The Birnie Group solar class and website were created with much-appreciated support from the NSF CRCD Program under grants 0203504 and 0509886. Continuing Support from the McLaren Endowment is also greatly appreciated!

Transparent Conductors as Applied to Solar Devices

Slides on these *other topics* might also be of interest (most collected during teaching years 2004 and 2005):

http://www.rci.rutgers.edu/~dbirnie/solarclass/BandGapandDopingLecture.pdf	Band Gap Engineering of Semiconductor Properties
http://www.rci.rutgers.edu/~dbirnie/solarclass/MultijunctionLecture.pdf	Multi-Junction Solar Device Design
http://www.rci.rutgers.edu/~dbirnie/solarclass/MBEgrowth.pdf	Molecular Beam Epitaxy
http://www.rci.rutgers.edu/~dbirnie/solarclass/amorphousSi.pdf	Amorphous Silicon Solar Cells
http://www.rci.rutgers.edu/~dbirnie/solarclass/ARCoatings.pdf	Anti-Reflection Coatings for Solar
http://www.rci.rutgers.edu/~dbirnie/solarclass/OrganicPV.pdf	Organic PV
http://www.rci.rutgers.edu/~dbirnie/solarclass/DSSC.pdf	Dye Sensitized Solar Cells
http://www.rci.rutgers.edu/~dbirnie/solarclass/MotorPrimerGaTech.pdf	Working with Simple DC Motors for Student Solar Projects
http://www.rci.rutgers.edu/~dbirnie/solarclass/2005ProjectResultsindex.htm	Examples of Previous Years' Student Solar Projects

Note: in some cases it may be possible to design custom courses that expand on the above materials (send me email!)

Journal Publications of Some Recent Research: (best viewed through department home index: http://mse.rutgers.edu/dunbar_p_birnie_iii)

Other Birnie Group Research:

Sol-Gel Coating Quality and Defects Analysis (mostly Spin Coating):	http://www.coatings.rutgers.edu
Solar Research at Rutgers: Broader Overview	http://www.solar.rutgers.edu
Solar and Electric Vehicles System Projects (early stage emphasis)	http://www.rave.rutgers.edu

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Transparent Conductors

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1 November 2004

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Outline

- What are Transparent Conductors?
- Why are they transparent?
- How can you make them?
- What characteristics are important?
- What new things are on the horizon?

