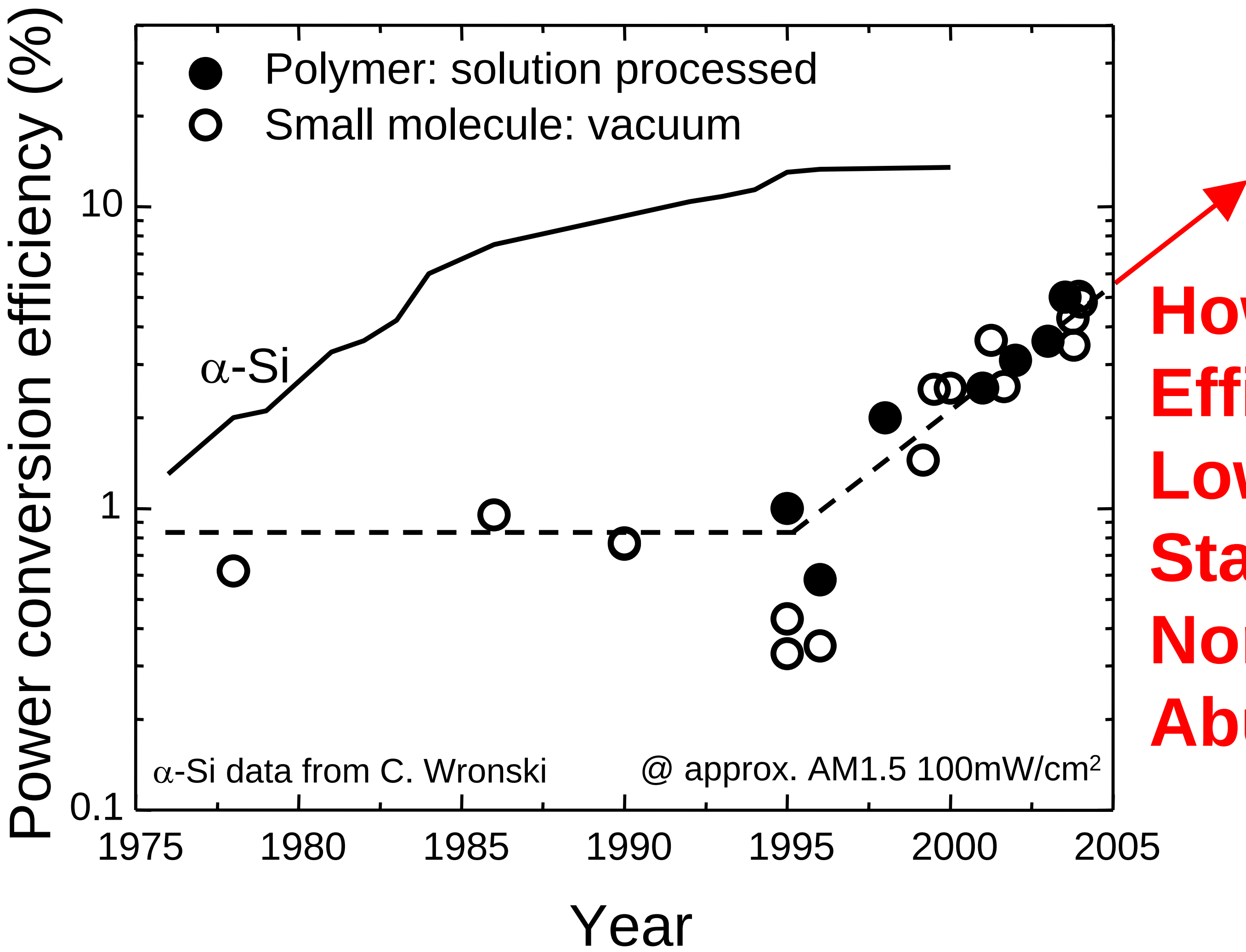


M. Shtein, unpublished



P. Peumans, unpublished

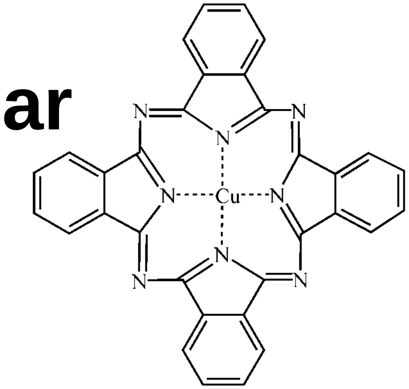
Efficient?
Progress in Organic Solar Cells



How?
Efficiency limits?
Low-cost?
Stable?
Non-toxic?
Abundant?

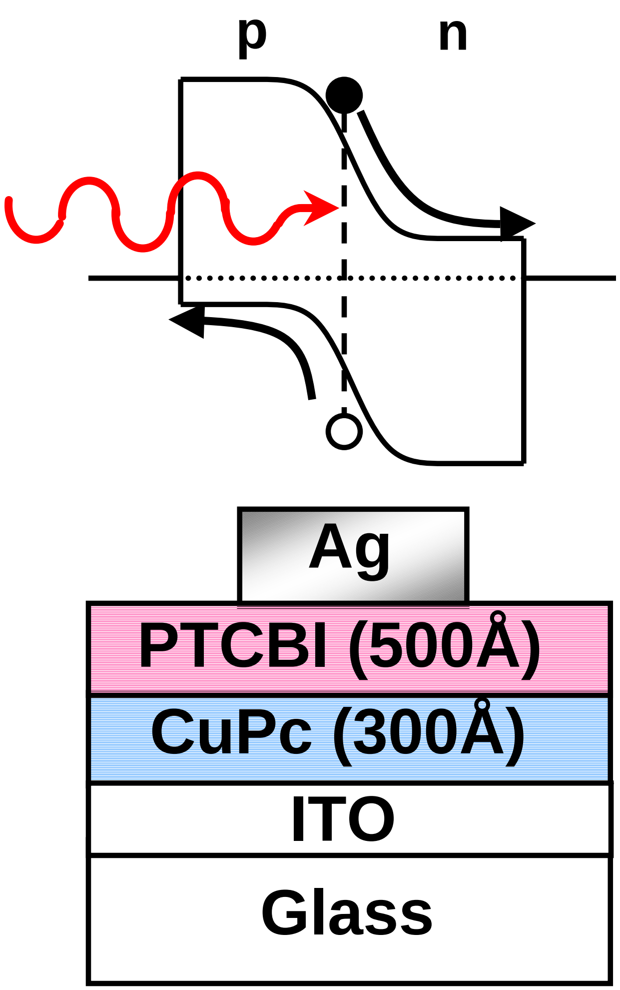
Phthalocyanines

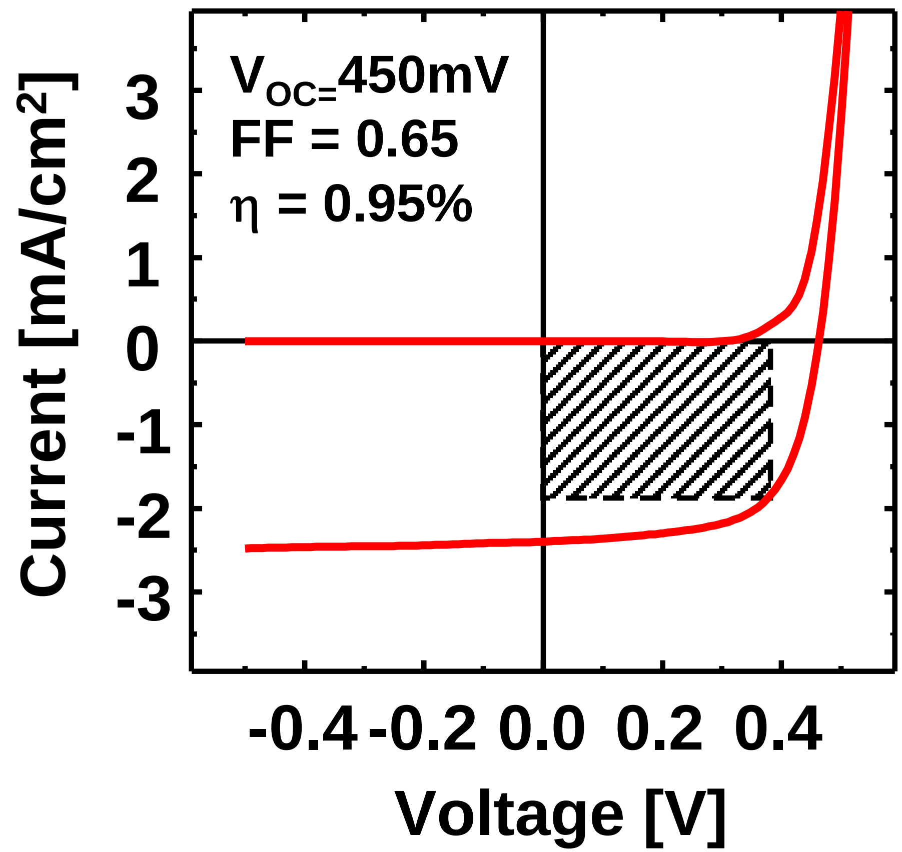
- Abundant: BASF makes 70,000 tons/year
- Non-toxic
- Low-cost: ~1$/g → 17¢/$m^2$
- Stable



