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!

# Hetero-Junction and Multi-Junction Solar Device Design

**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/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/TransparentConductors.pdf | Transparent Conductors for Solar |
| 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:**

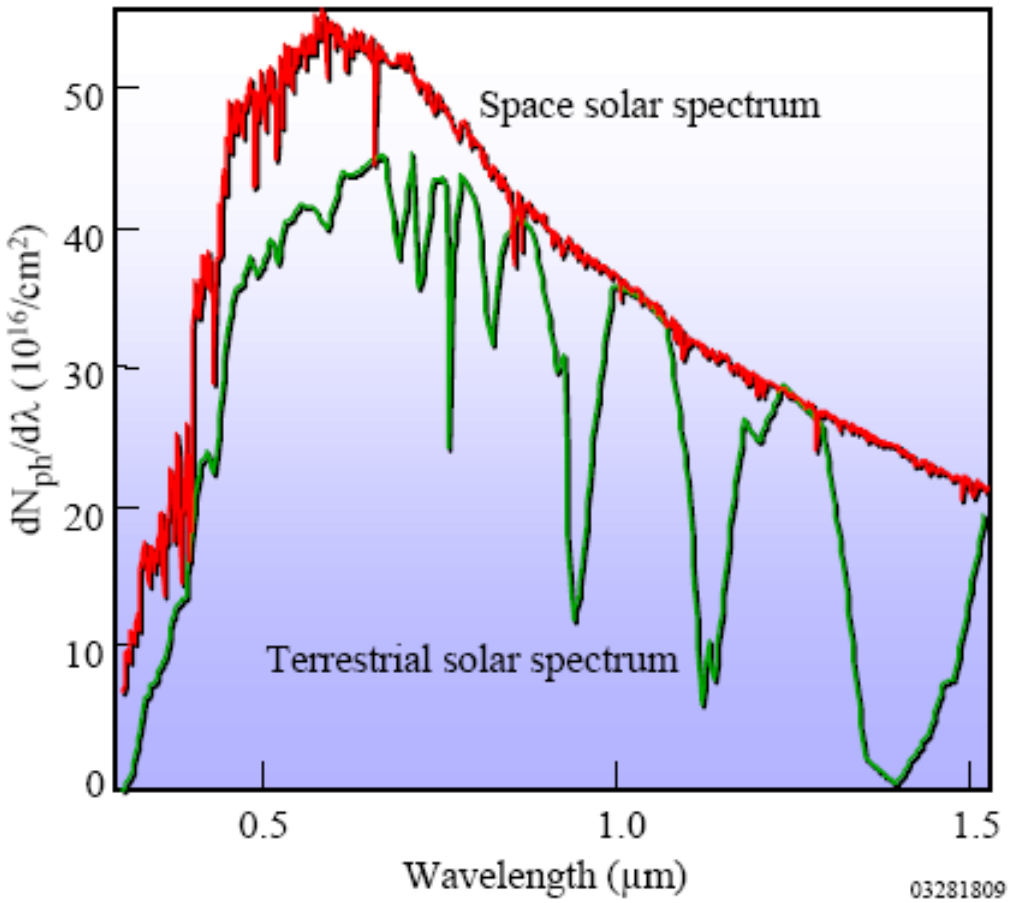
| | |
|---|---|
| Sol-Gel Coating Quality and Defects Analysis (mostly Spin Coating): | http://www.coatings.rutgers.edu |
| Solar Research at Rutgers: Broader Overview | http://www.solar.rutgers.edu |
| Solar and Electric Vehicles System Projects (early stage emphasis) | http://www.rave.rutgers.edu |