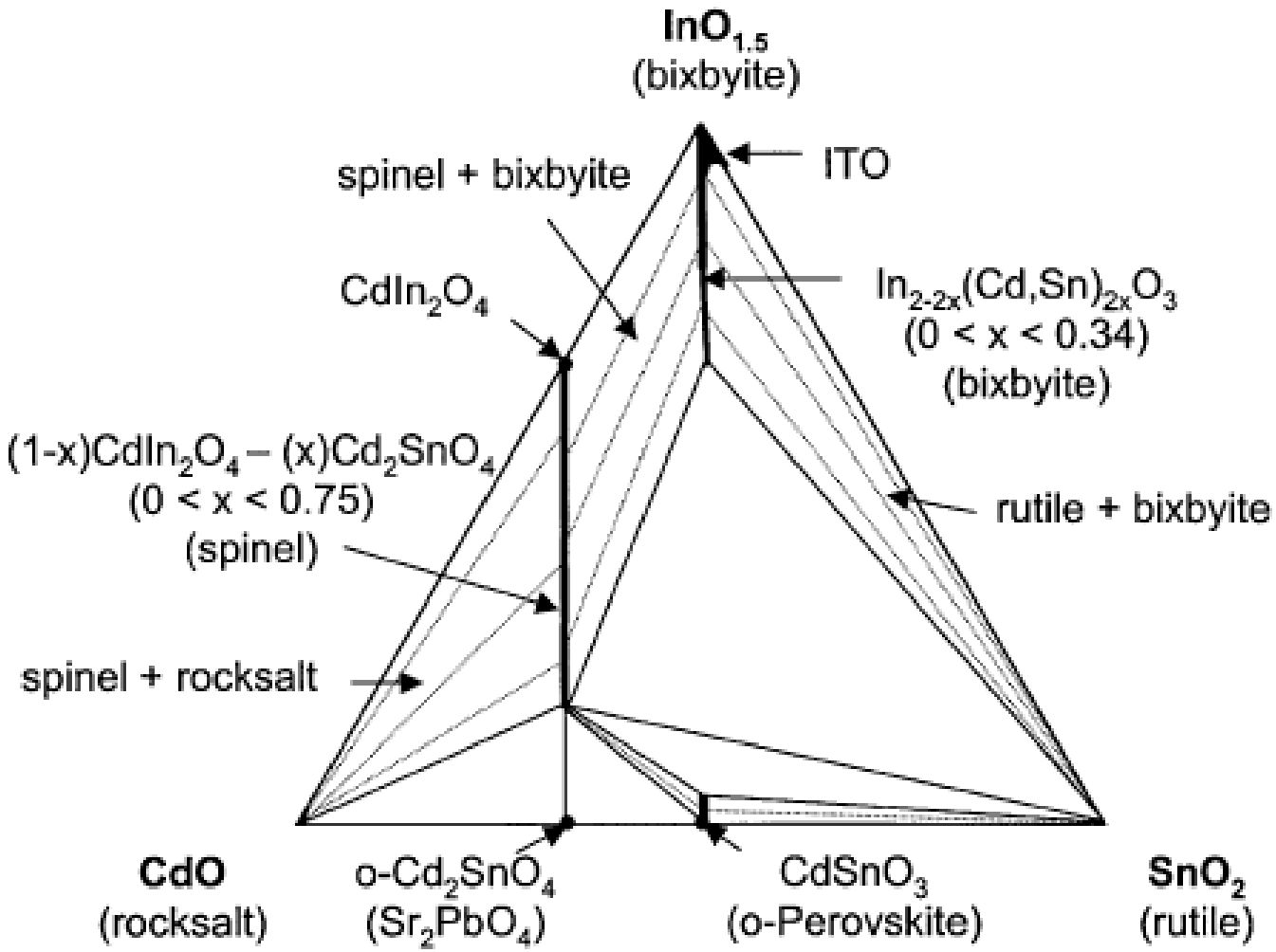
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What are They?

- Transparent Conducting Oxides (TCO's)
- Classic TCO is ITO – "Indium Tin Oxide"
- Other important ones are: ZnO:Al; Fluorinated Tin Oxide (FTO), cadmium stannate, antimony tin oxide (ATO)… and many more.

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Phase Relations and Structures



After: T.O.Mason – Thin Solid Films, 2003

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Defect Incorporation Reactions

$$CdO + SnO_2 + 2In_{In}^{x} \rightarrow Cd'_{In} + Sn_{In}^{\bullet} + In_2O_3$$

$$In_2O_3 + Cd_{Cd}^{x} + Sn_{Sn}^{x} \rightarrow In_{Cd}^{\bullet} + In'_{Sn} + CdSnO_3$$