Historical Perspective

pn-diode PV cell

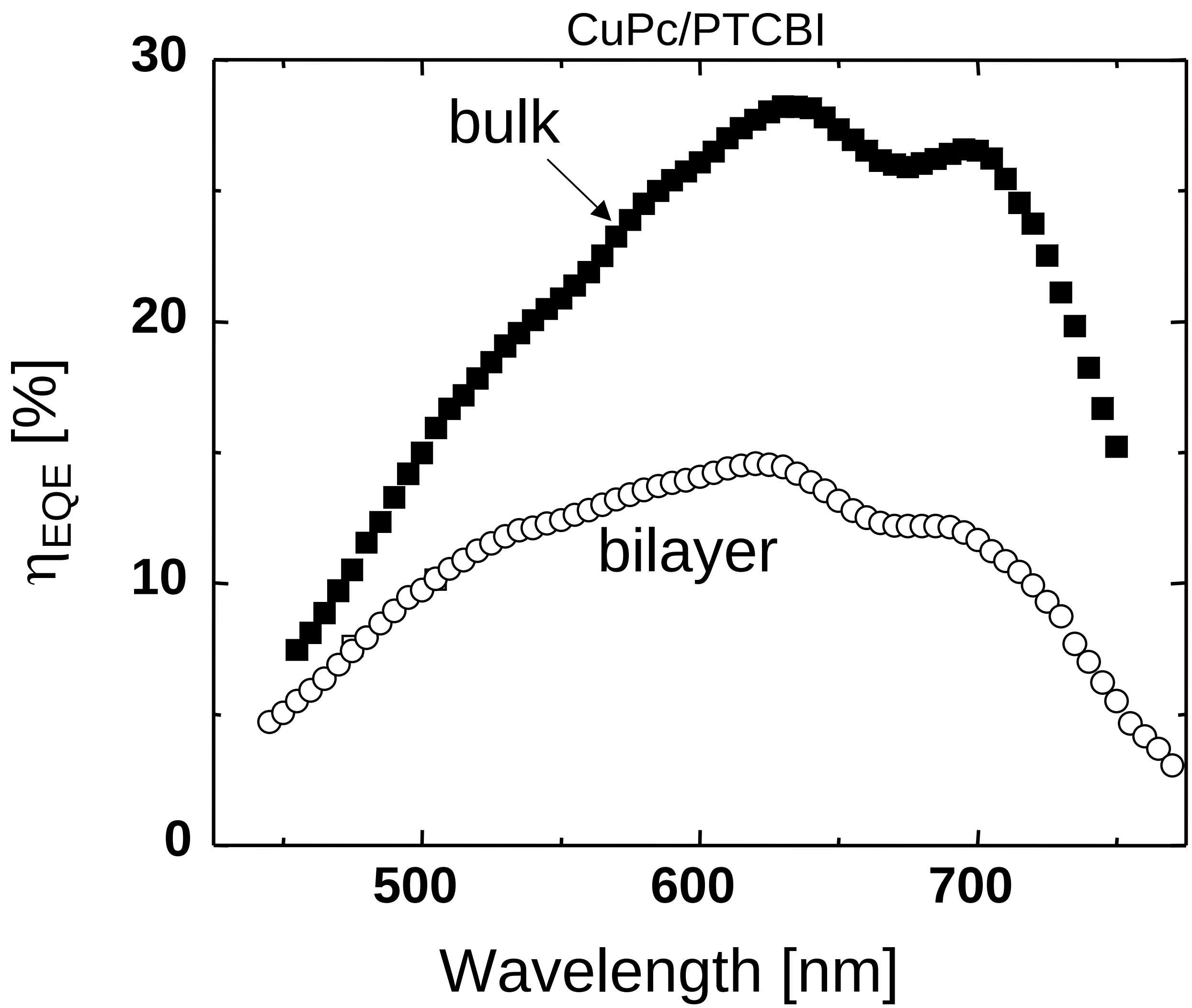


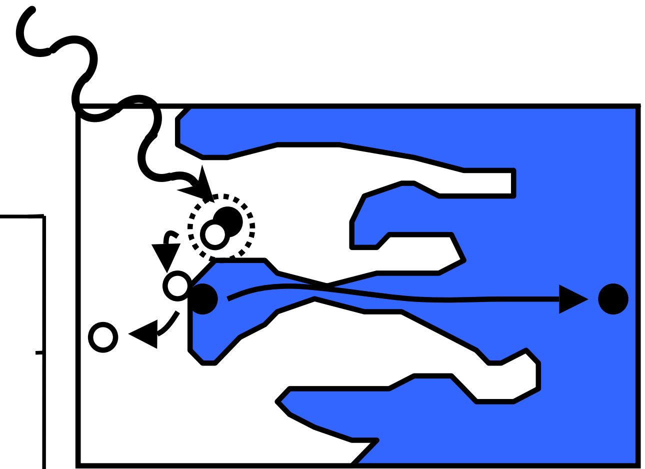


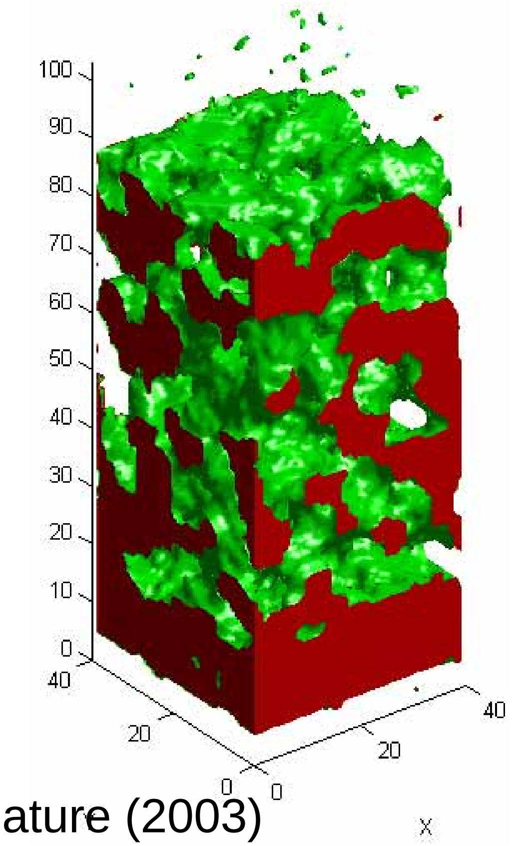
C.W. Tang, Appl. Phys. Lett. **48**, 183 (1986).

