

## Section 11

# Bandstructure Measurements

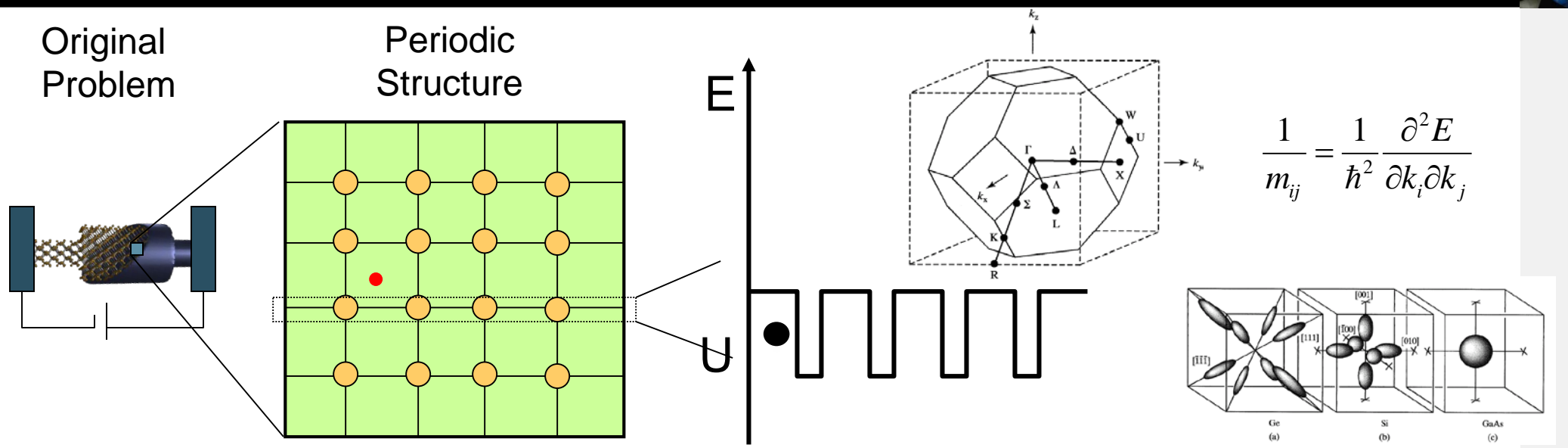
Gerhard Klimeck

[gekco@purdue.edu](mailto:gekco@purdue.edu)



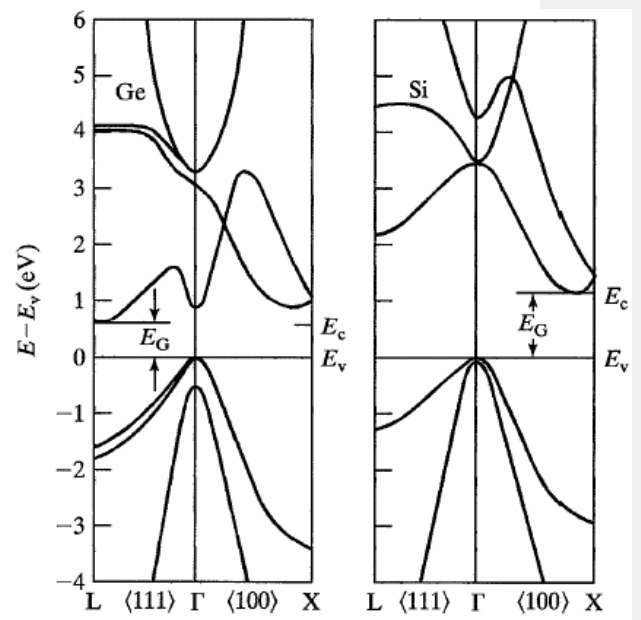
School of Electrical and  
Computer Engineering