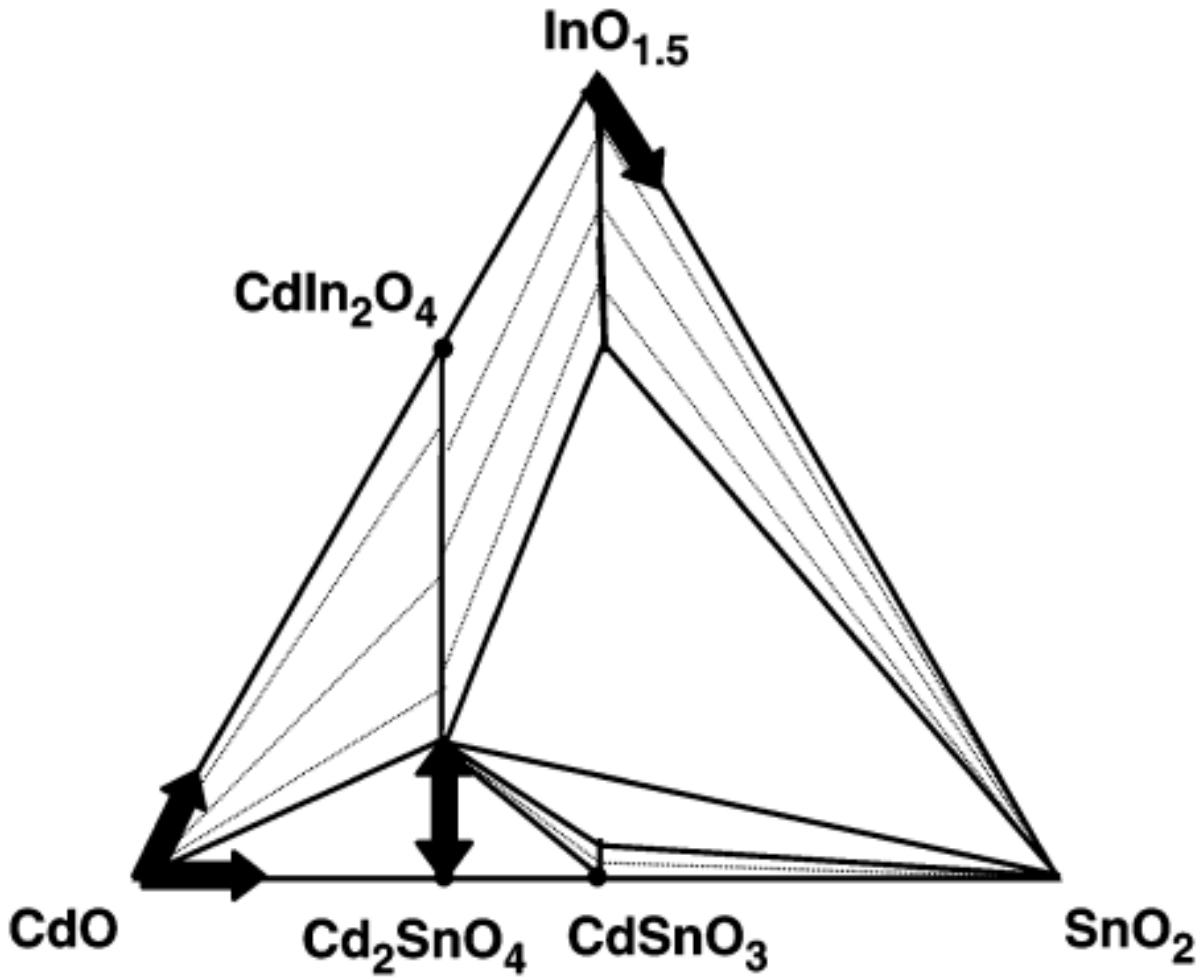
$$2SnO_2 \rightarrow (2Sn_{In}^{\bullet}O''_{i})^{x} + 3O_O^{x}$$