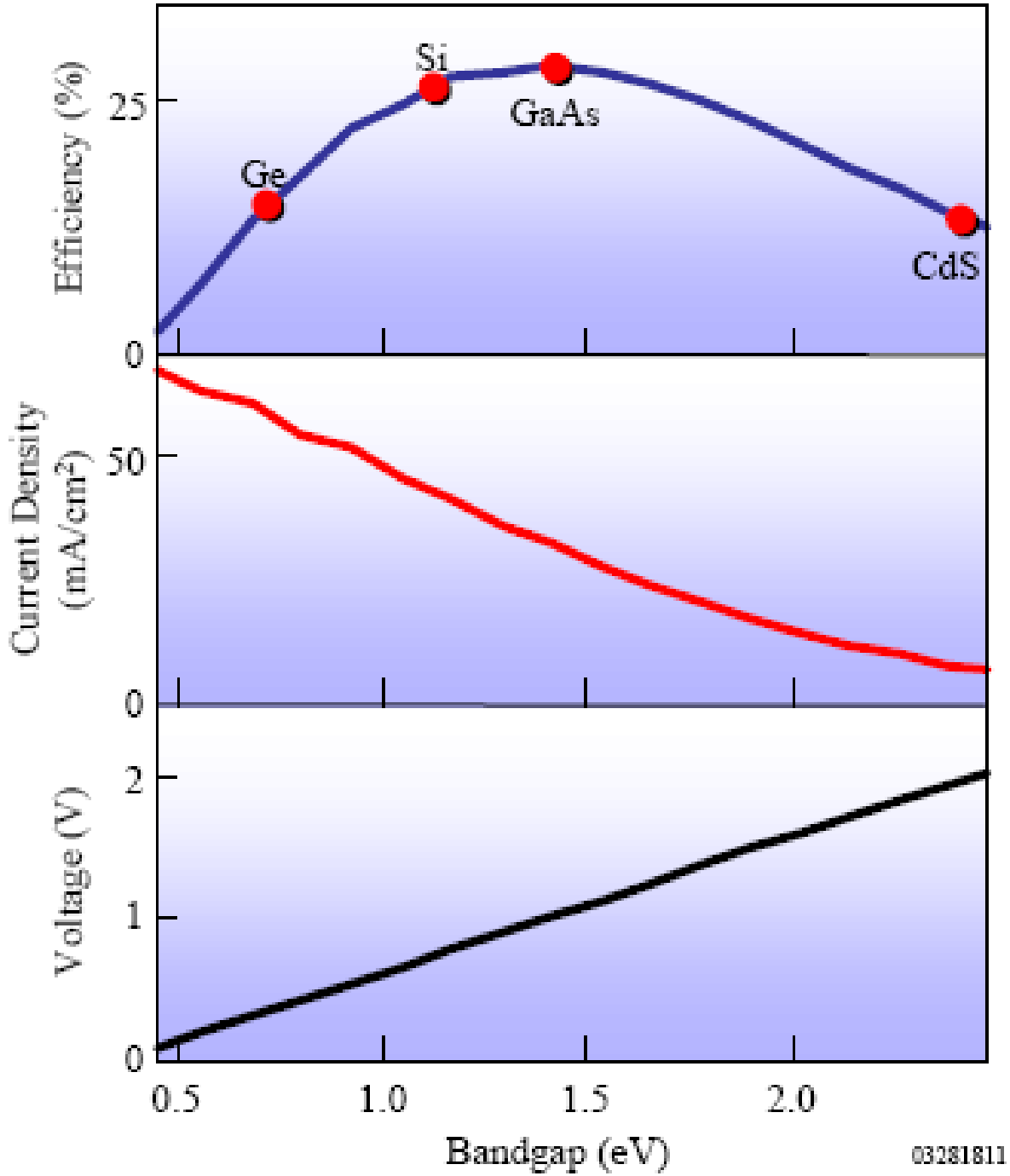
RUTGERS UNIVERSITY

**Professor Dunbar P. Birnie, III (dunbar.birnie@rutgers.edu)**
**Department of Materials Science and Engineering**
**http://mse.rutgers.edu/faculty/dunbar_p_birnie**

# Heterojunction and Multijunction Solar Cells

October 2004


Space solar spectrum
Terrestrial solar spectrum
50
40
30
20
10
0
0.5
1.0
1.5
$dN_{ph}/d\lambda$ ($10^{16}$/cm$^2$)
Wavelength (μm)
03281809


Efficiency (%)
25
0
Si
GaAs
Ge
CdS
Current Density (mA/cm²)
50
0
Voltage (V)
2
1
0
0.5
1.0
1.5
2.0
Bandgap (eV)
03281811

# Heterojunction Idea

- Bi-layer structure of different semiconducting materials
- “top” layer has wider band gap
- “bottom” layer has narrower band bap
- Layers are  p and n type alternately
- Junction forms at the interface between the two materials