# Section 11 Bandstructure Measurements



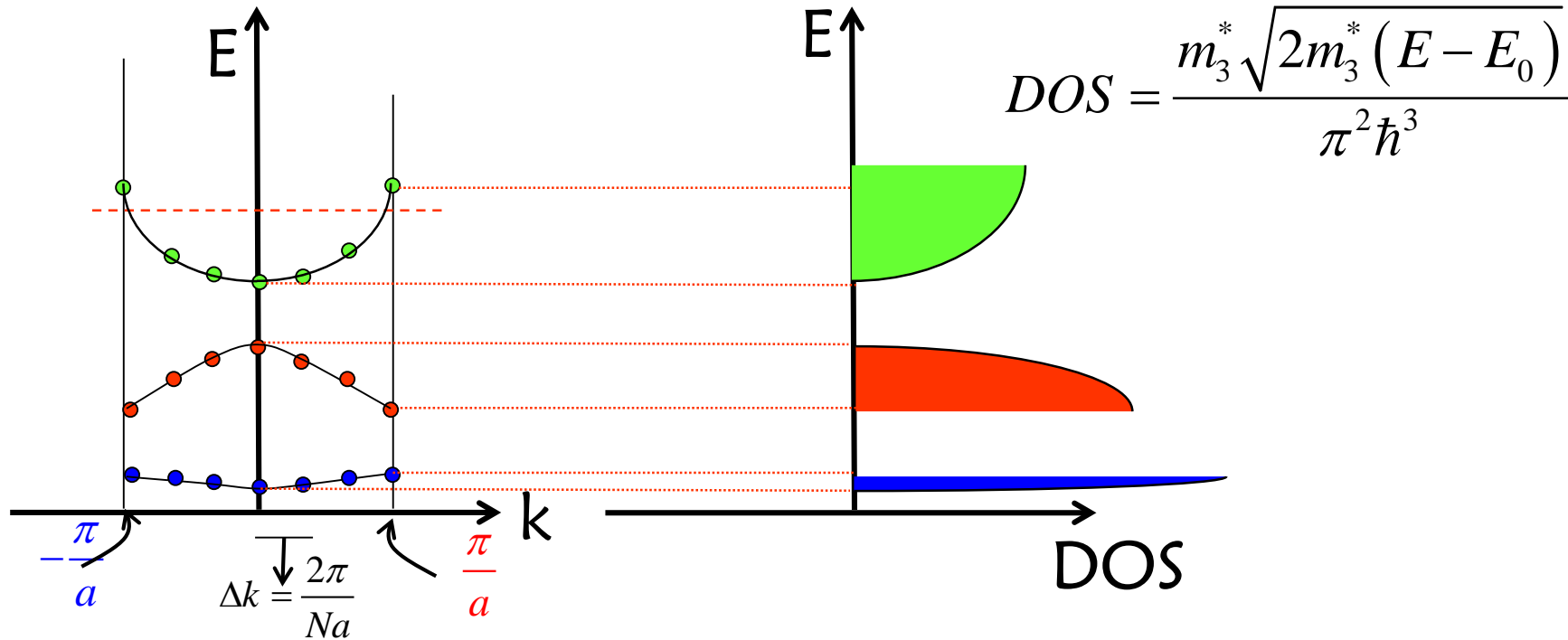
- Section 7 – Bandstructure in 1D Periodic Potentials
- Section 8 – Brillouin Zone - Reciprocal Lattice
- Section 9 – Constant Energy Surfaces & DOS
- Section 10 – Bandstructure in Real Materials (Si, Ge, GaAs)