$$SnO_2 \rightarrow (Sn_{Cd}^{\bullet\bullet}V''_{Cd})^{x} + 2O_O^{x}$$

After: T.O.Mason – Thin Solid Films, 2003

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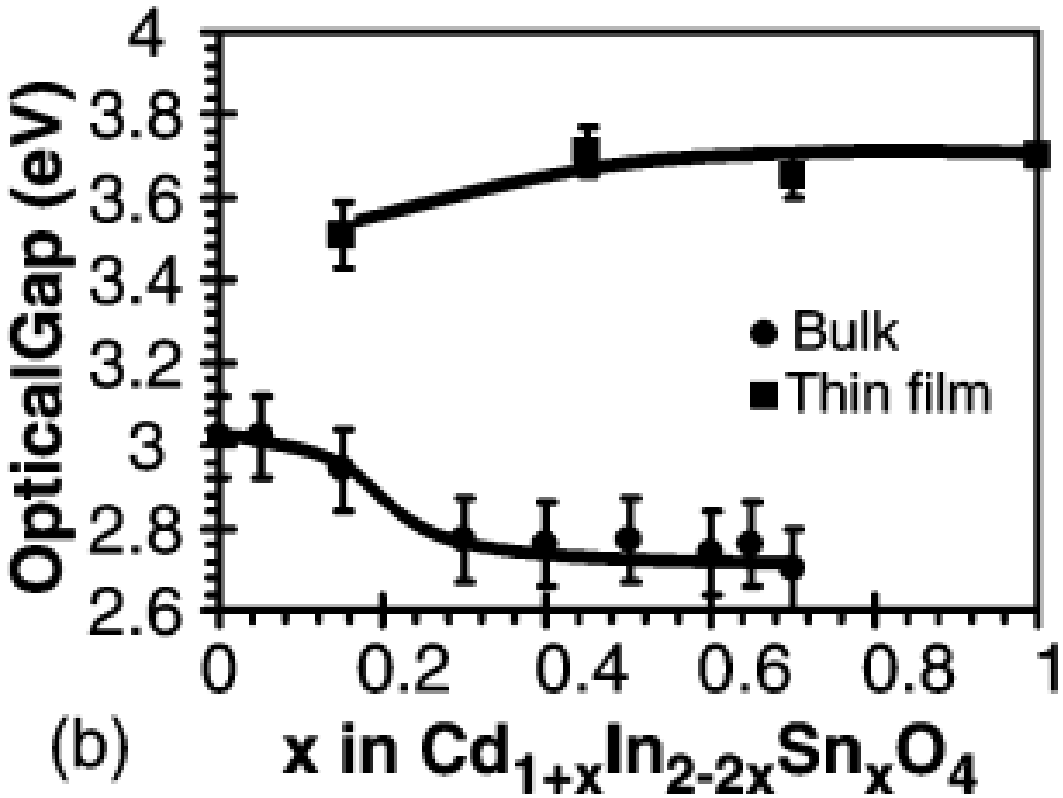
Thin Film Non-Equilibrium



After: T.O.Mason – Thin Solid Films, 2003

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Properties of TCO's



After: T.O.Mason – Thin Solid Films, 2003

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Conductivity is Important

- Conductivity in Thin Films
- “Sheet Resistance” concept
  - “Ohms per Square”
- How to Measure Resistance:
  - Four probe linear contacts
  - Four probe – Van der Paaw – versatile
- Interactions between layers very important

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Why are they Transparent?

- Defects and Proximity of Band of Defect Levels Within the Band Gap
- Very High Carrier Concentration

- Often Used as Heat Reflective Glass for Architectural applications.

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How Can You Make Them?

- Spray Pyrolysis
- Sputtering (RF, DC)
- Sol-Gel
- MOCVD
- Etc.etc.