Nanostructured Solar Cells

~2 fold increase in quantum efficiency



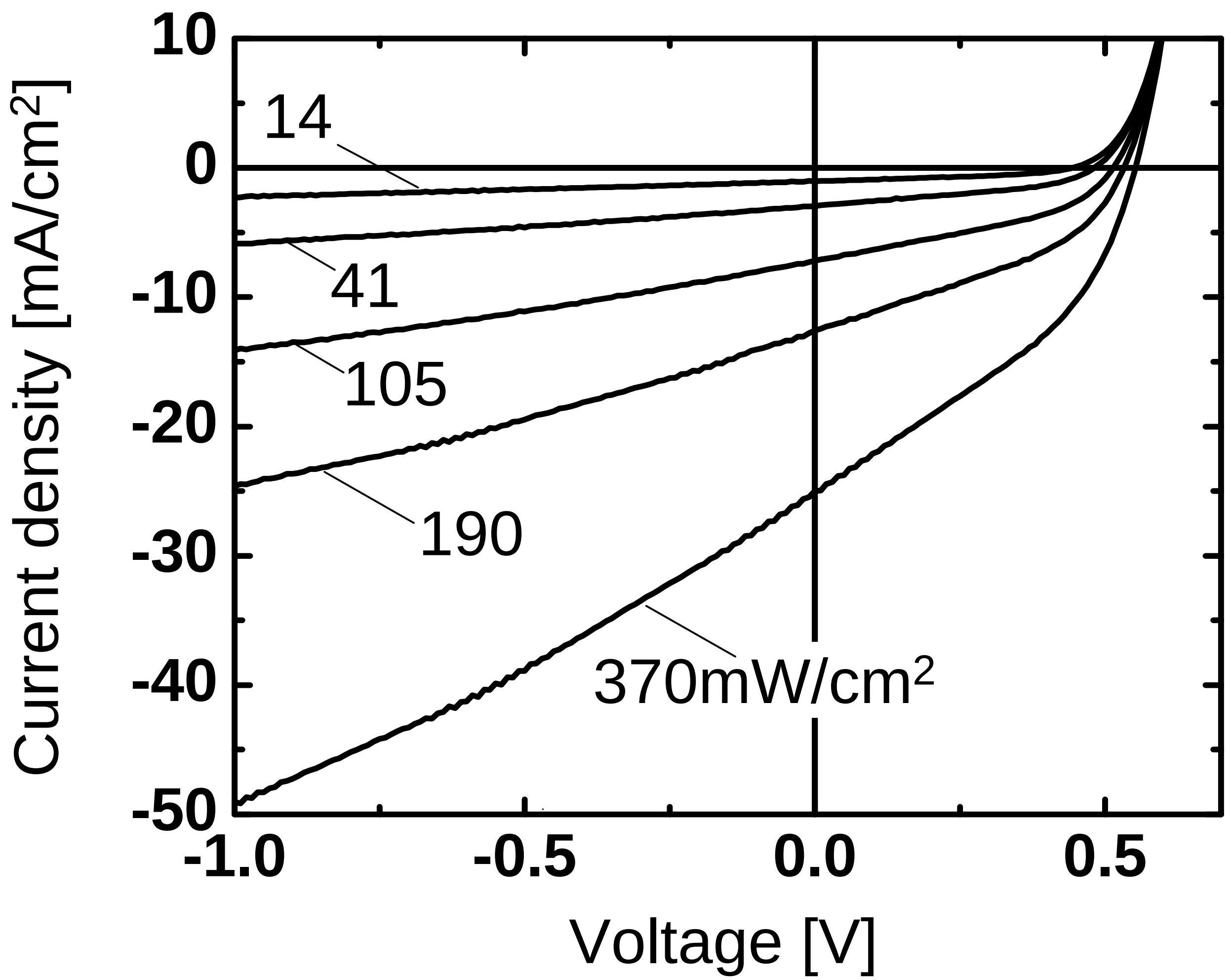


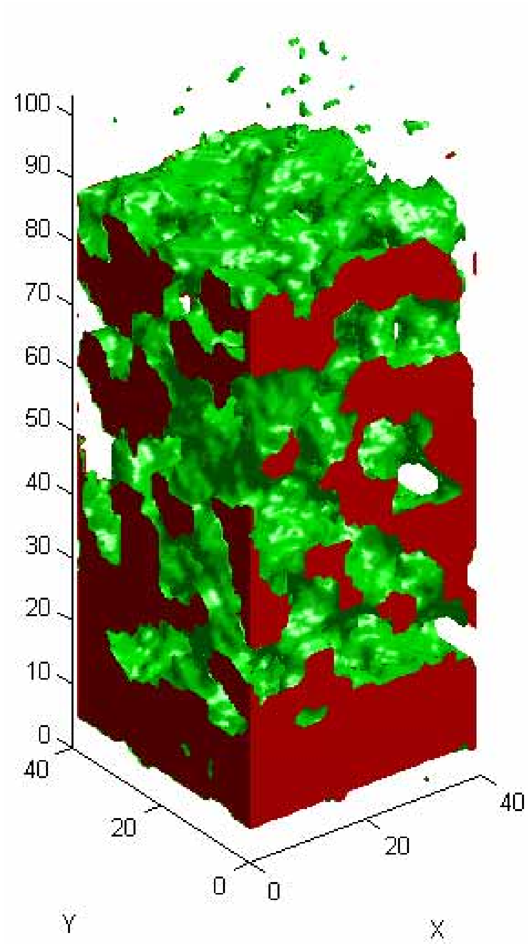


P. Peumans, S. Uchida and S.R. Forrest, Nature (2003)

Unexplained Losses

Usually attributed to low mobilities

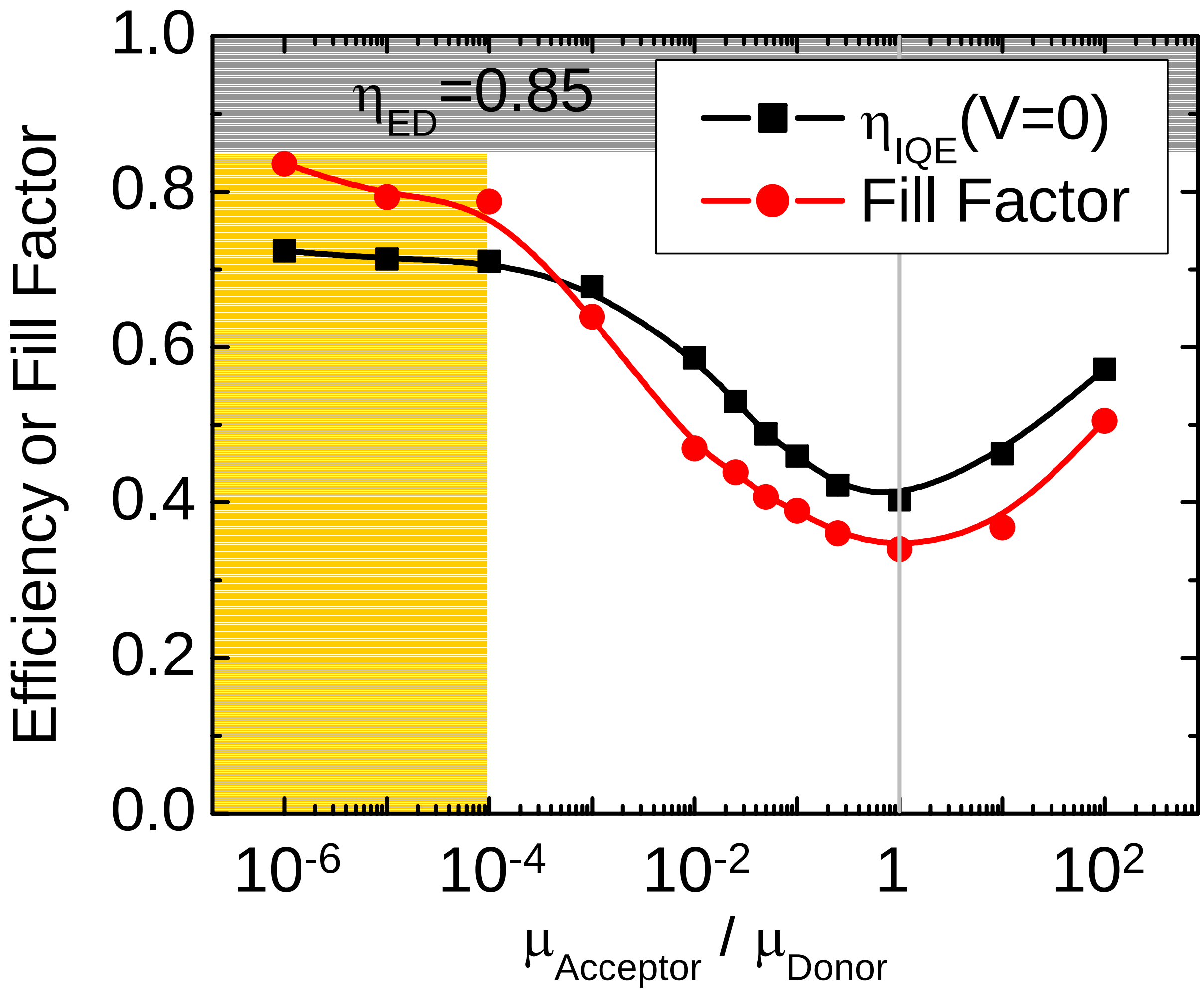




P. Peumans, et al., Nature ***425****, 158 (2003).*

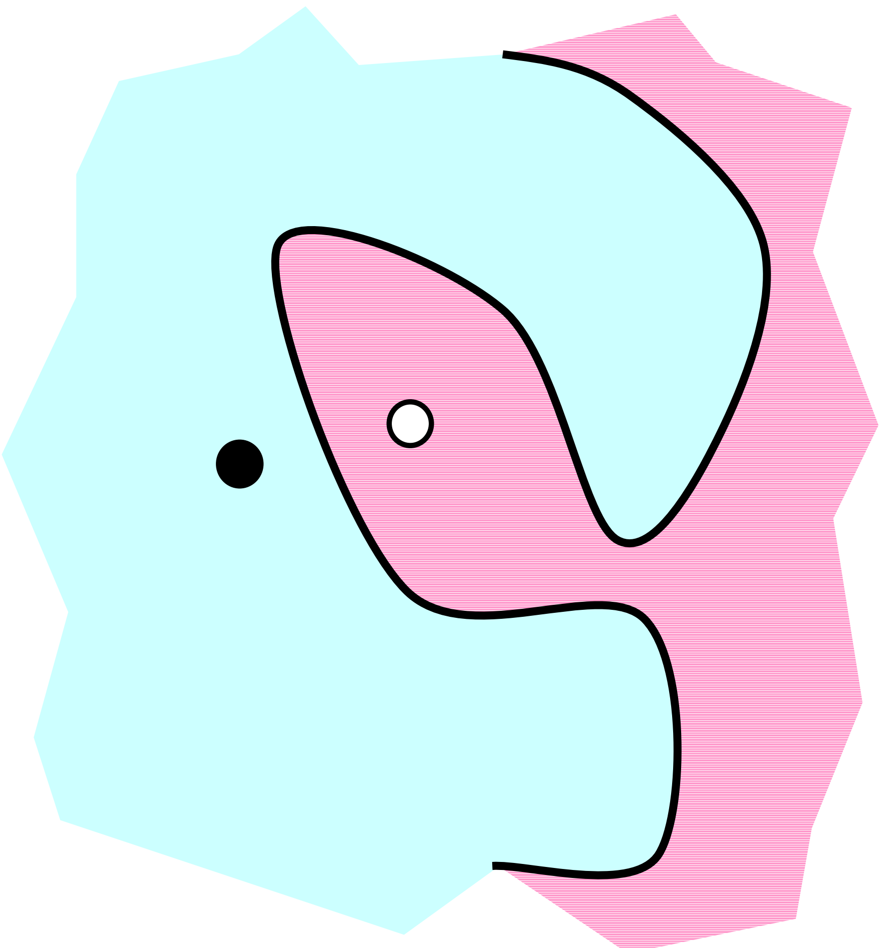
Ratio of Charge Carrier Mobilities

It is not mobility that counts, but mobility ratio!