# CIGS Heterostructure Device

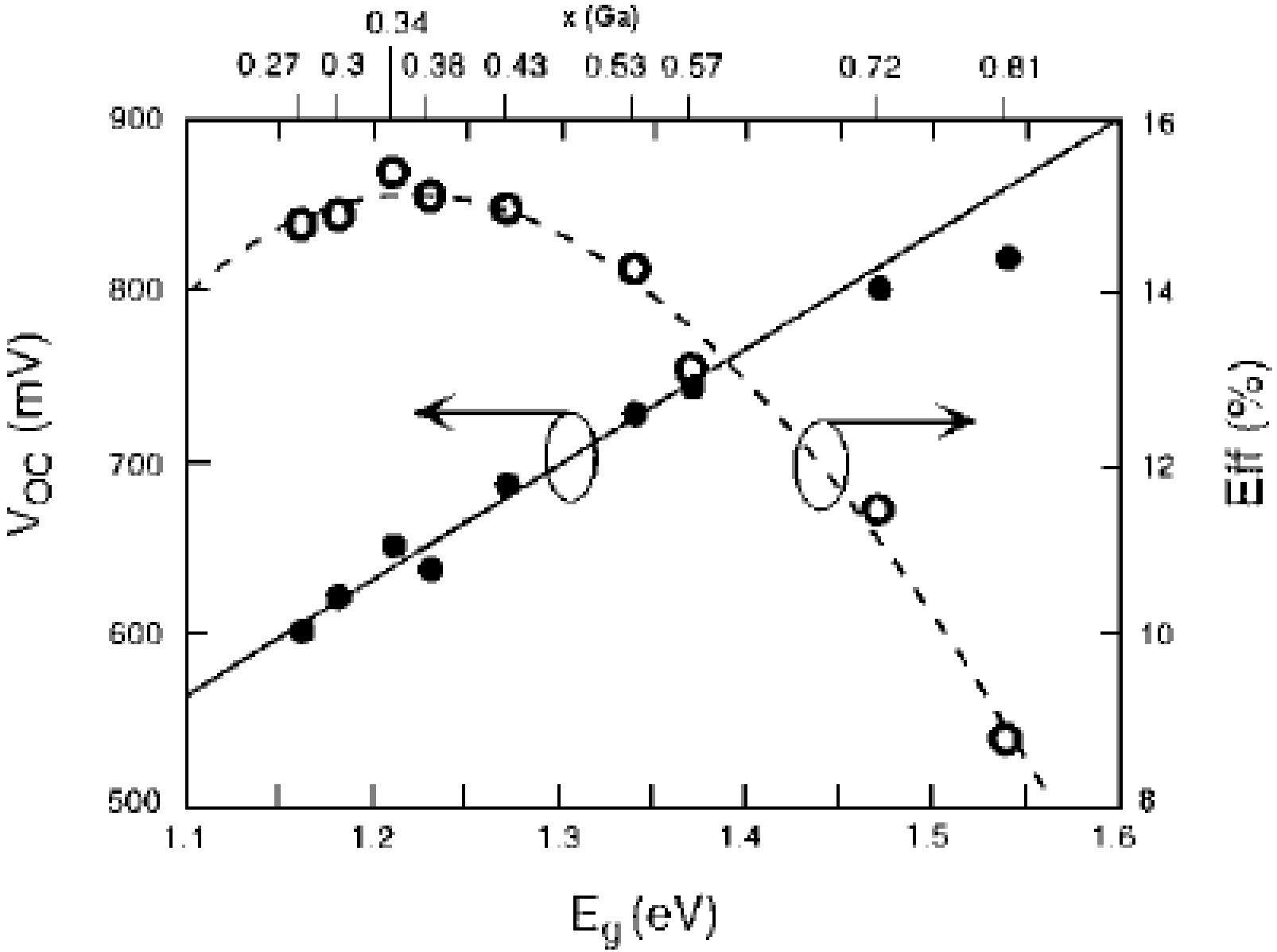


transparent conductor (ZnO)
absorber (Cu(In,Ga)$Se_2$)
substrate (glass)
buffer layer (CdS)
back contact (Mo)

Figure 1 *CIS module*

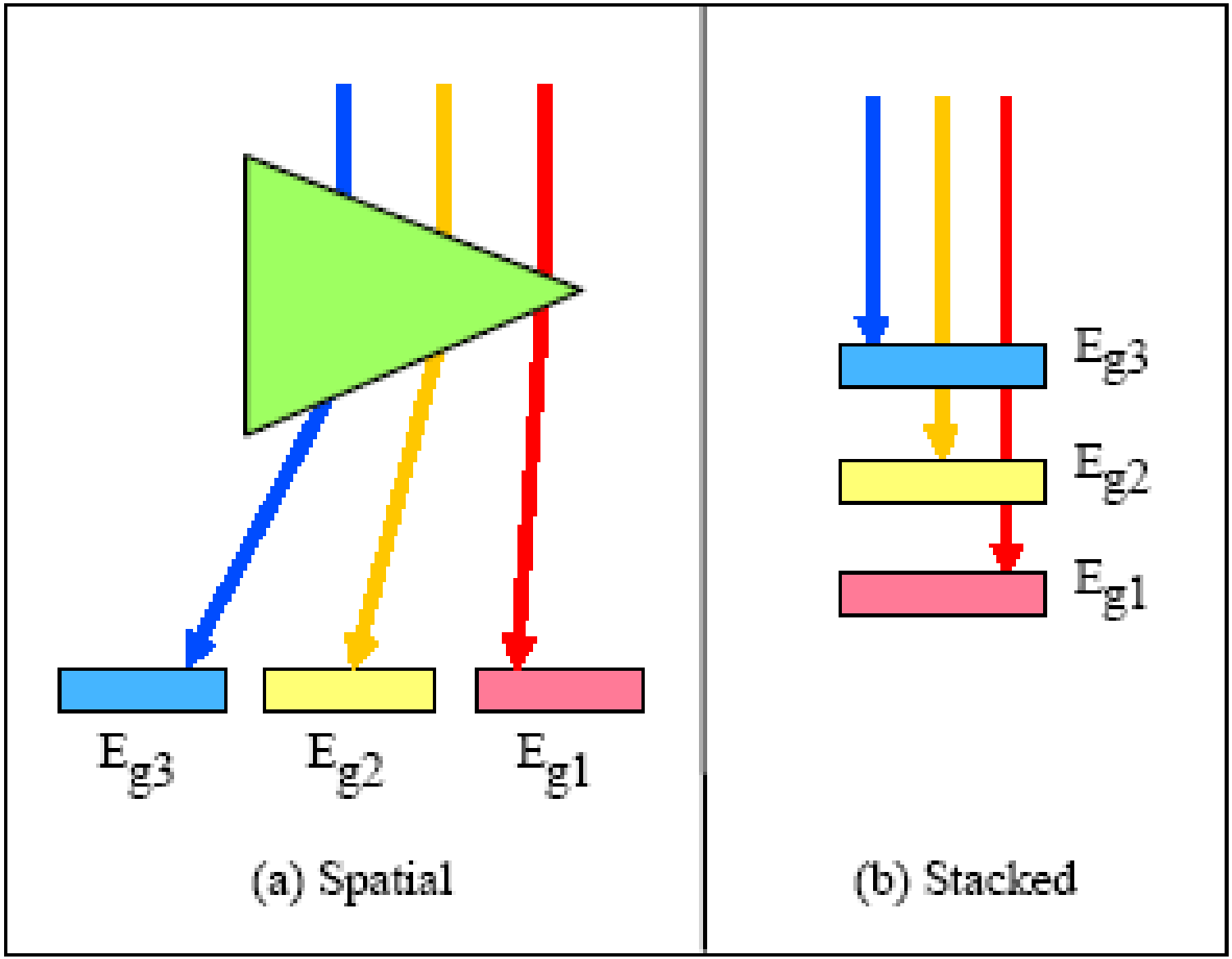
Table 1 *generic CIS module fabrication sequence*