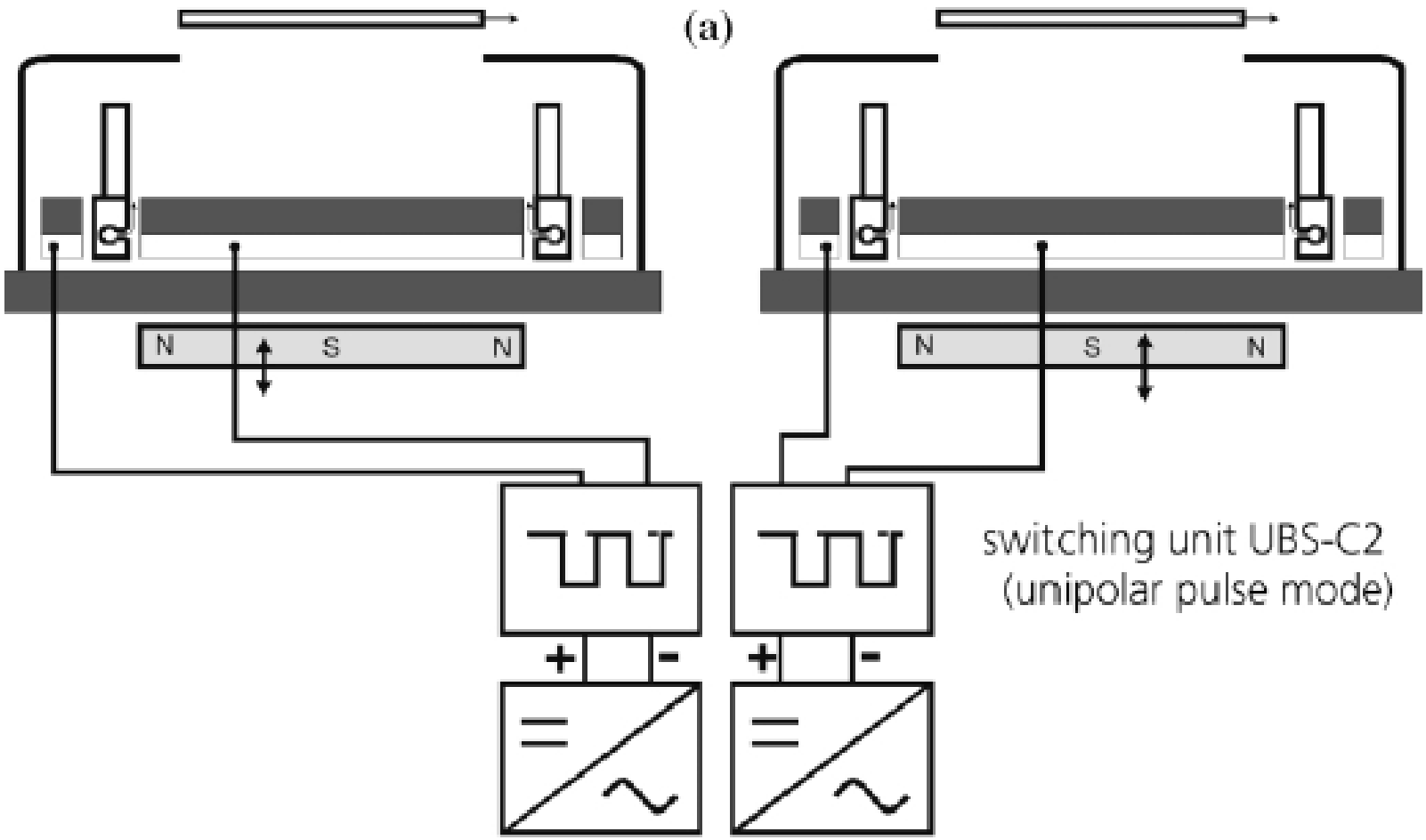
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Spray Pyrolysis

- Typical salt precursors – chlorides often
- Aqueous or alcohol or volatile organics as carrier solvents
  - Solubility is key
  - Evaporation and/or combustion is important
- Hot Substrate Important

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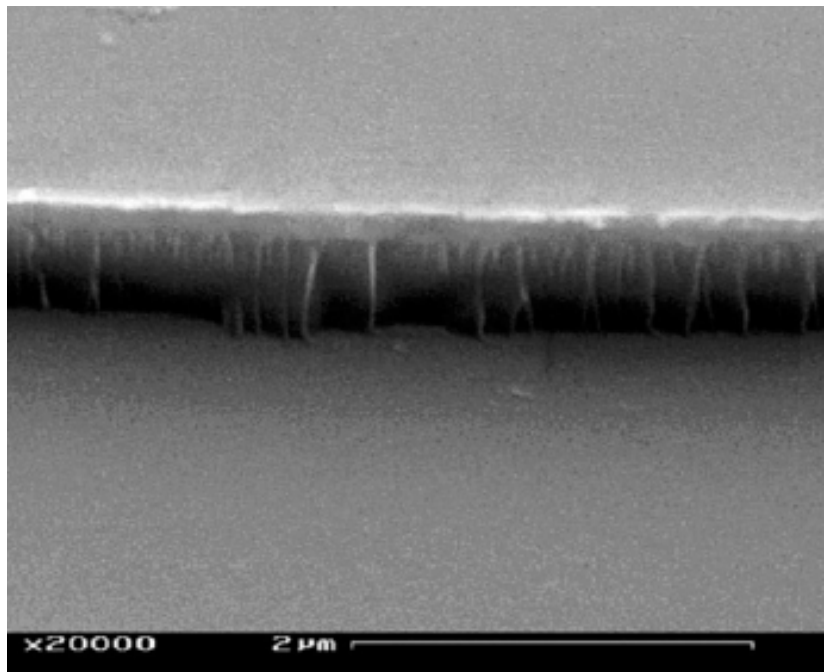
Magnetron Sputtering



After: Frach – Thin Solid Films, 2003

Sputtering Issues

- Plasma energetics and bombardment
- “Target” Stoichiometry
- Temperature of the Substrate