Toy Model

Low Mobility Ratio



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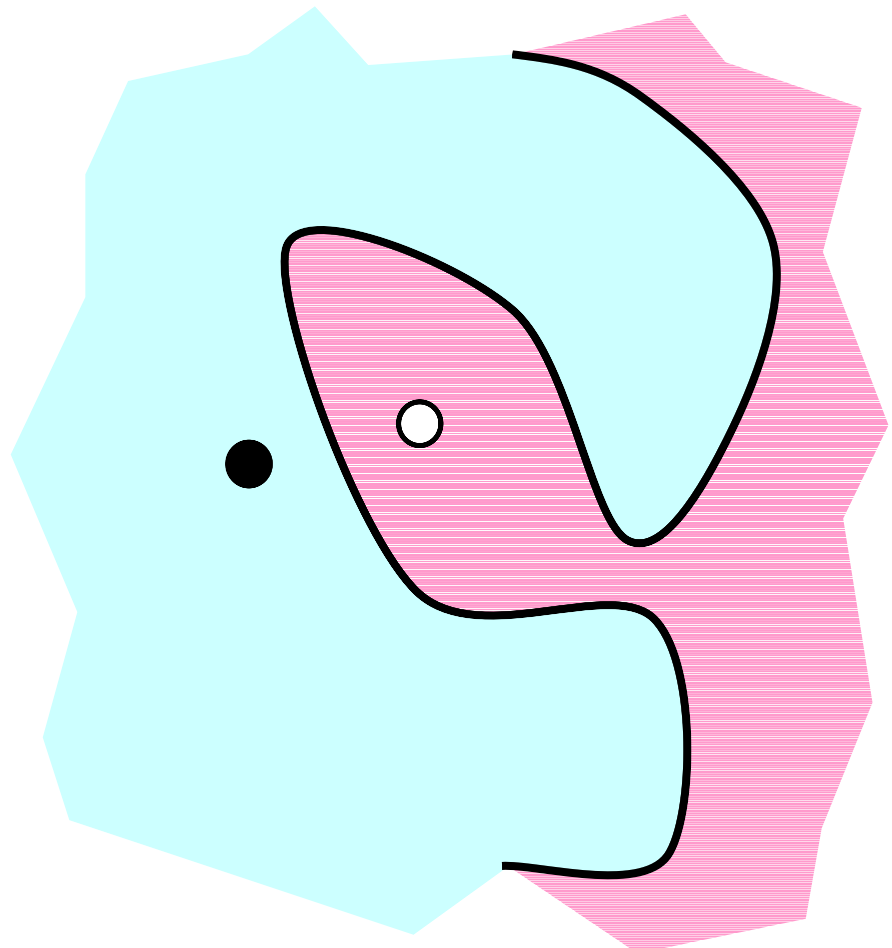

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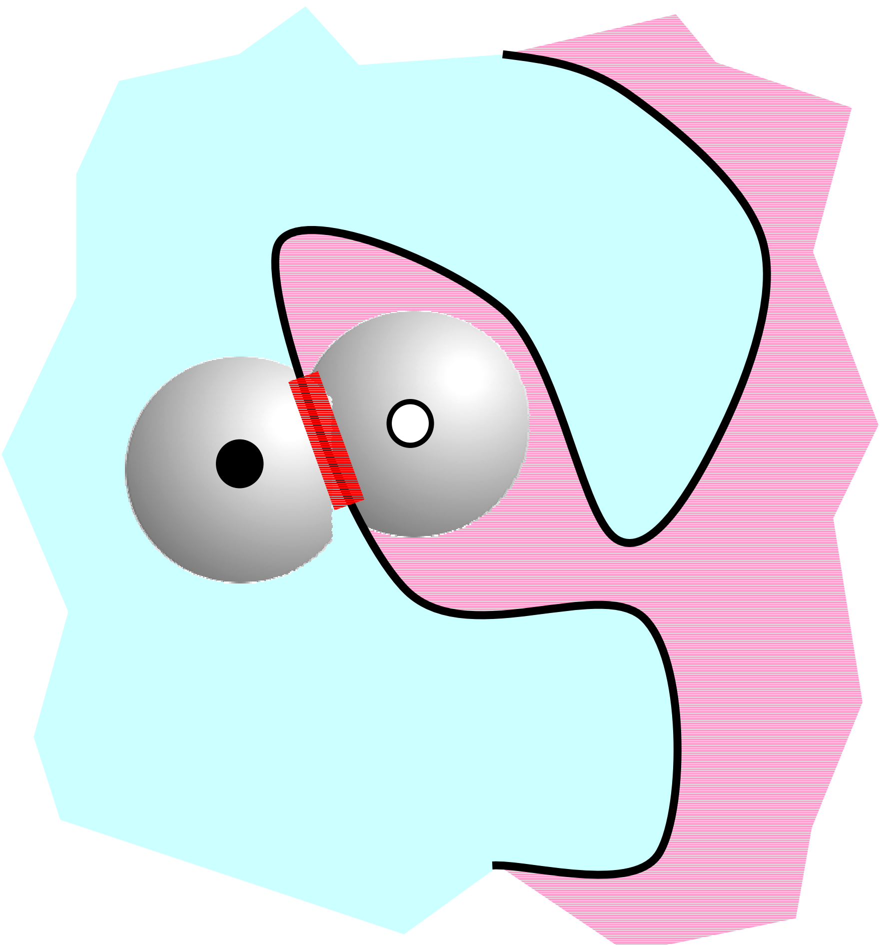

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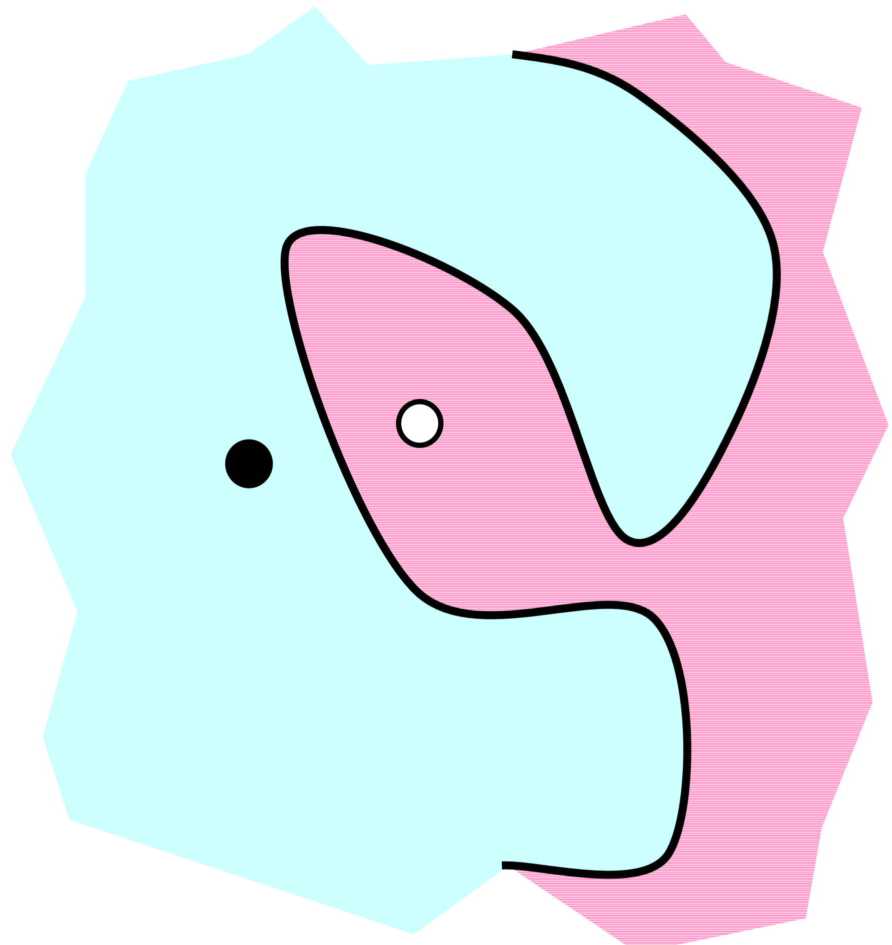

