2.626 Fundamentals of Photovoltaics
Fall 2008

# Charge Collection

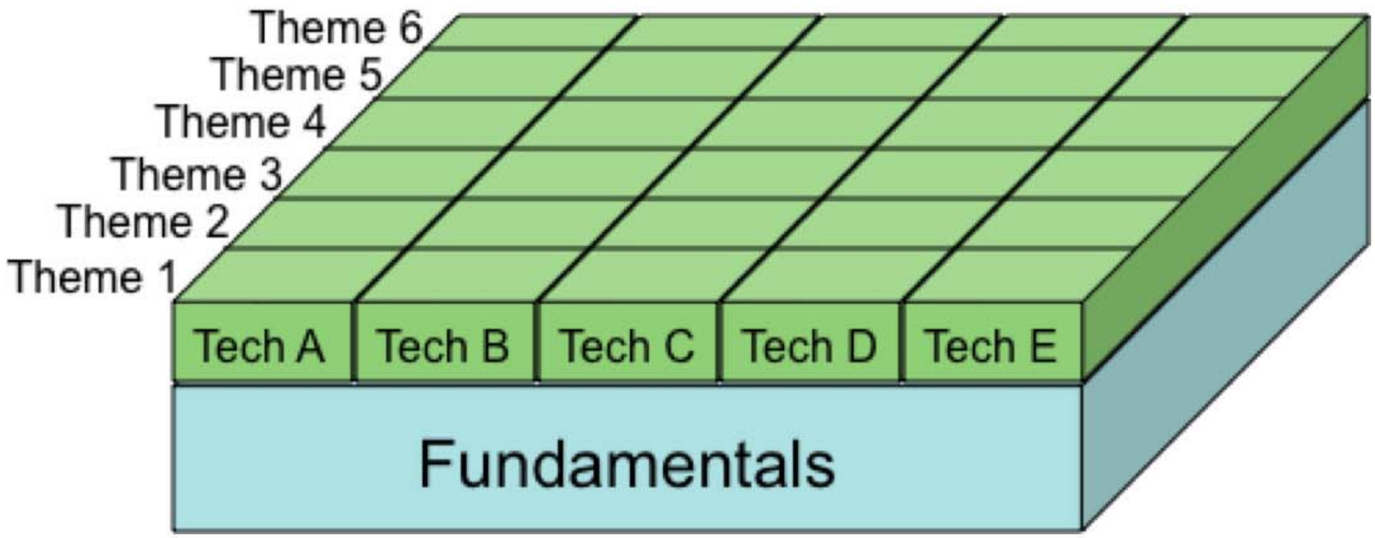
Lecture 7 – 2.626

Tonio Buonassisi

# General Announcements

- Books: Order is made.
- Quiz #1: In one week.
  - Thursday = Review
- Homework Assignment #1: Due today.
  - Homework Assignment #2: Postponed until after exam.
- Class Projects
- Concept Quiz
  - First, a brief review of pn-junctions…

# Syllabus Check



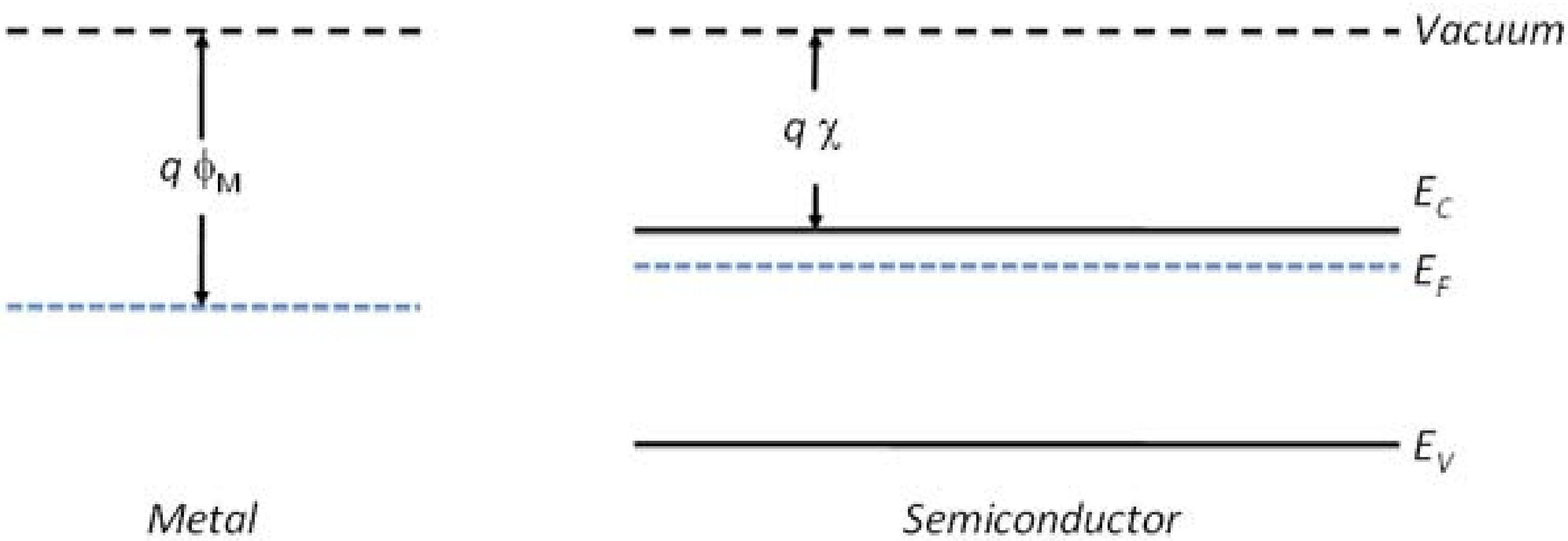
# Today's Topics

- Metallization. Schottky and Ohmic contacts.
- Advanced concepts for charge collection (hot carrier devices).
- Solar cell device architectures.
- *Common limitations of efficiency, short-circuit current, fill factor, open-circuit voltage (separate "efficiency" lecture).*
- *Lab component: Assessing the efficiency of a solar cell device, and performance loss mechanisms, simulating solar cell efficiencies using "commercial" software package PC1D. (postponed).*