| **Process step** | **Standard method** | **alternatives** |
|---|---|---|
| 1. glass cutting and cleaning | scribe & break; wash, rinse, dry | plasma clean |
| 2. Mo back contact deposition | DC microwave sputtering | e-beam evaporation |
| 3. Patterning (#1) | laser scribing | etching, lift-off, photolithography |
| 4. CIS absorber formation | Cu/In/Ga precursor deposition + selenization | co-evaporation |
| 5. CdS buffer layer deposition | chemical bath deposition | evaporation, CVD, sputtering |
| 6. Patterning (#2) | mechanical scribing | laser scribing |
| 7. ZnO transparent conductor | DC microwave sputtering | RF microwave sputtering, CVD, ALE |
| 8. Patterning (#3) | mechanical scribing | laser scribing |
| 9. contacting & encapsulation | vacuum lamination with EVA | UV-cured acrylic, Tefzel |

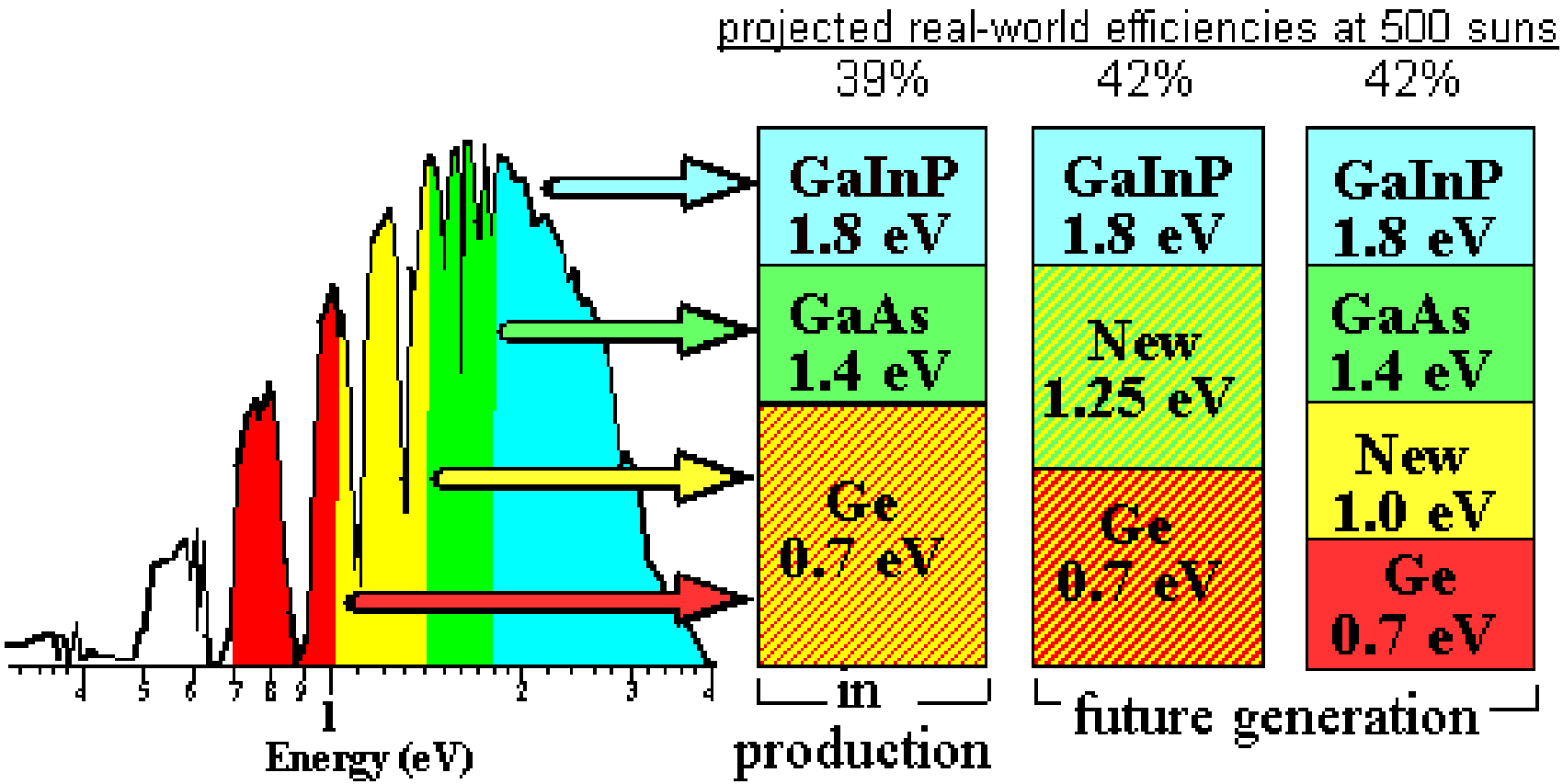

0.34
x (Ga)
0.27 0.3 0.38 0.43 0.53 0.57 0.72 0.81
900
800
700
600
500
16
14
12
10
8
1.1
1.2
1.3
1.4
1.5
1.6
$V_{OC}$ (mV)
Eff (%)
$E_g$ (eV)