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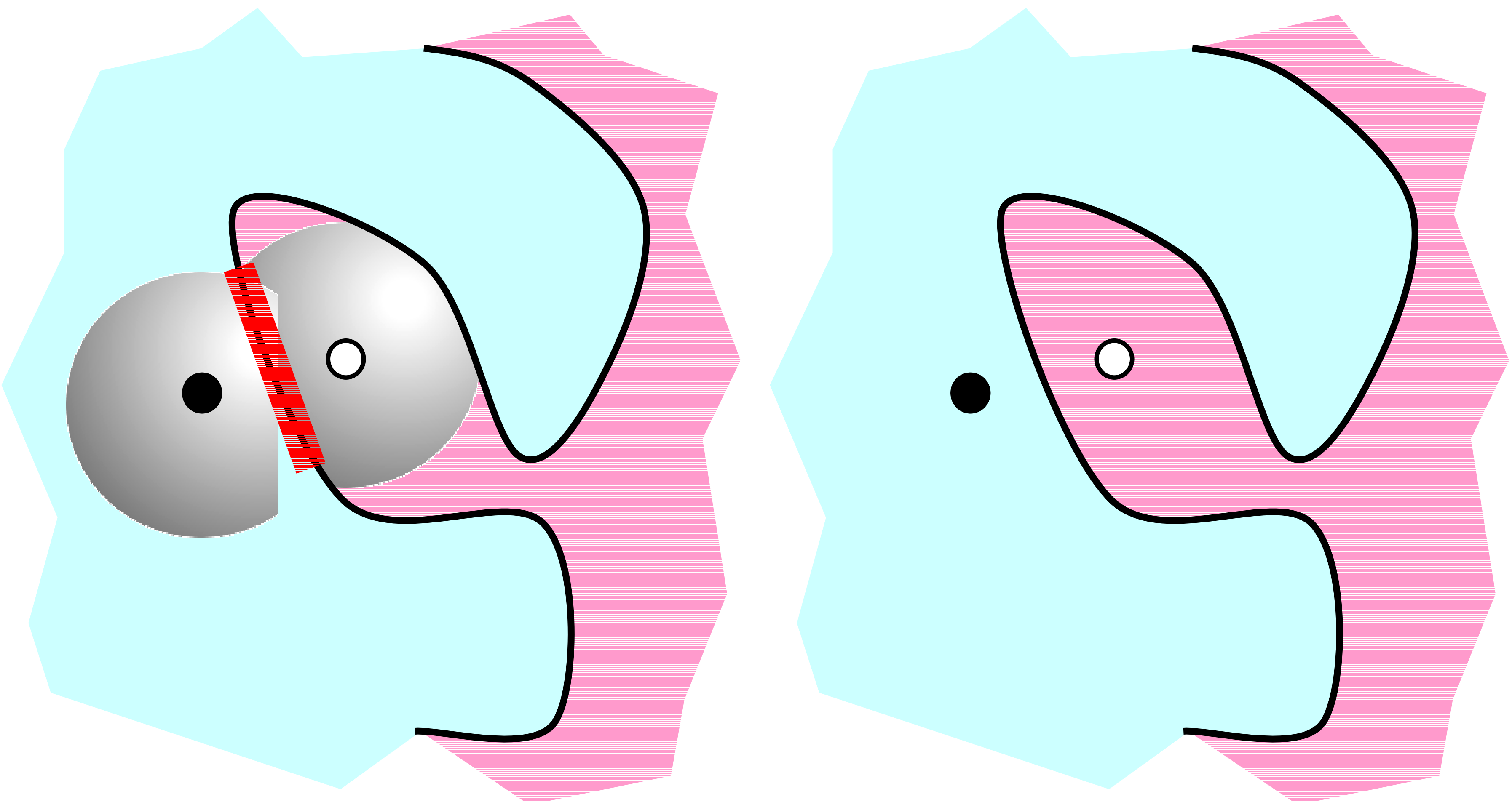

Toy Model

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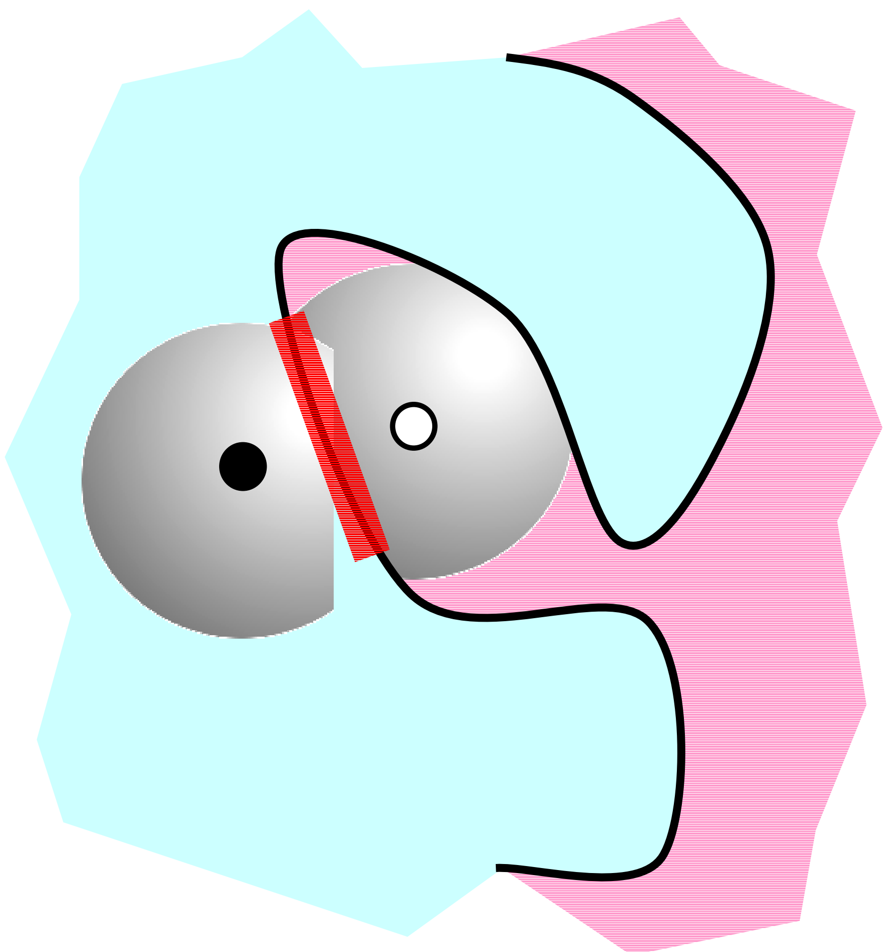
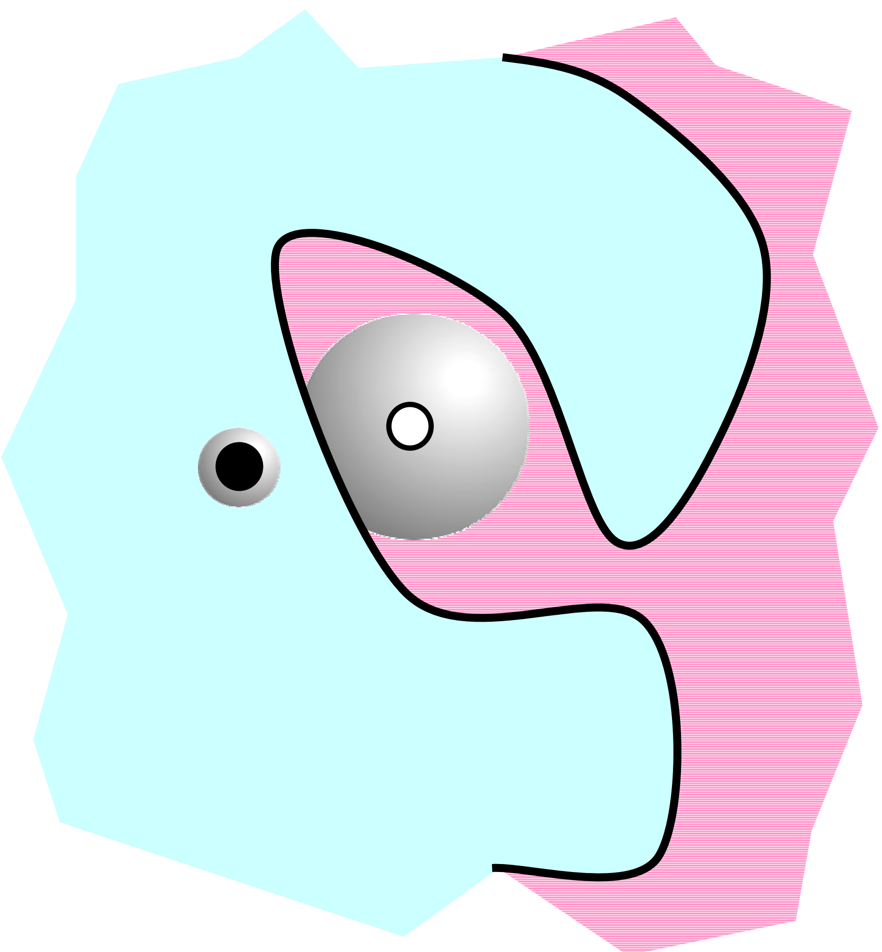