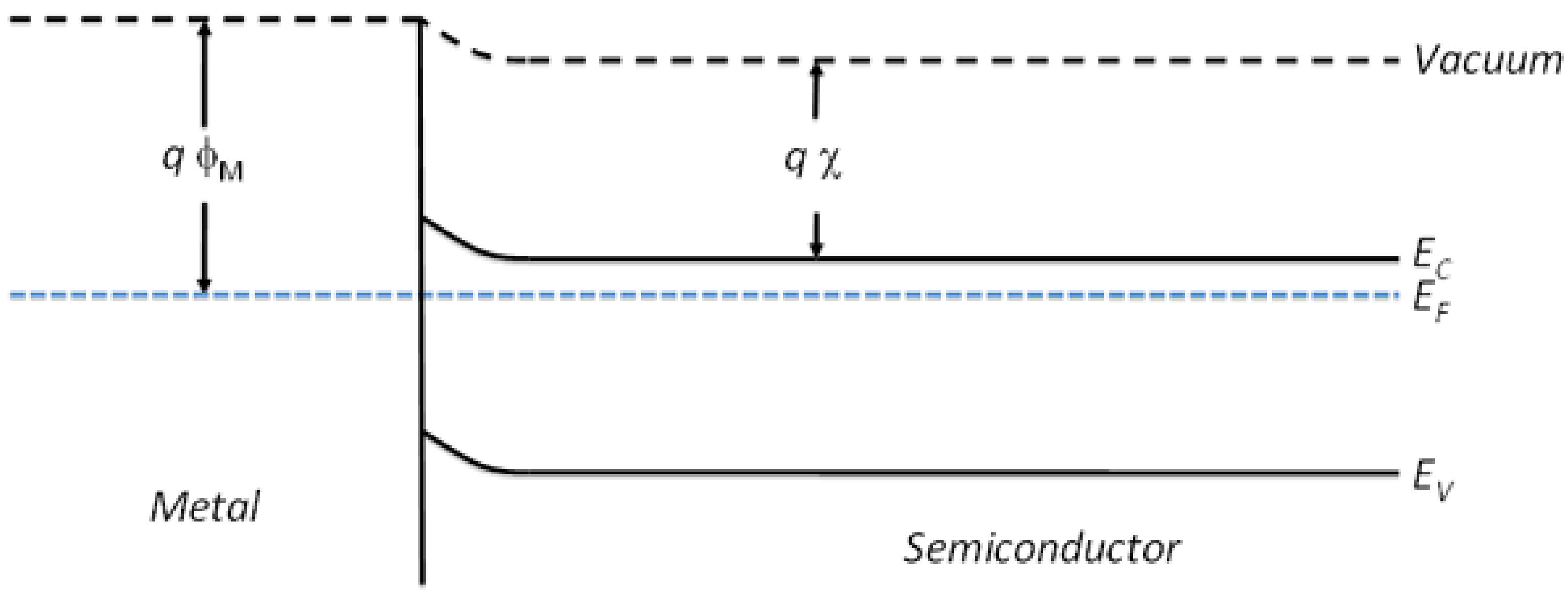
# Contacts…

- …extract carriers from device.
- …prevent back-diffusion of carriers into device.
- …are studied extensively in the semiconductor industry (several good review papers) for “common” semiconductors.
- …are semiconductor-specific: While fundamentals generally apply universally, the devil is in the details, and each material system requires individual optimization.

# Contacts



# Contacts



# Contacts

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http://www.iue.tuwien.ac.at/phd/ayalew/img308.png

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# Types of Contacts

- **Ohmic:**
  - Electron barrier height $\leq 0$.
  - Linear I-V curve.

- **Schottky:**
  - Electron barrier height $> 0$.
  - Exponential I-V curve.

# Evaluating Metals for Contacts - Theoretical

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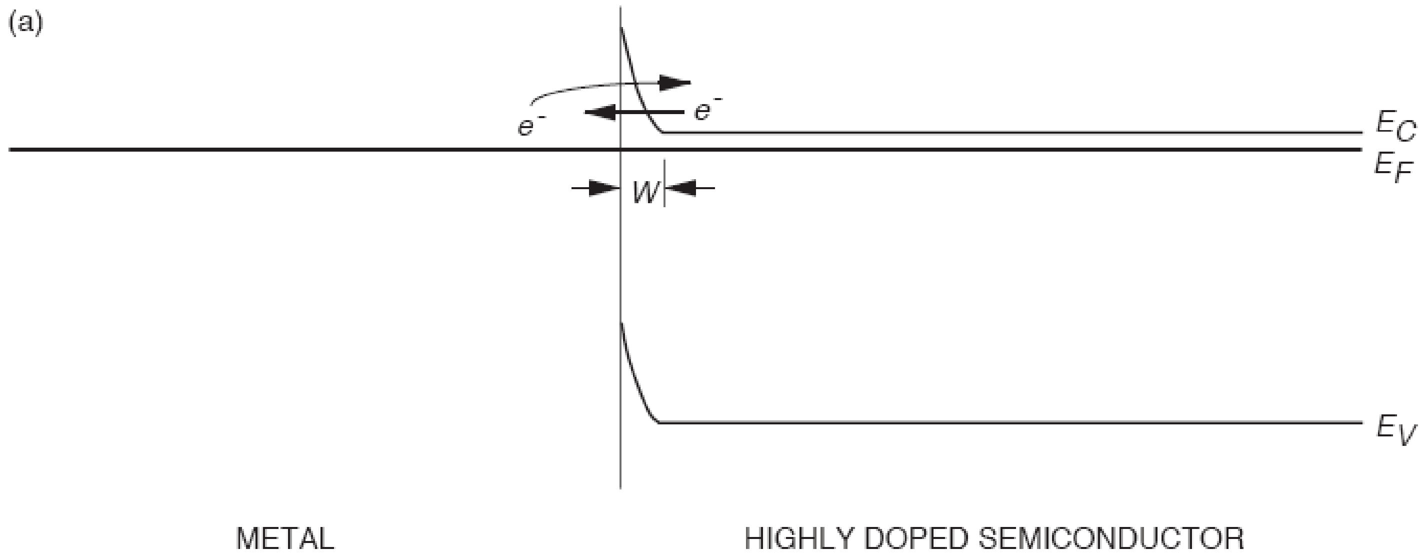
# Evaluating Metals for Contacts - Practical

- Sources:
  - Reference books
  - Review articles
  - Scientific articles
  - Trusted websites

Image removed due to copyright restrictions. Please see http://www.siliconfareast.com/ohmic_table.htm