- 11.1 Bandgap measurements
- 11.2 Effective mass measurements



Reference: Vol. 6, Ch. 3

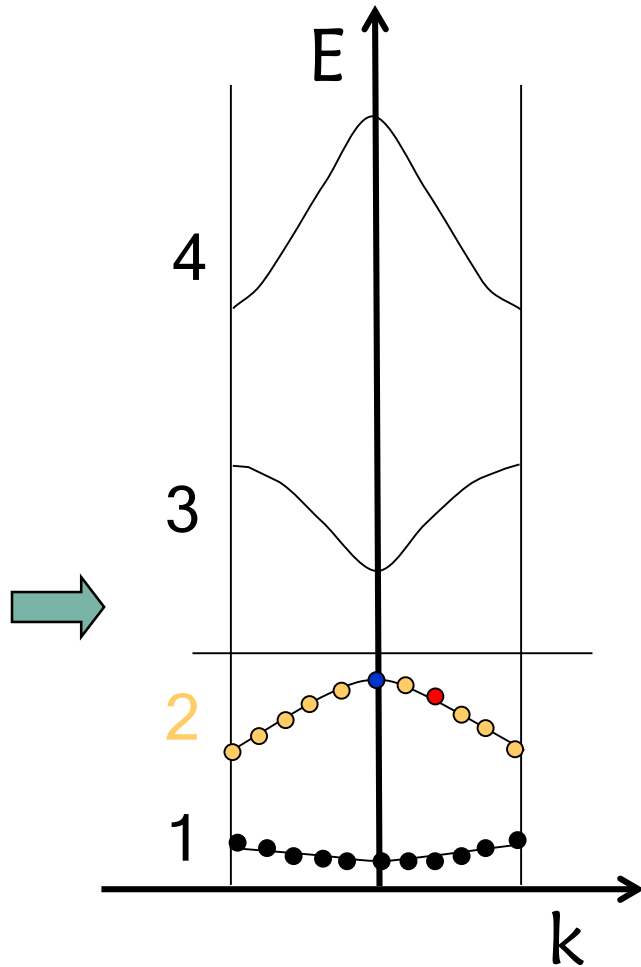
# Reminder: Momentum vs. DOS



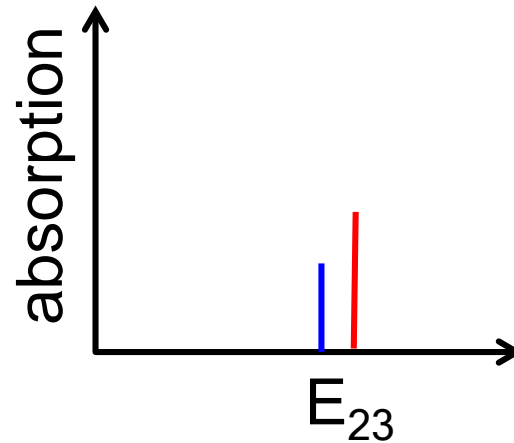
Important things to remember:

- Momentum  $k$  entered our thinking as a quantum number
- Each quantum number is creating ONE state
- Often “just” need the number of available states in an energy range  
=> Density of States  
=> appears to be solely determined by
  - » 1) band edge,
  - » 2) effective mass