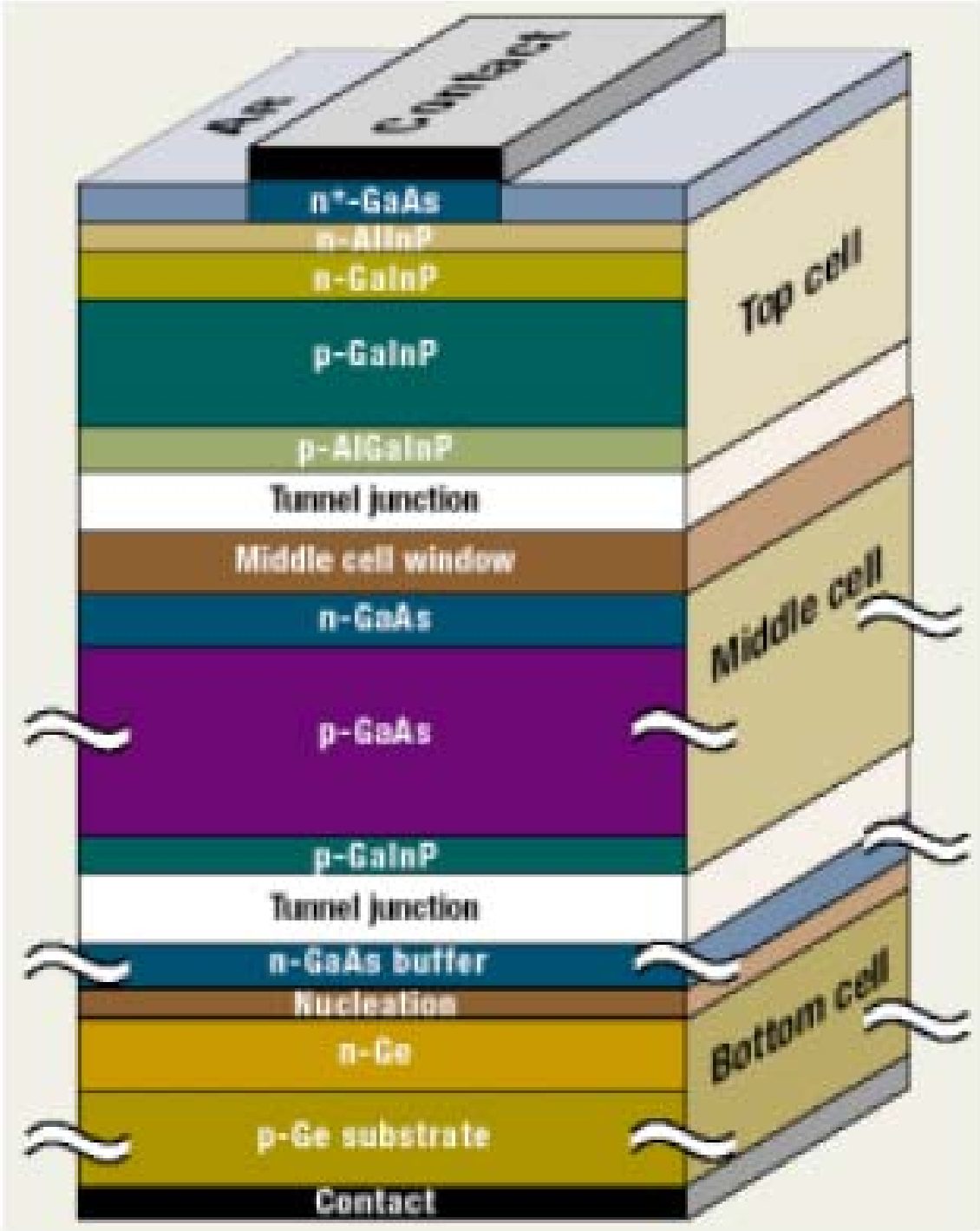
# Multijunction Idea

- Stack Many Layers to segment the Incoming Light
- Each layer has a pn junction
- Each layer generates a photovoltage
- Each layer generates photocurrent
- Current must be matched
- Voltages add together