# Tunneling

Highly-doped semiconductor

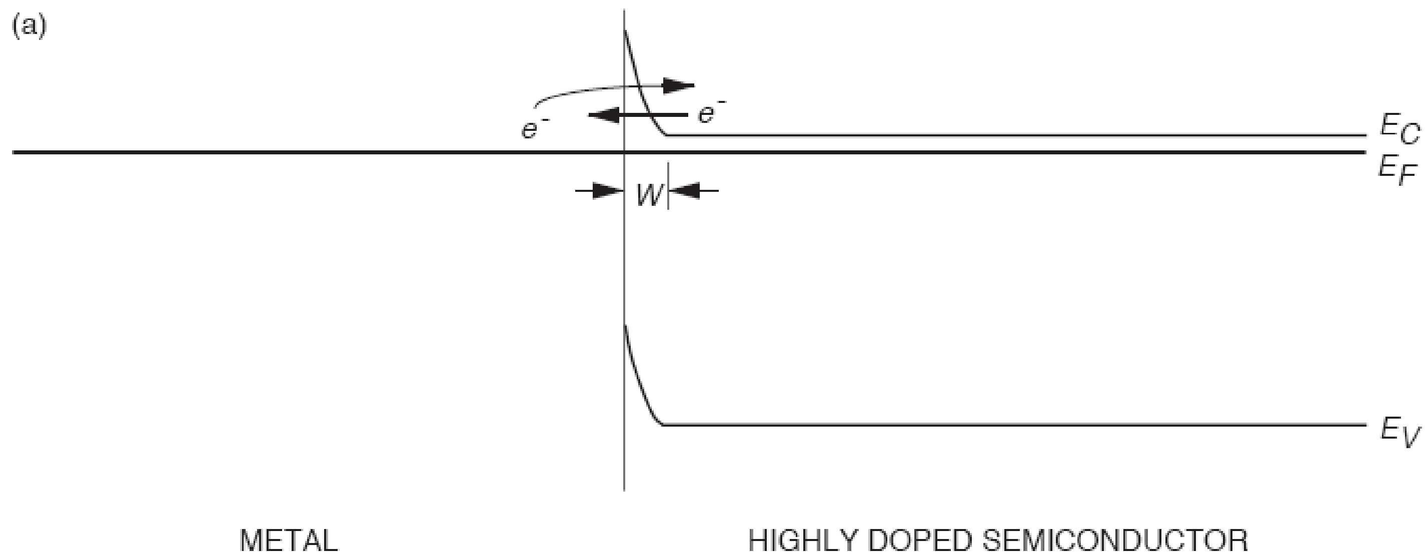



Courtesy NASA/JPL-Caltech. Used with permission.

http://parts.jpl.nasa.gov/mmic/3-II.PDF

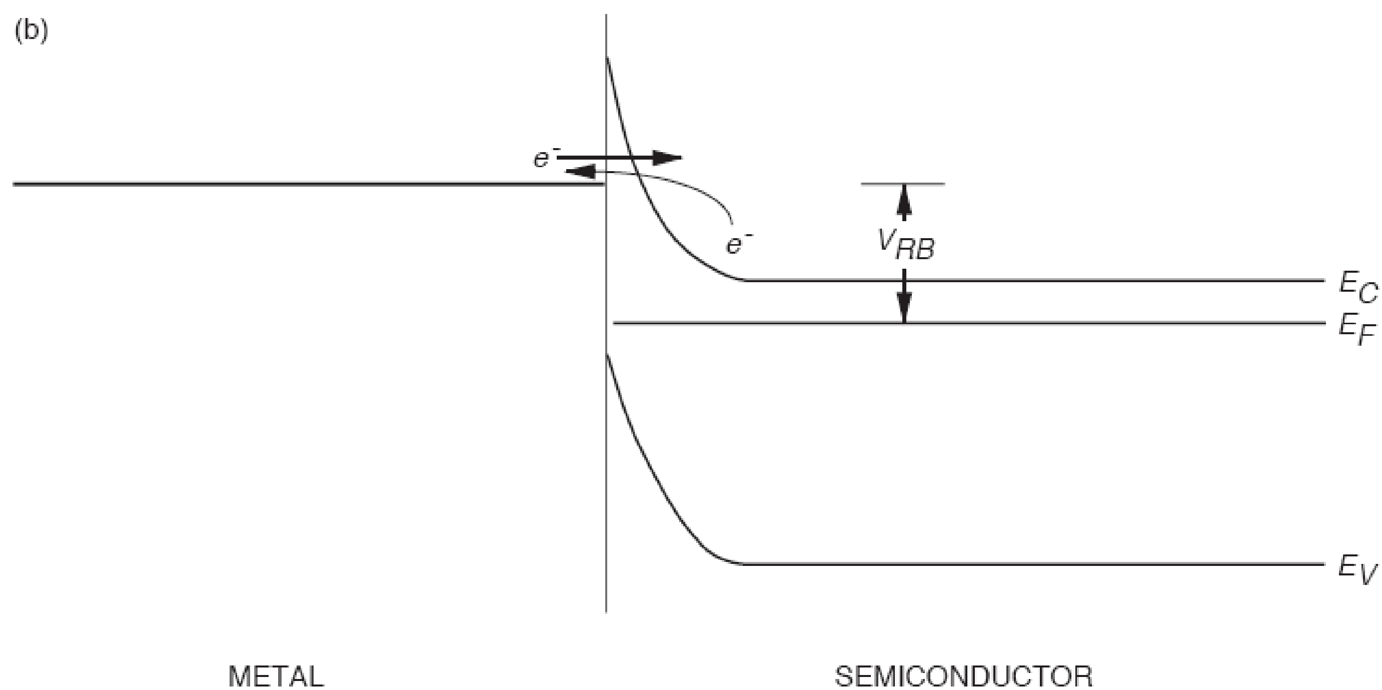
# Tunneling

Highly-doped semiconductor






Reverse-bias semiconductor




http://parts.jpl.nasa.gov/mmic/3-II.PDF

# Advanced Concepts

- Transparent Conducting Oxides (TCOs)
  - Simultaneous optimization of optical properties (transparency) and electrical properties (conductivity) a challenge!
- Ultra-thin metal contacts
- Hot carriers
- Surface charge

# Hot Carrier Cells

## Review of Loss Mechanisms

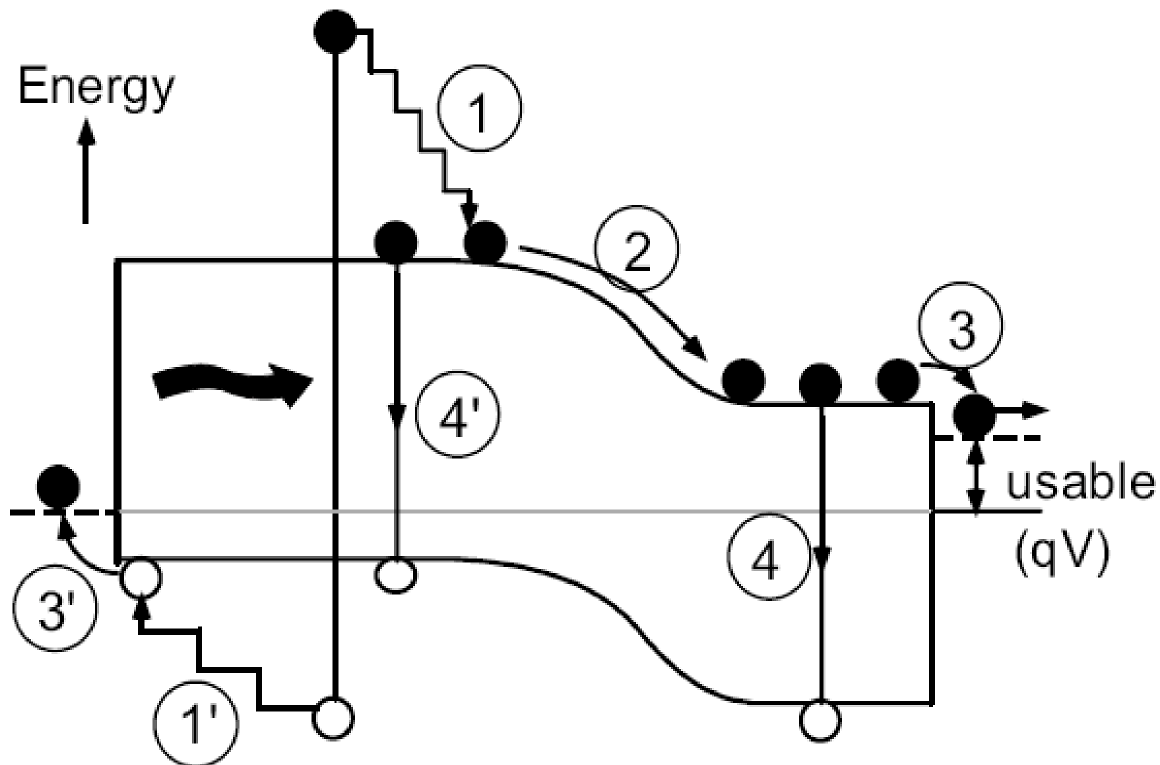





Fig. 1. Loss processes in a standard solar cell: (1) thermalisation loss; (2) and (3) junction and contact voltage loss; (4) recombination loss.