After: Frach – Thin Solid Films, 2003

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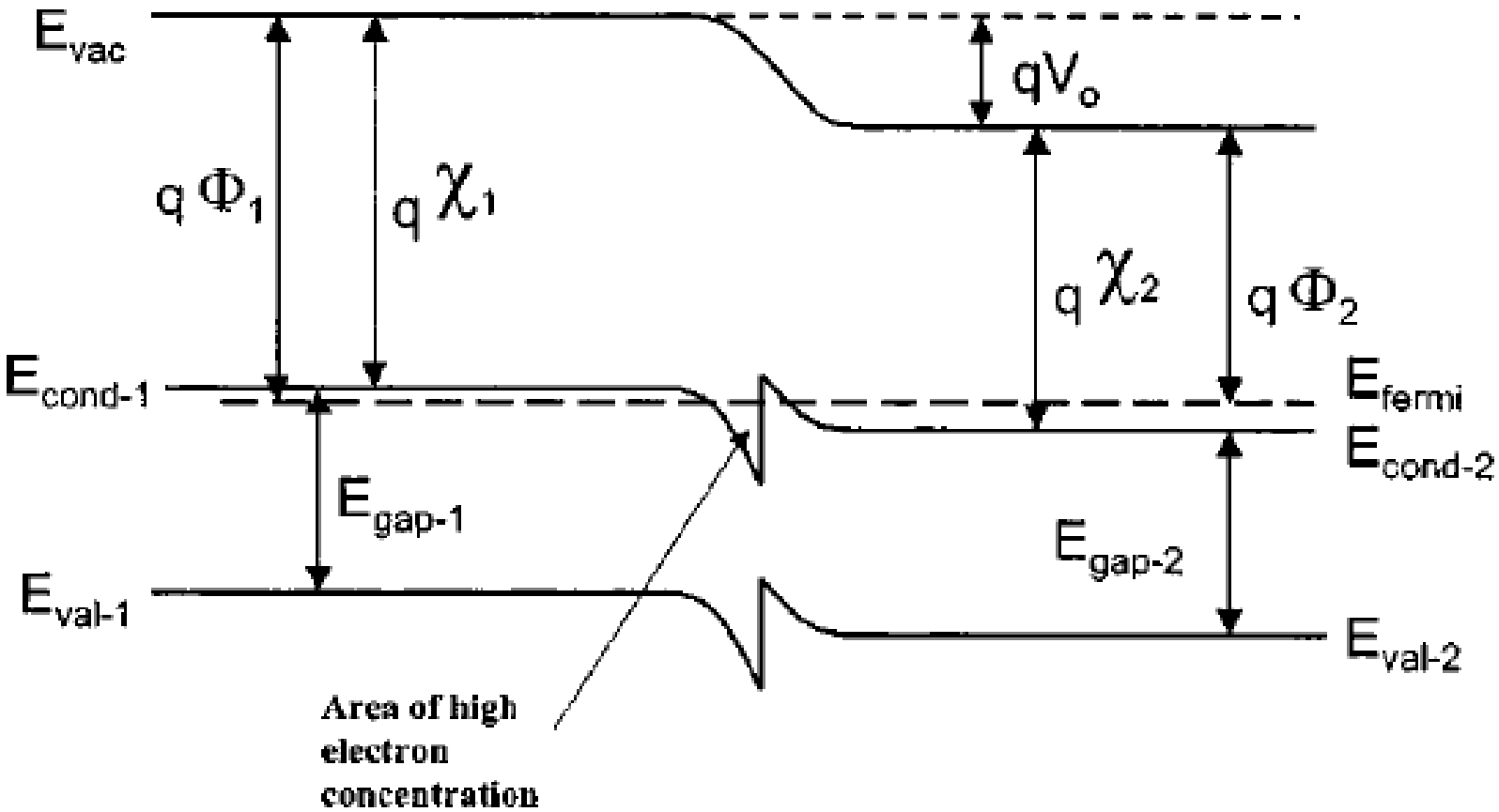
New Directions

- Conduction is Lateral
- Limitations are:
  - Scattering by Defects
  - Quantity of Carriers
- Unify Both in Multilayer Structure?