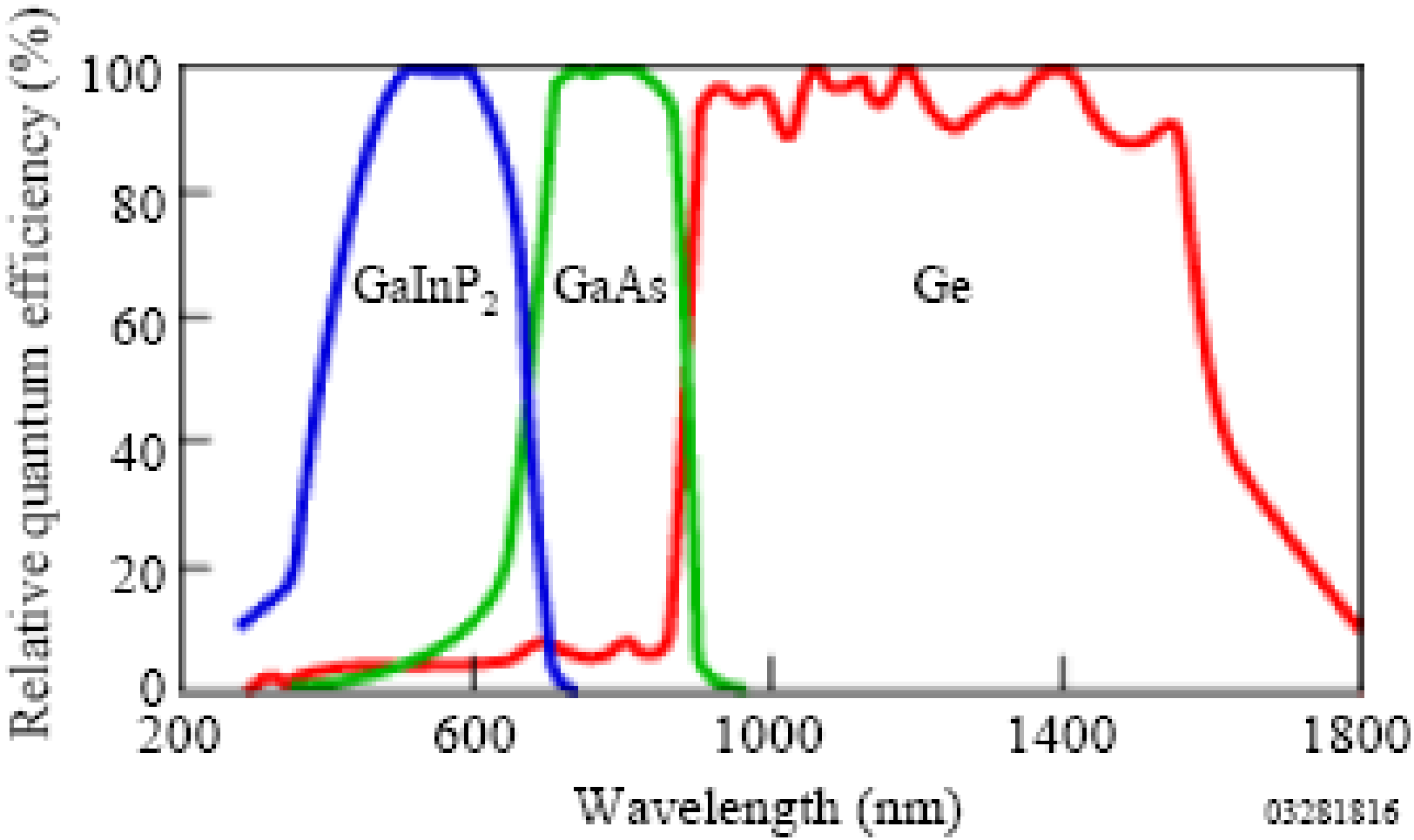

$E_{g3}$
$E_{g2}$
$E_{g1}$
(a) Spatial
$E_{g3}$
$E_{g2}$
$E_{g1}$
(b) Stacked
03281813