M. Green, Third generation photovoltaics: solar cells for 2020 and beyond. *Physica E* **14**, 65 (2002).

# Hot Carrier Cells

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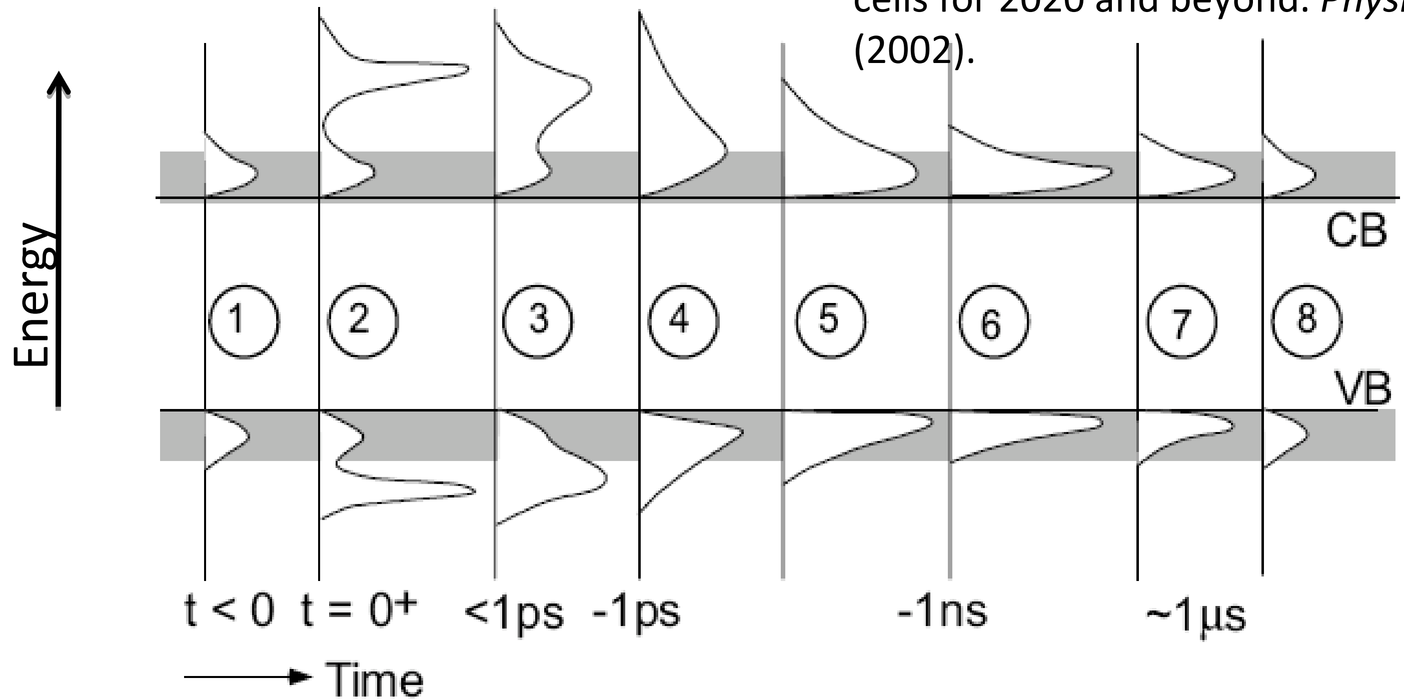


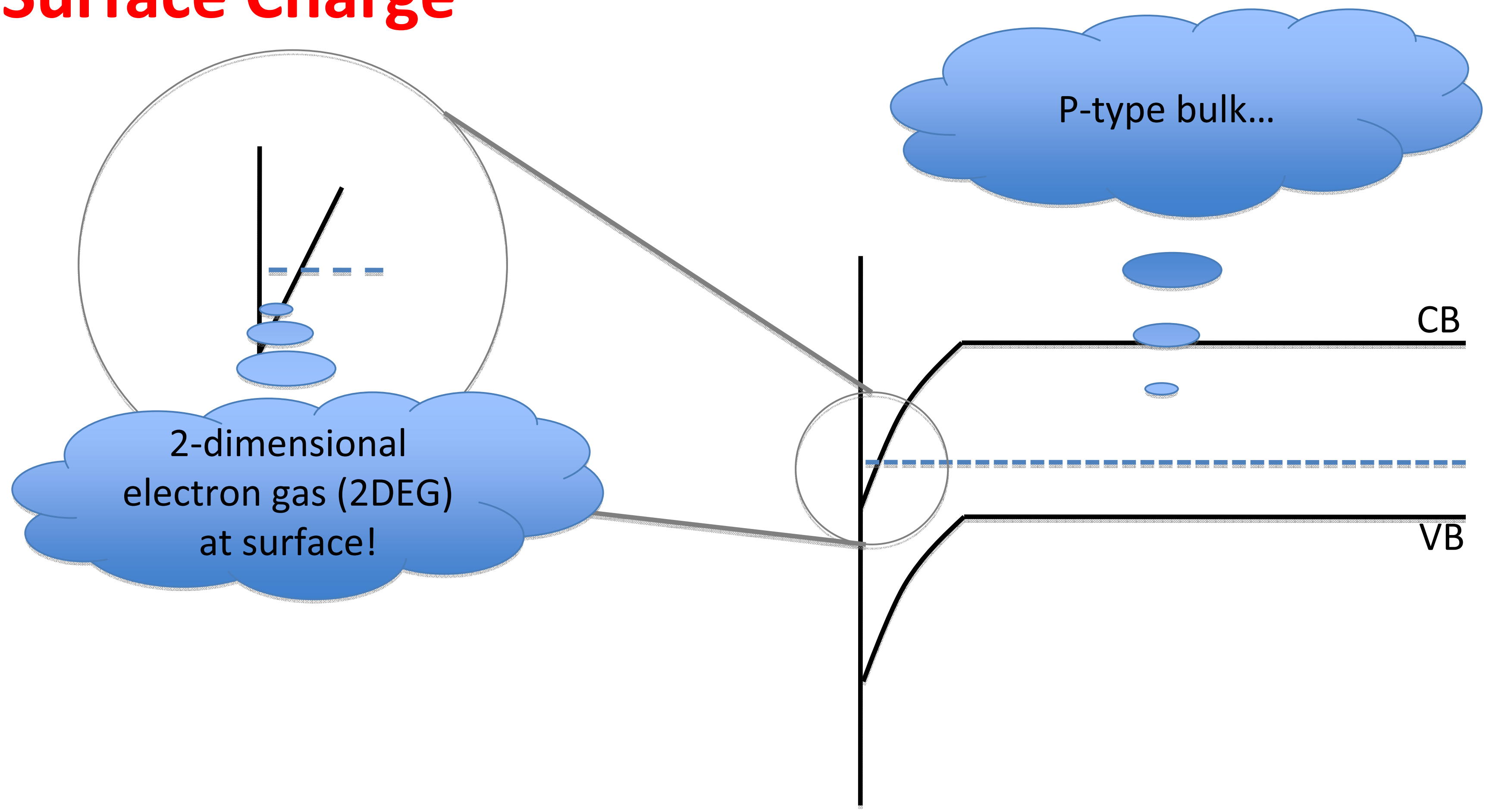



Fig. 4. Energy relaxation of carriers after a short, high-intensity laser pulse at $t = 0$.