$$\sigma = n e \mu = \frac{n e^2 \tau}{m^*}$$

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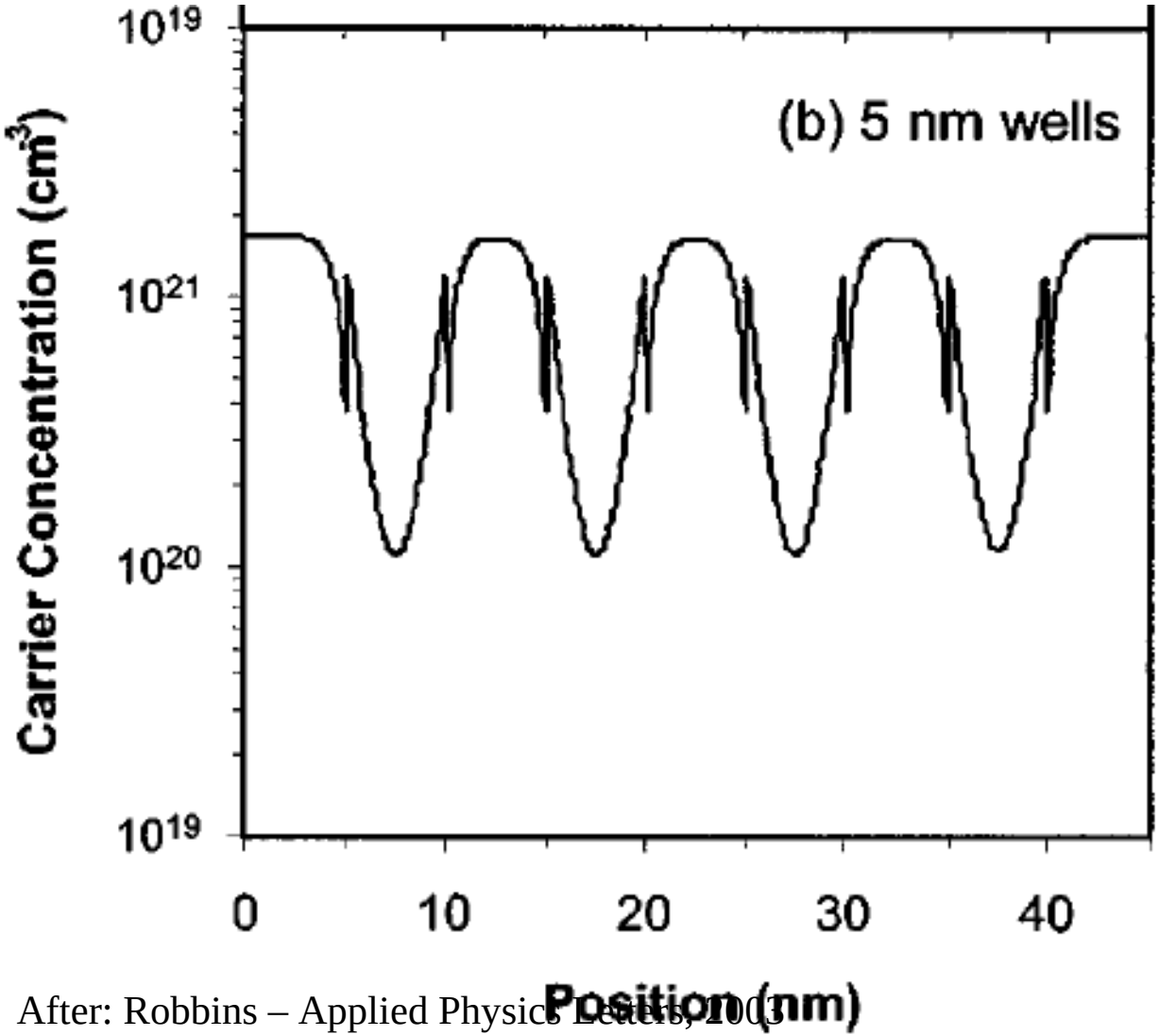
Contact Band Diagram



After: Robbins – Applied Physics Letters, 2003

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Multilayer Concentration Profile



After: Robbins – Applied Physics Letters, 2003