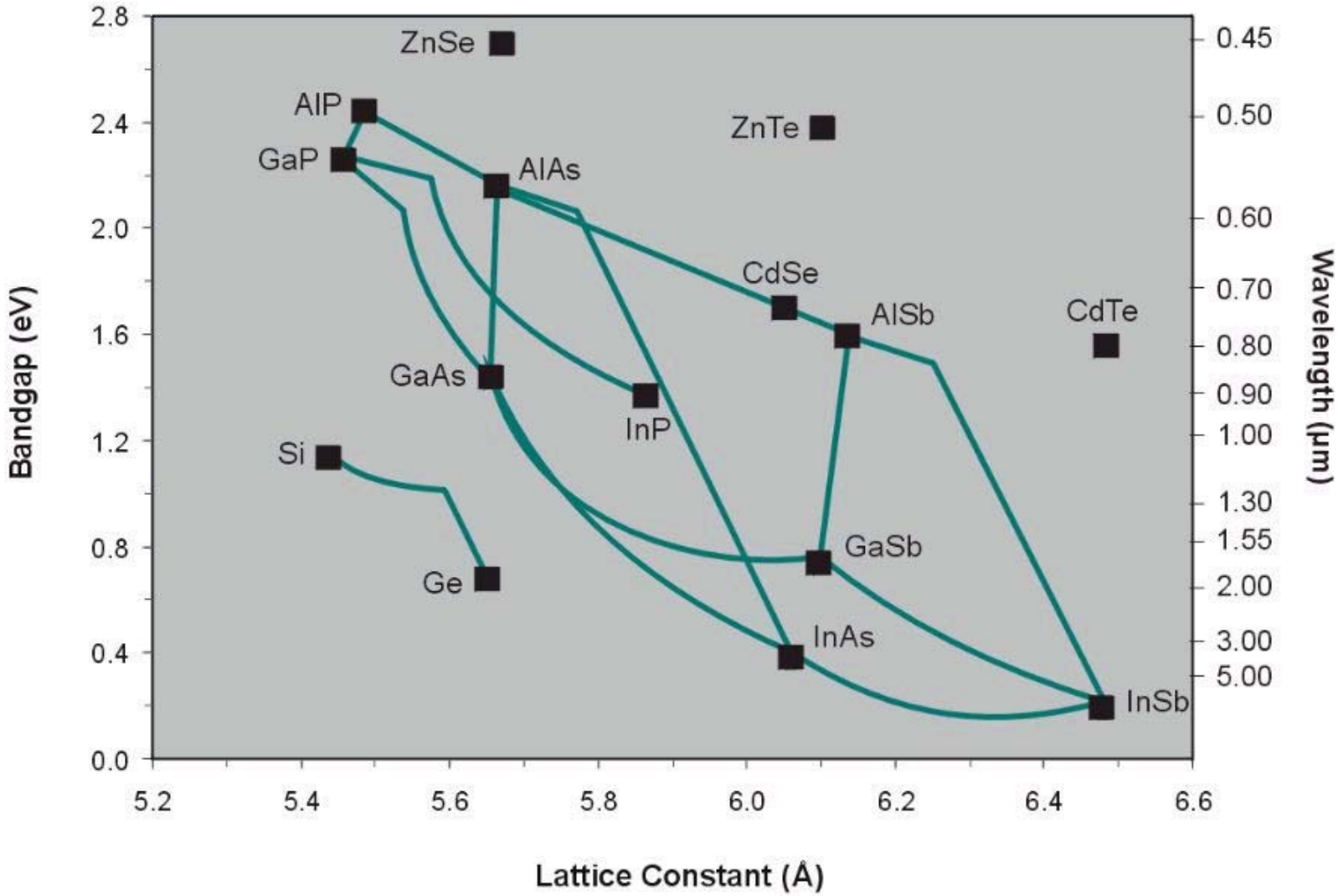
# Splitting the Spectrum



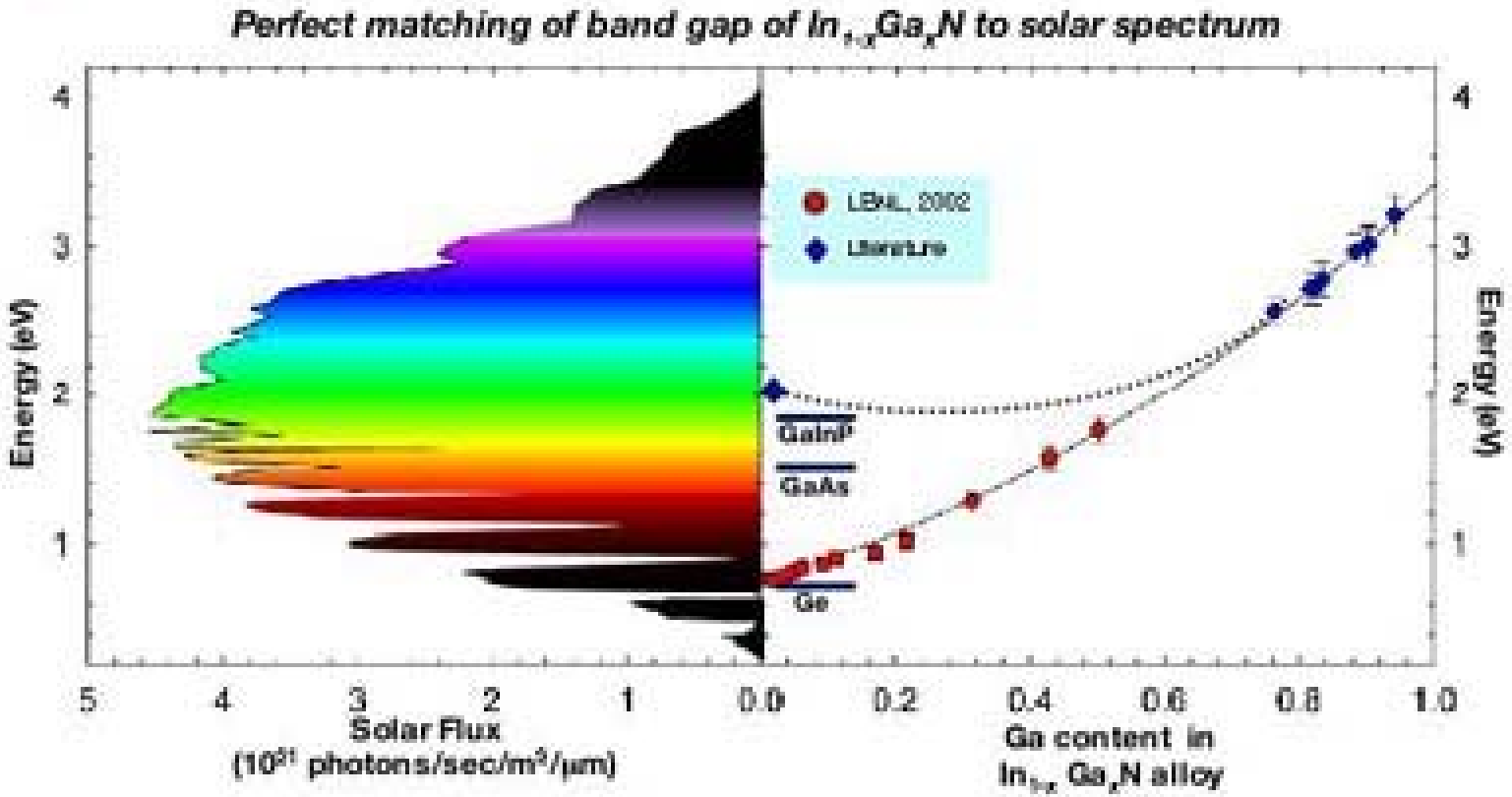

Contact
n⁺-GaAs
n-AlInP
n-GaInP
p-GaInP
p-AlGaInP
Tunnel junction
Middle cell window
n-GaAs
p-GaAs
p-GaInP
Tunnel junction
n-GaAs buffer
Nucleation
n-Ge
p-Ge substrate
Contact
Top cell
Middle cell
Bottom cell