Hot carriers lose energy due to inelastic collisions with lattice atoms (phonon creation).

*If carriers can be extracted before inelastic collisions occur, then one could, in principle, create a very high-efficiency device!*

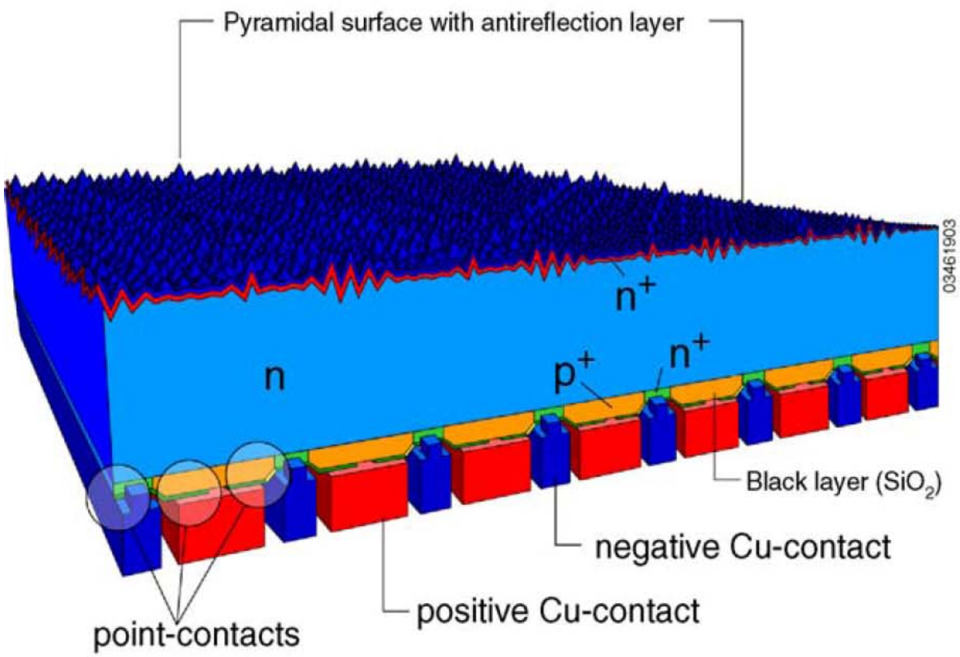
# Surface Charge



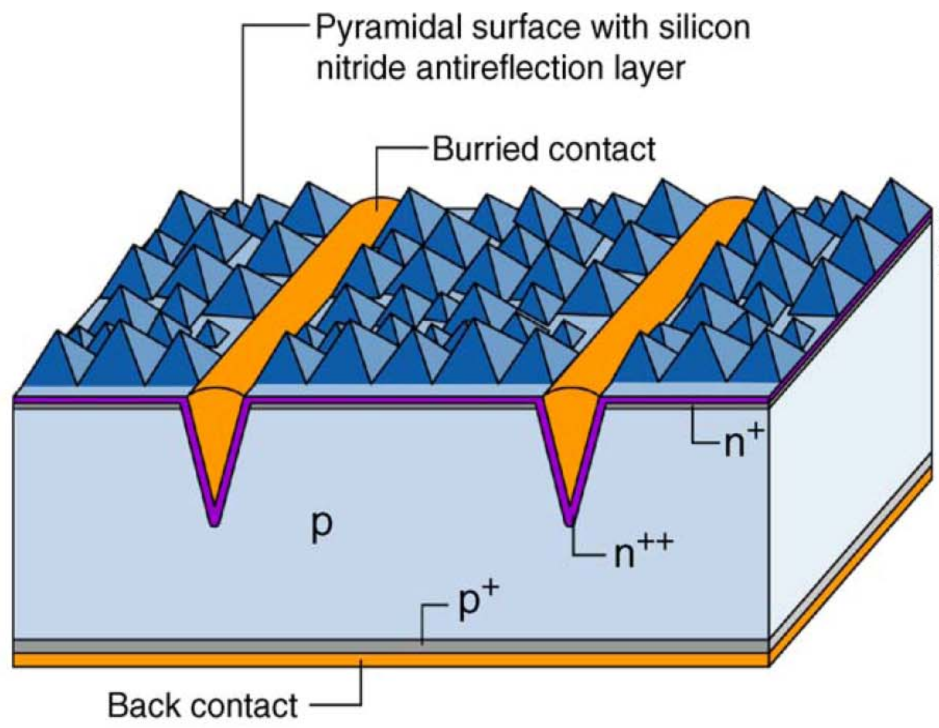

Surface charge can pin the Fermi level, bending bands even without an external contact.

*In extreme cases, surface charge can result in different apparent conductivity types of bulk and surface. E.g., InN.*

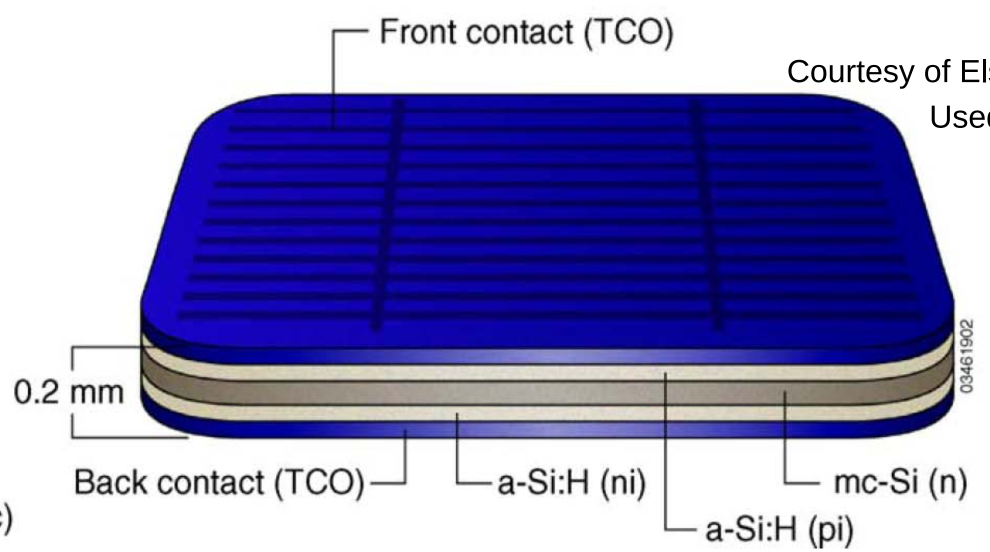
# Solar Cell Device Architectures: c-Si (Innovative)