High Mobility Ratio



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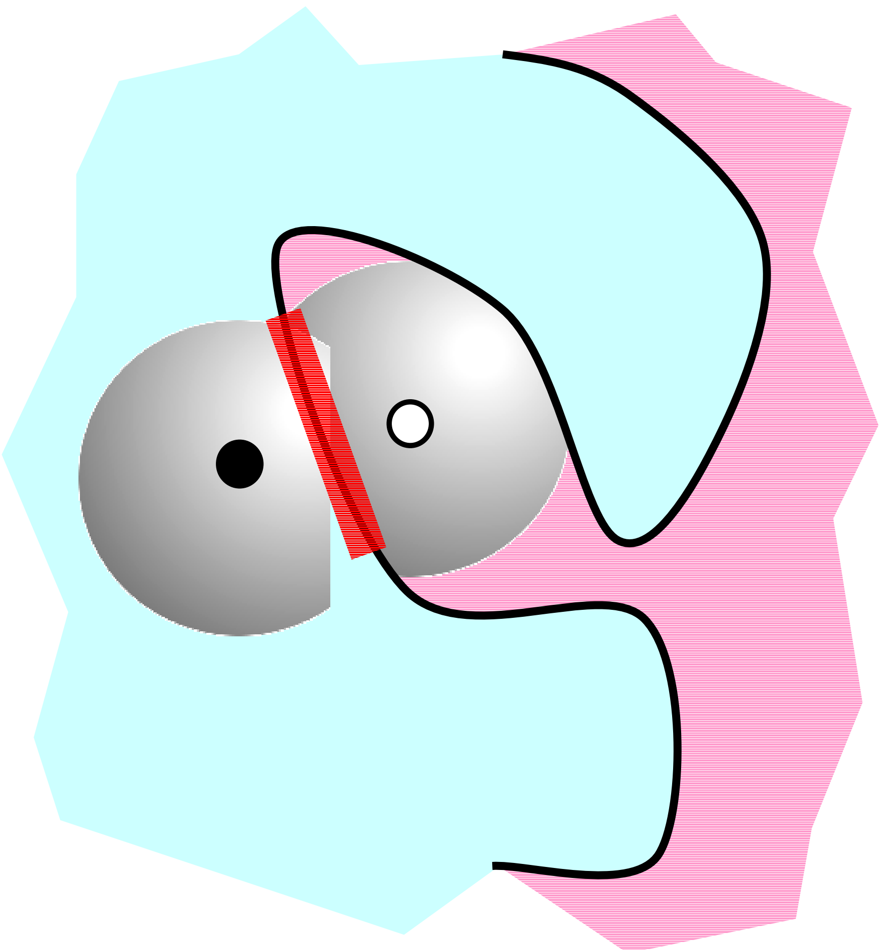
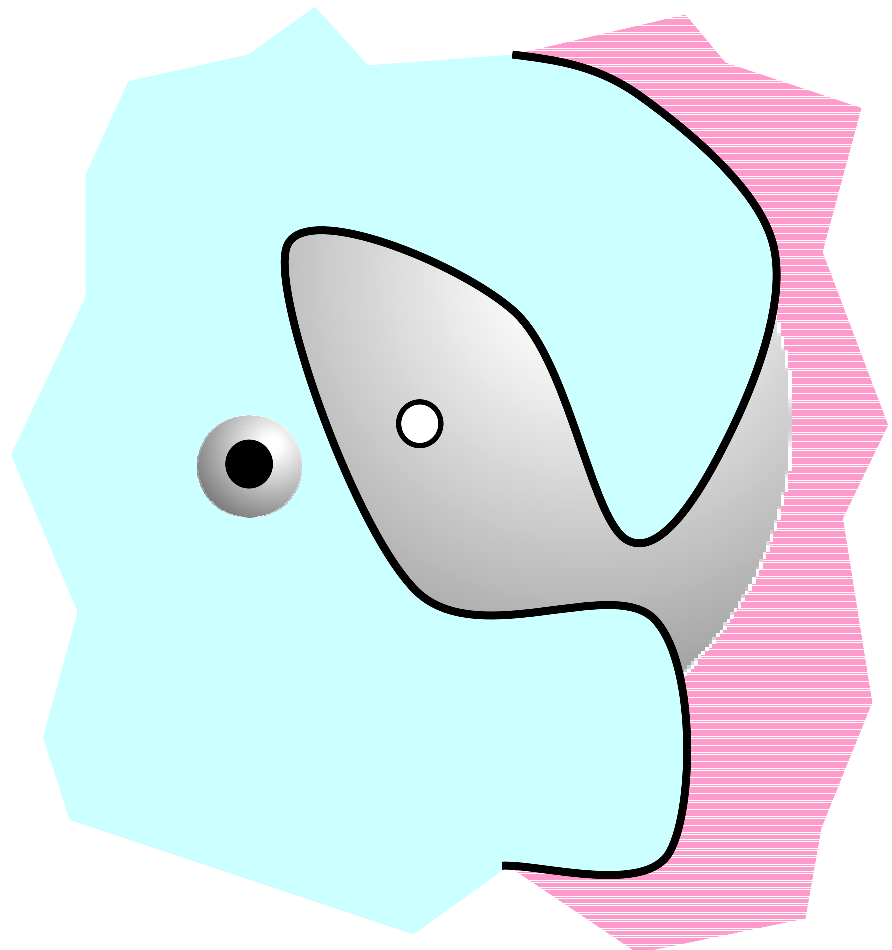
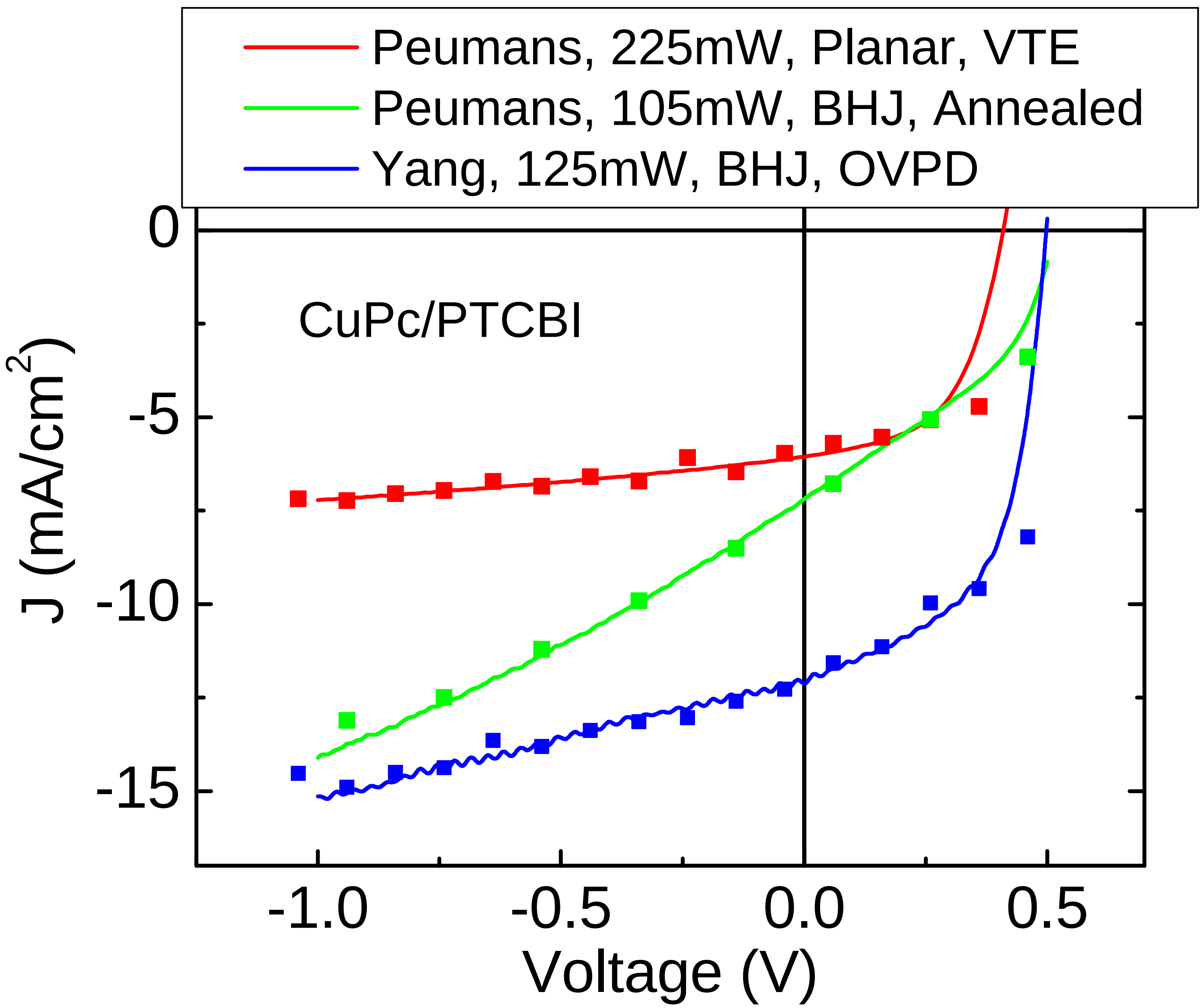
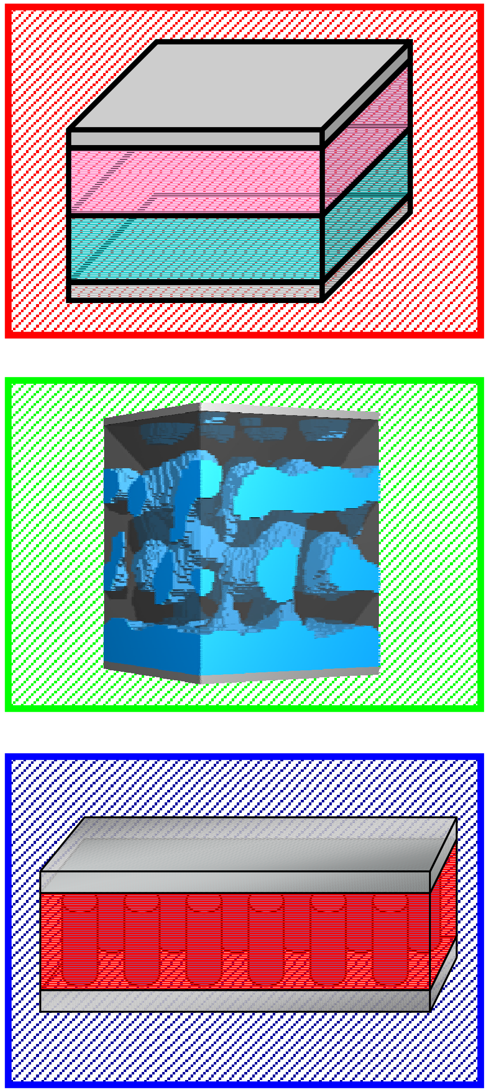