# Spectral Capture Efficiency




ZnSe
AlP
GaP
AlAs
ZnTe
CdSe
AlSb
CdTe
GaAs
InP
Si
Ge
GaSb
InAs
InSb
Bandgap (eV)
Wavelength (µm)
Lattice Constant (Å)
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
0.45
0.50
0.60
0.70
0.80
0.90
1.00
1.30
1.55
2.00
3.00
5.00
5.2
5.4
5.6
5.8
6.0
6.2
6.4
6.6

# Full Solar Spectrum Photovoltaic Materials Identified



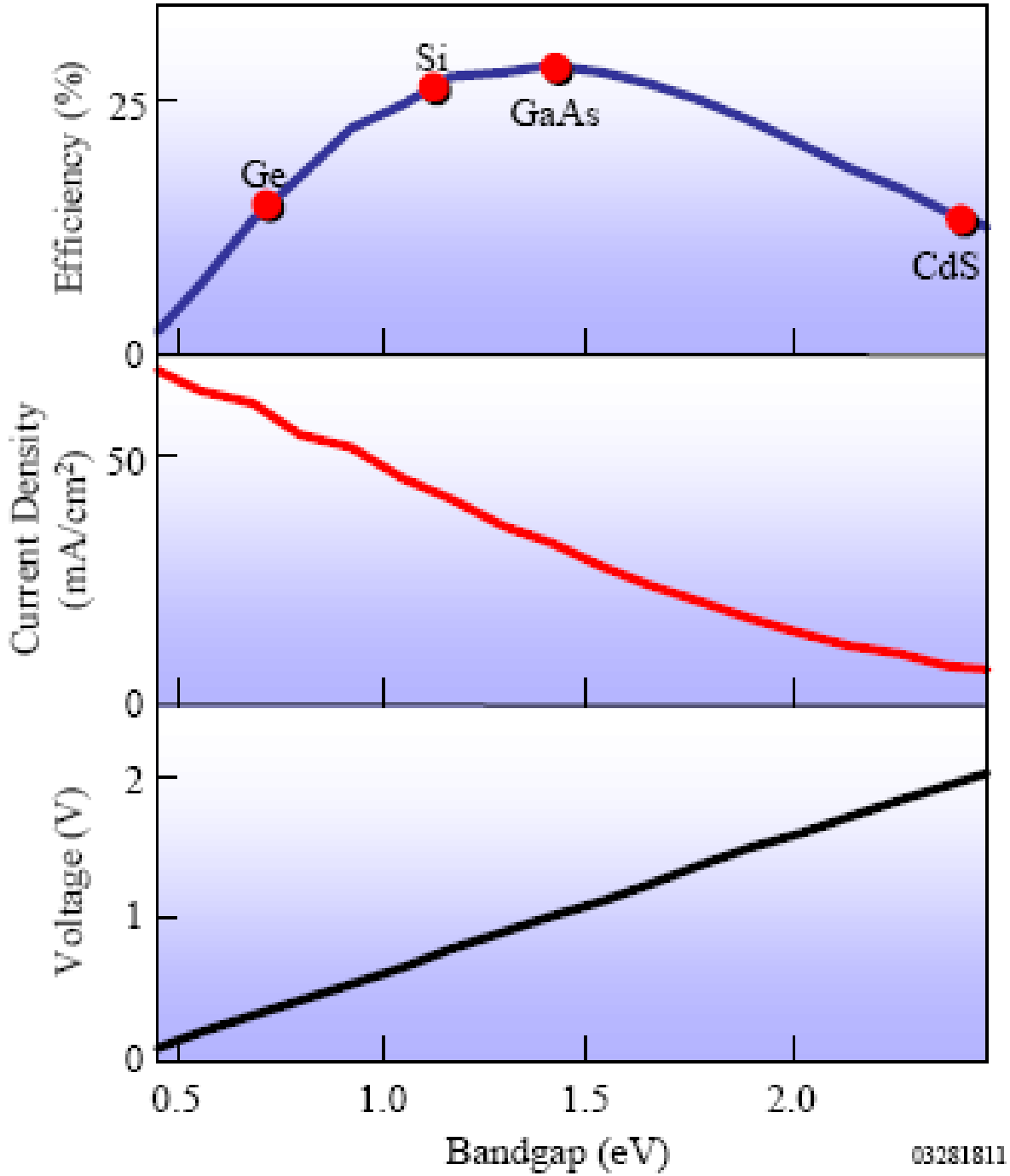

*Efficient solar cells use multiple semiconductors with fixed energy gaps (e.g. a GaInP/GaAs/Ge triple junction cell) to capture as much of the solar spectrum as possible (left). LBNL researchers have shown, using materials grown at Cornell University and Japan, that the direct energy gap of $In_{1-x}Ga_xN$ spans nearly the energy range 0.7 – 3.4 eV of the solar spectrum (left), not 2.0–3.4 eV as reported in the literature (dotted line, right). Multijunction solar cell based on this single ternary system could have efficiencies as high as 50%.*

# References


- http://www.ecn.nl/docs/library/report/1999/c99046.pdf
- http://www.lbl.gov/msd/PIs/Walukiewicz/02/02_8_Full_Solar_Spectrum.html

# HW Assignment

- Optimize a 5 Junction Cell
- Determine what the band gap value should be for each junction
- Use the Current Matching Condition to segment the solar Spectrum
- Assume $V_{pp}=E_g$-0.4volts
- Determine what the overall voltage and current density output would be.


Efficiency (%)
25
0
Si
GaAs
Ge
CdS
Current Density (mA/cm²)
50
0
Voltage (V)
2
1
0
0.5
1.0
1.5
2.0
Bandgap (eV)
03281811