(a)




(b)

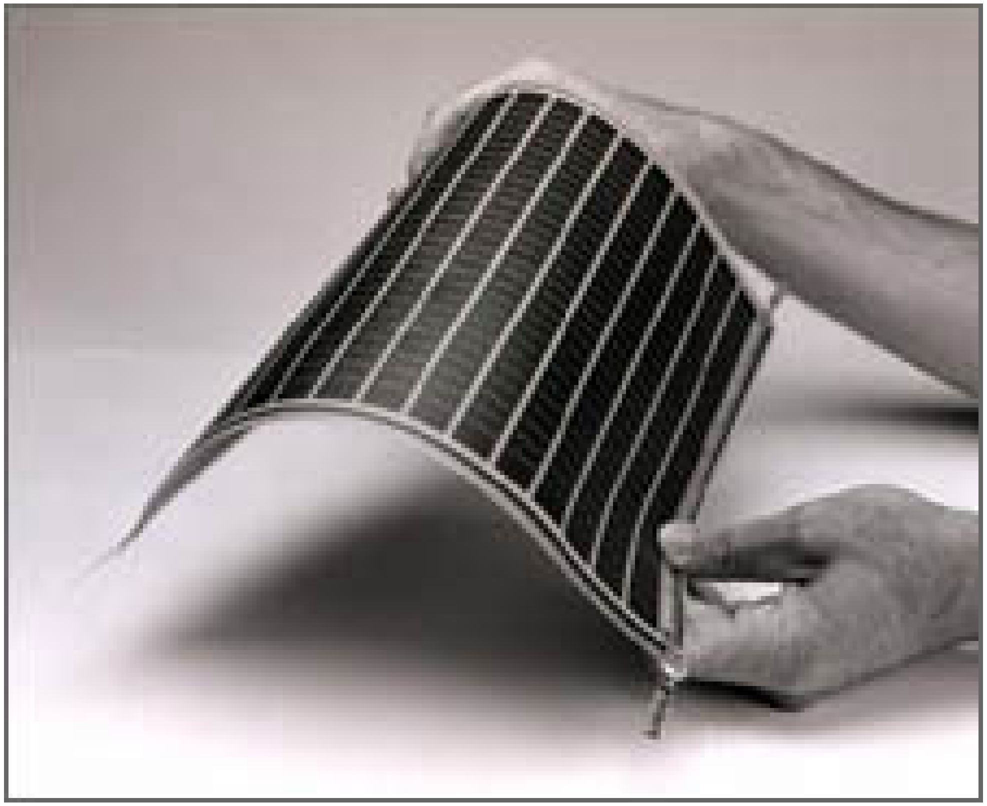



(c)



L.L. Kazmerski, Journal of Electron Spectroscopy and Related Phenomena 150 (2006) 105–135

# Solar Cell Device Architectures: Thin Films



Courtesy EERE.

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# Solar Cell Device Architectures: Thin Films

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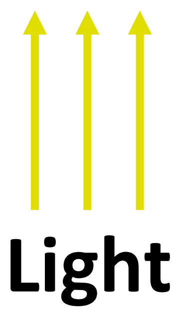
http://level2.phys.strath.ac.uk/SolarEnergy/img/intro.gif

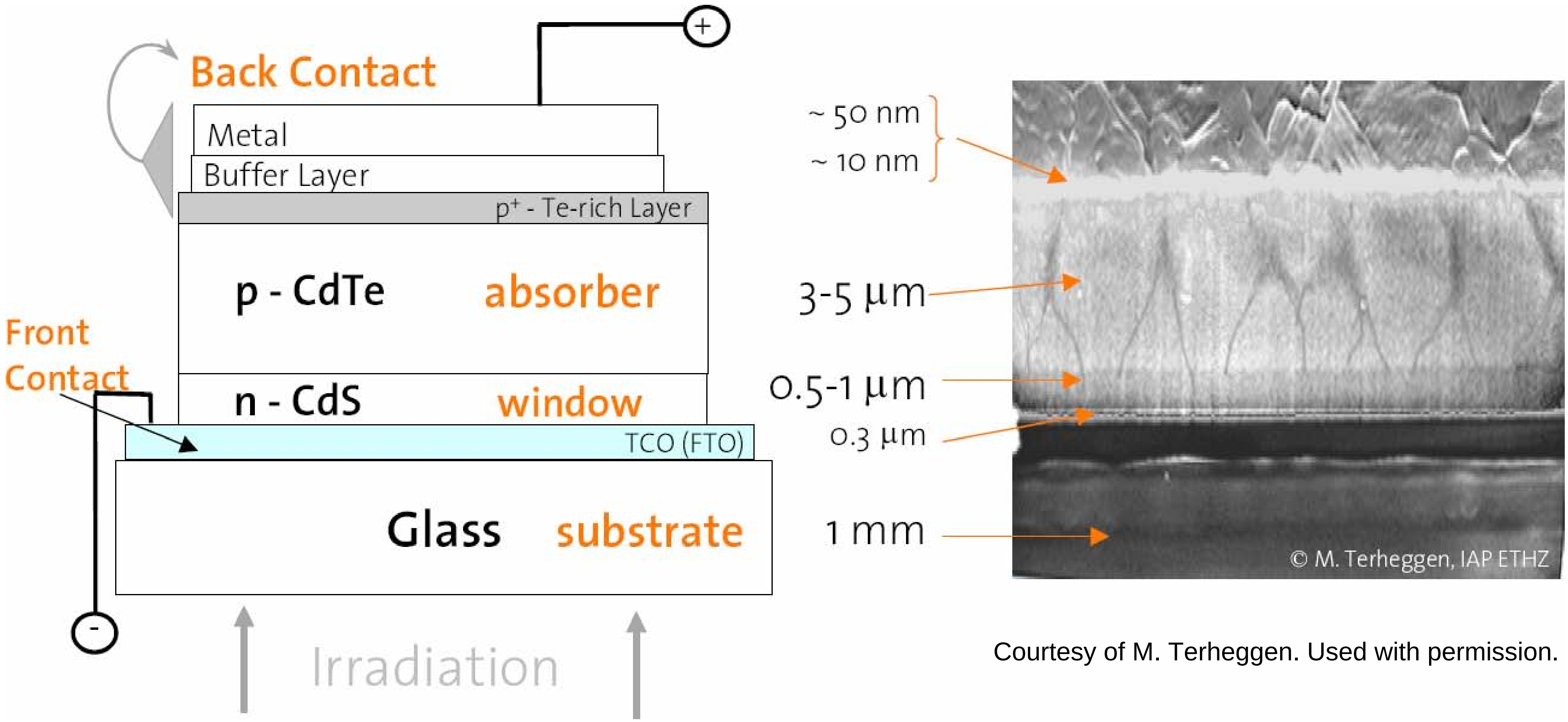
Image removed due to copyright restrictions. Please see Fig. 1 in
Klein, A., et al. "Interfaces in Thin Film Solar Cells." Record of the
31st IEEE Photovoltaic Specialists Conference (2005): 205-210.