High Mobility Ratio



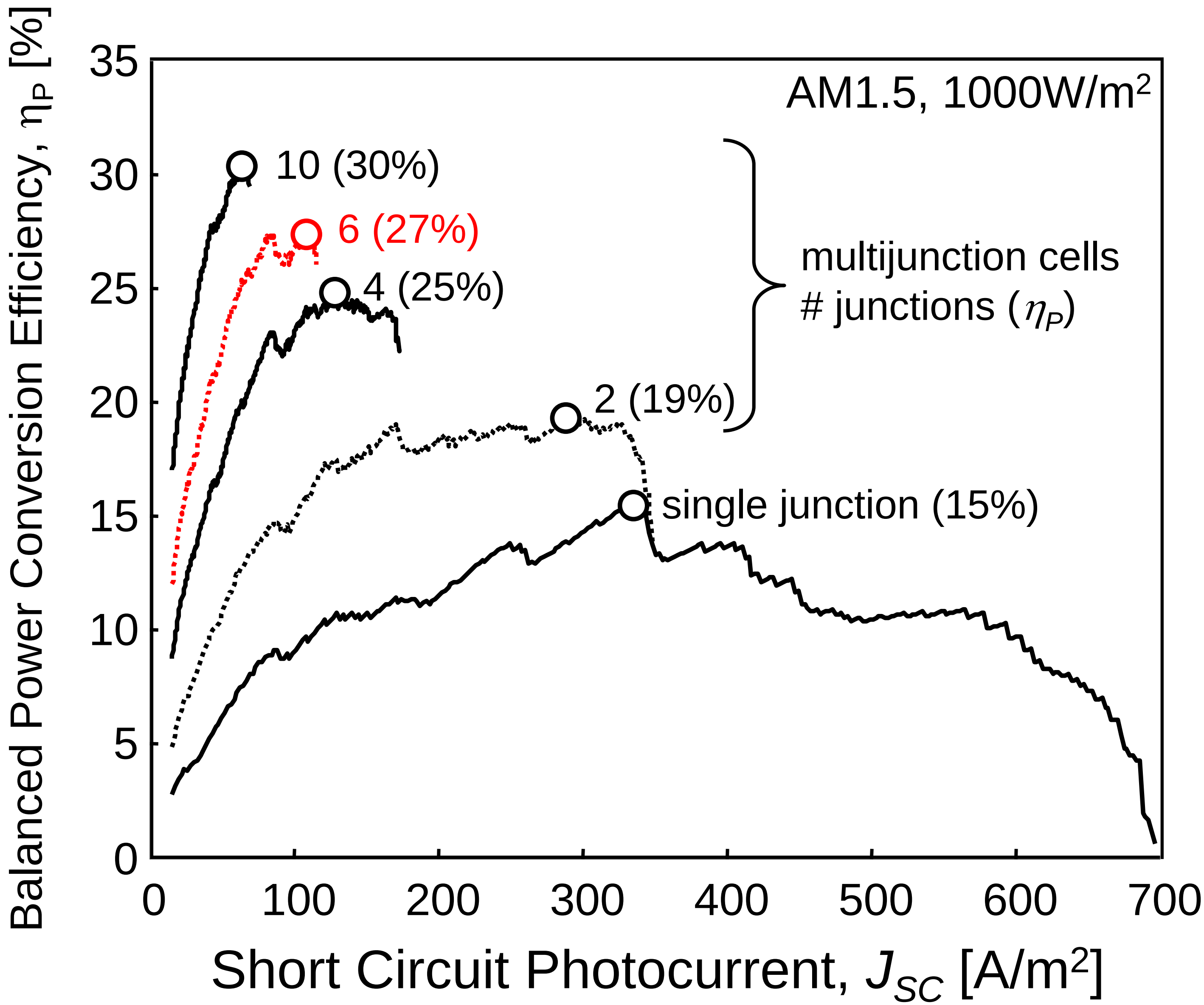
Ordered Structures



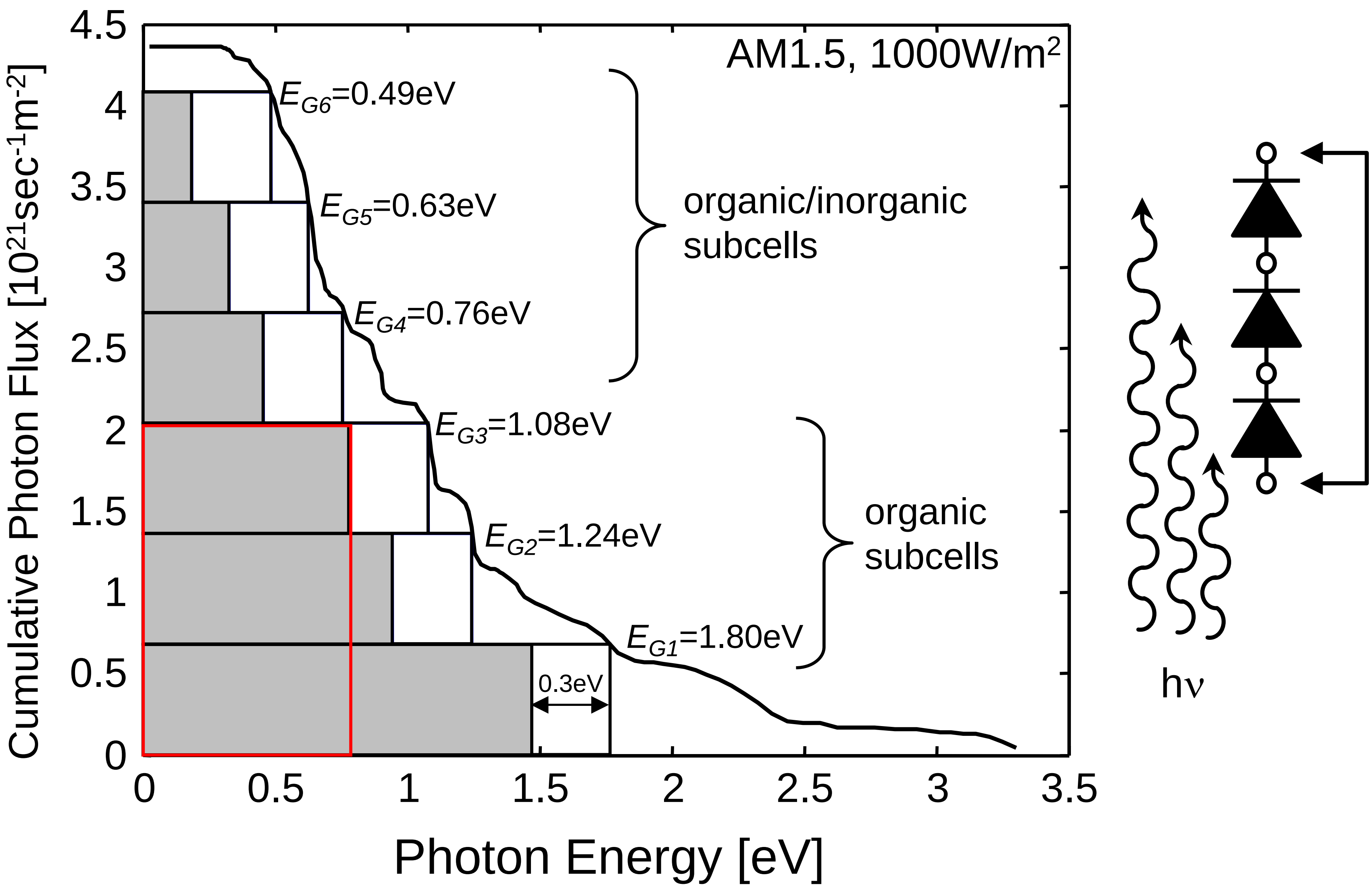


F. Yang, et al, *Nature Materials*, **4**, 37-41, 2005

What's Next? Multijunction Cells

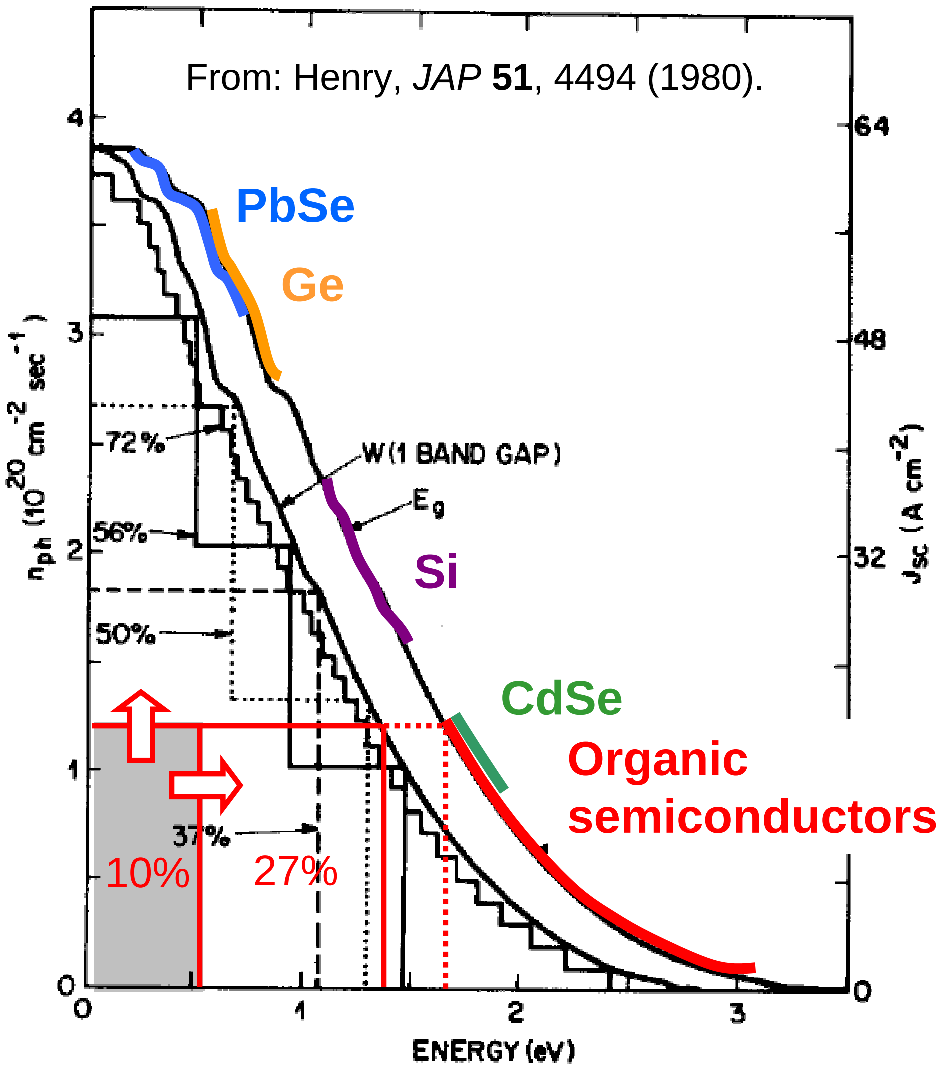


Material Requirements

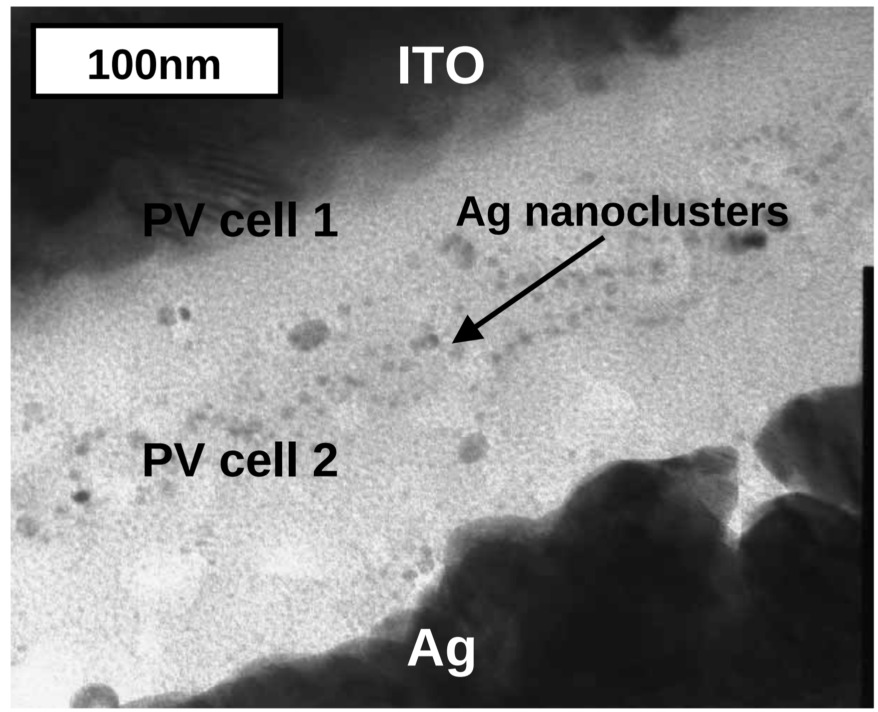


Nanoparticle Technology

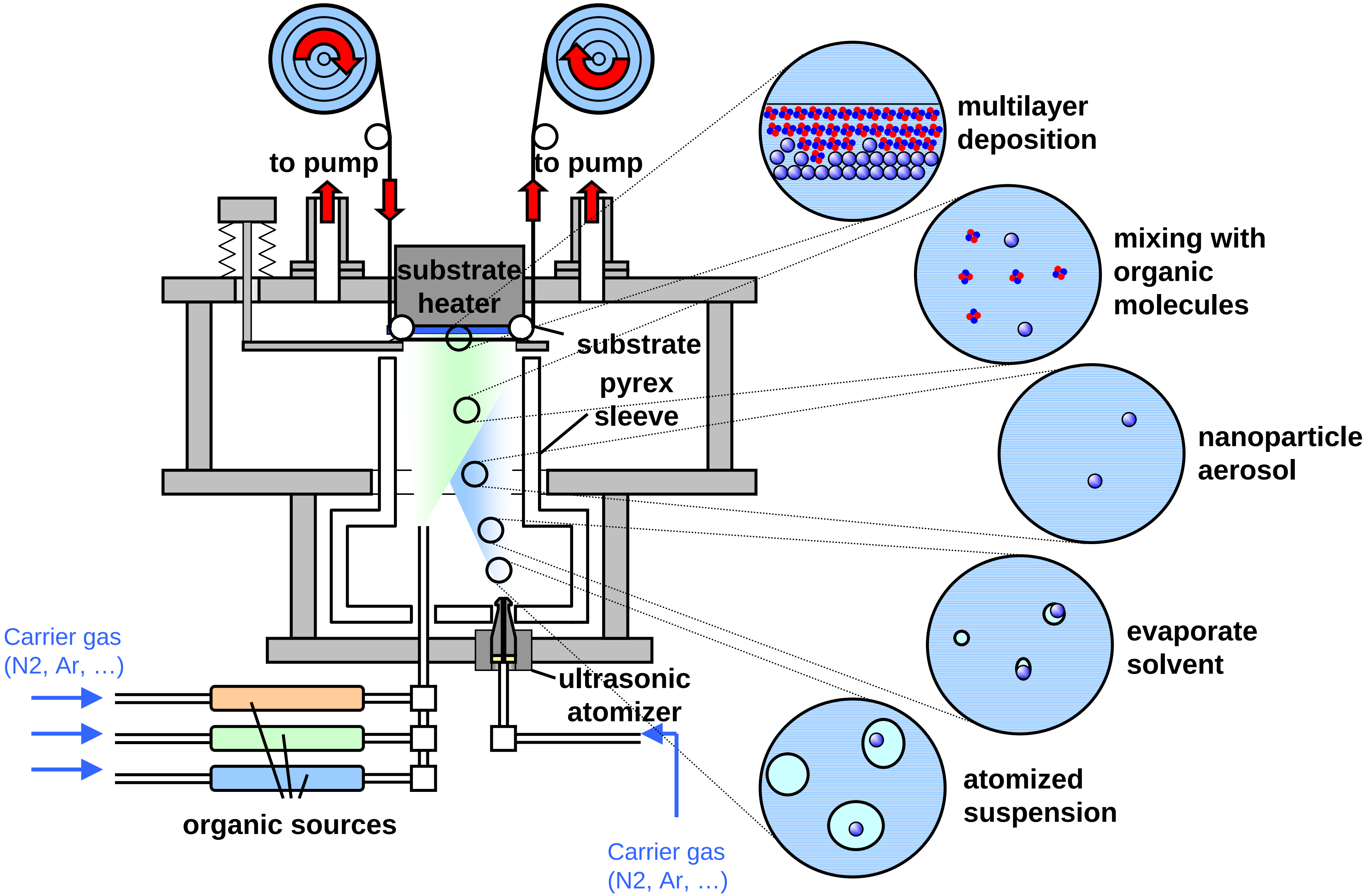
Semiconducting absorbers



Metallic recombination centers



Manufacturing Technology



Conclusions

- Organic pigments are promising materials for large-scale photovoltaics
  - Low-cost, stable, non-toxic, abundant, efficient
- A detailed understanding of the underlying physics can result in large gains in efficiency
- Multijunction organic solar cells have an efficiency potential >20%
- Efforts required:
  - Energy level engineered molecules
  - Multijunction cells
  - Manufacturing technology
  - Packaging technology

Vacuum Deposition is a Low-Cost Technology

Examples from Applied Films