# Solar Cell Device Architectures: Thin Films





# Solar Cell Device Architectures: Thin Films




Courtesy of M. Terheggen. Used with permission.

# Dye-Sensitized Solar Cell

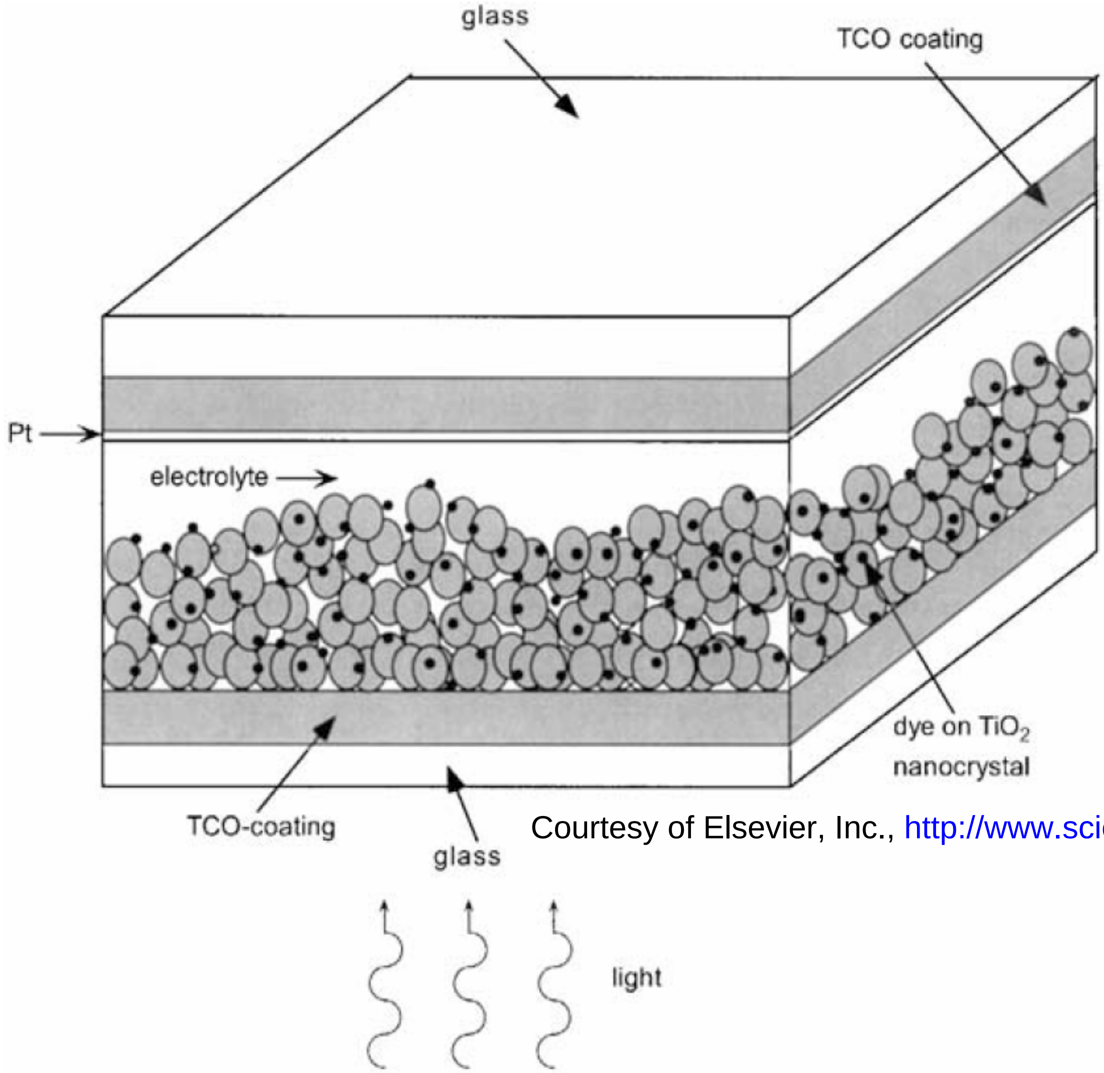
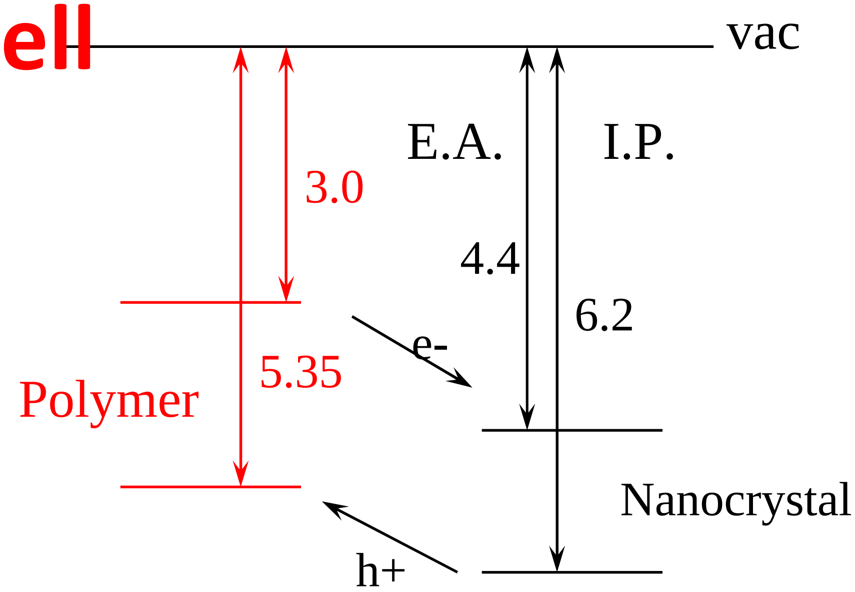


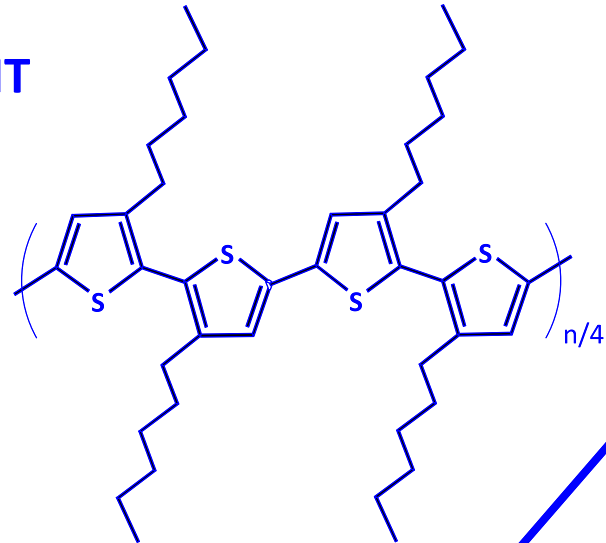


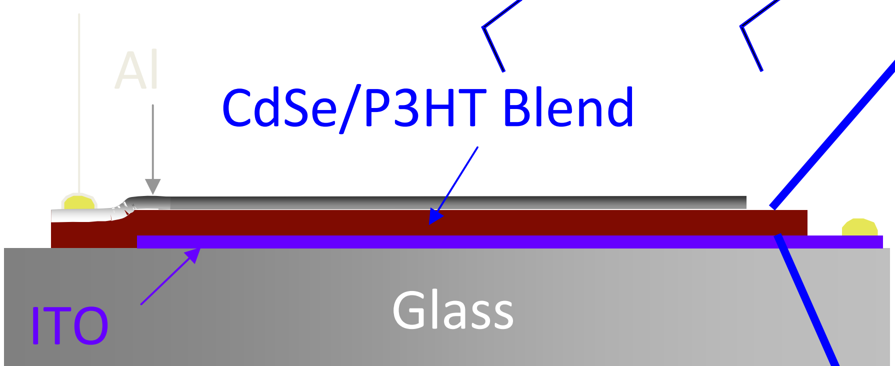

Fig. 9. Nanocrystalline $TiO_2$ dye-sensitised solar cell.

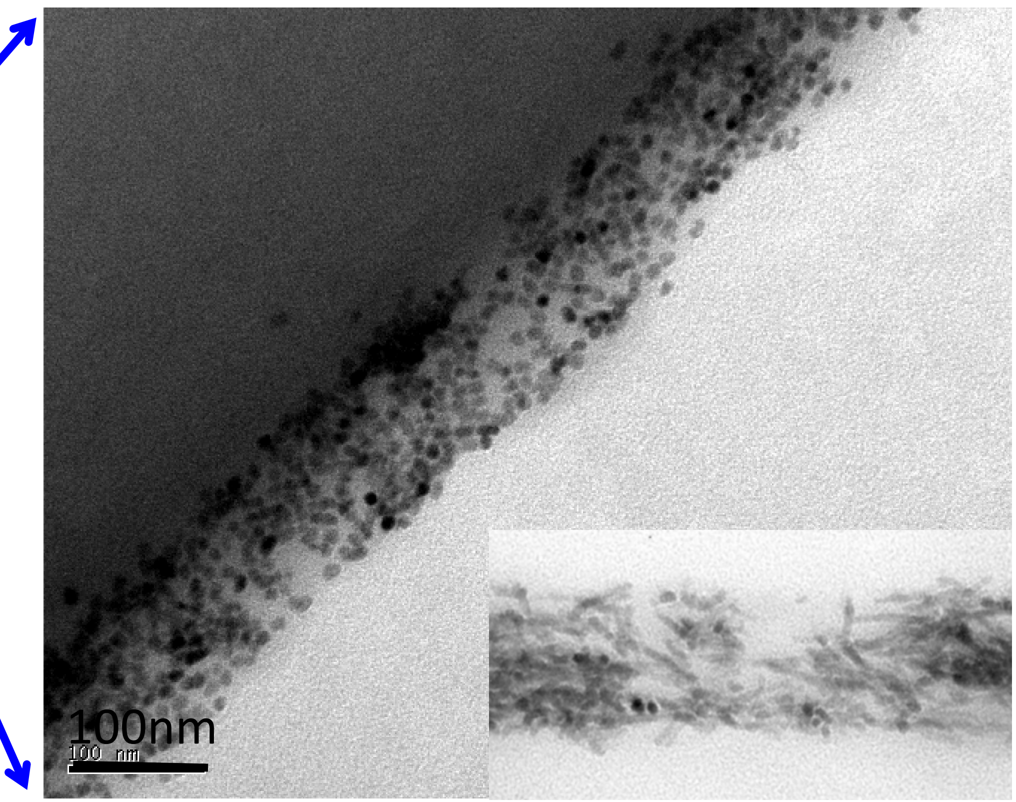
# Nanocrystal Polymer Solar Cell



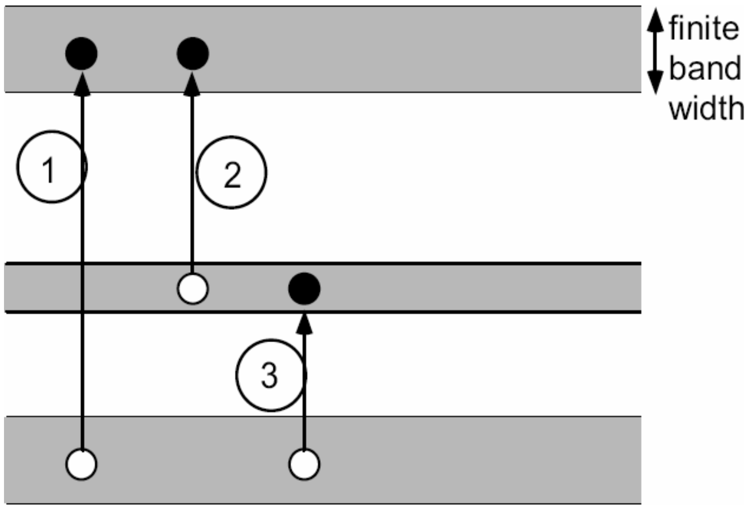

**Regioregular P3HT**



# Contact Challenges in Future Materials



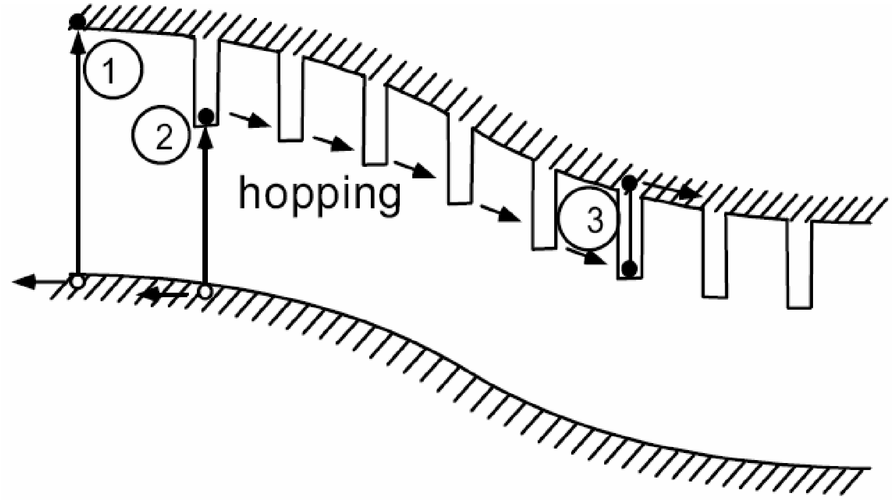




Fig. 7. Multiple quantum well solar cell meeting the constraints of three-band theory.



M.A. Green, *Physica E* **14** (2002) 65

- How to efficiency extract charge from a multiband material?

# Next Class

- *Review for Quiz #1.*