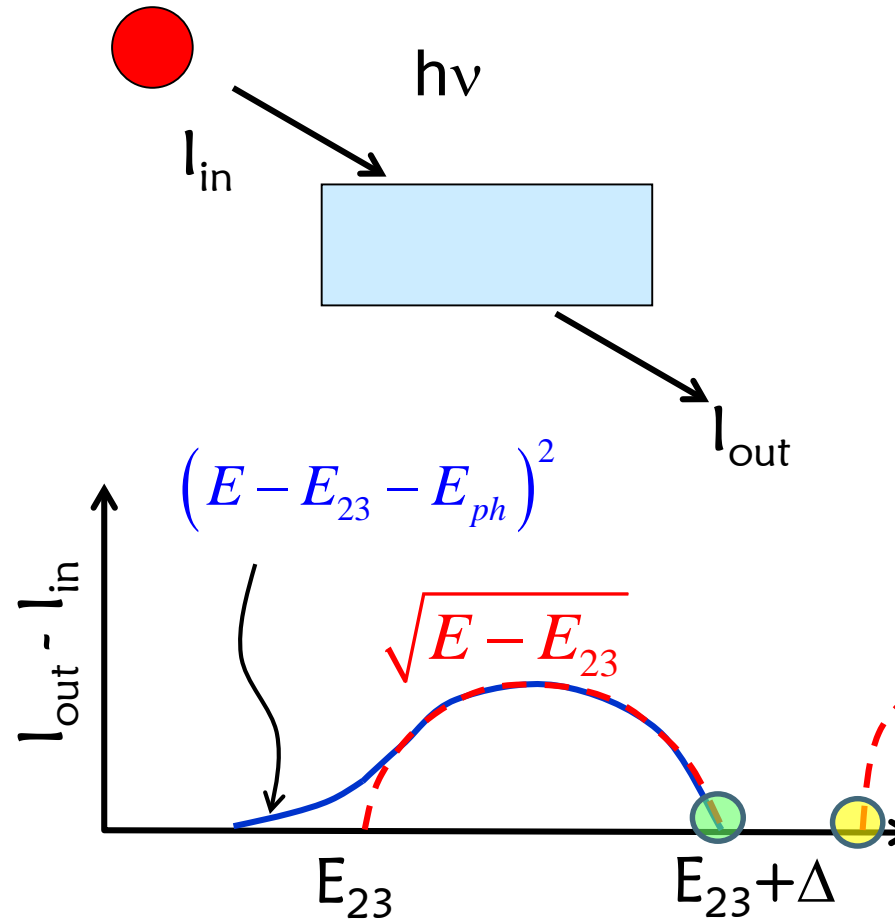
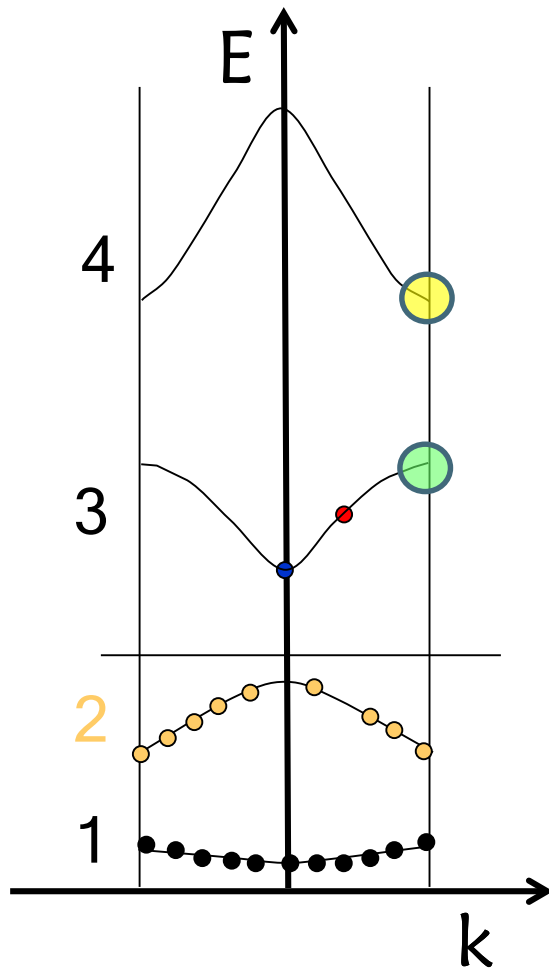
# Measurement of Band Gap



Photons are only absorbed between bands that have filled and empty states



# Measurement of Energy Gap

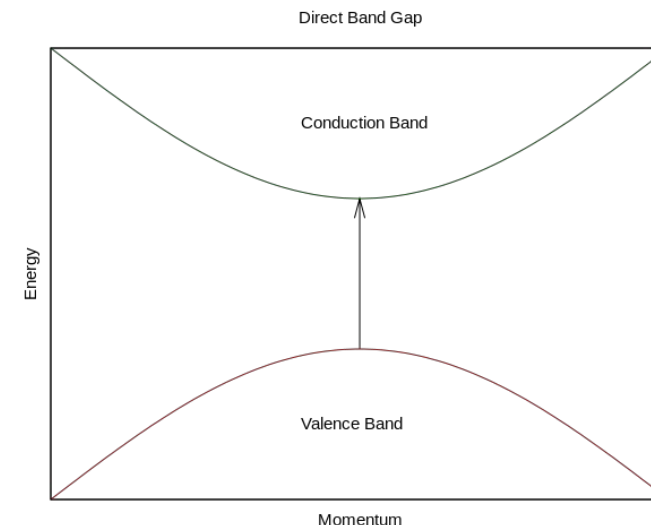
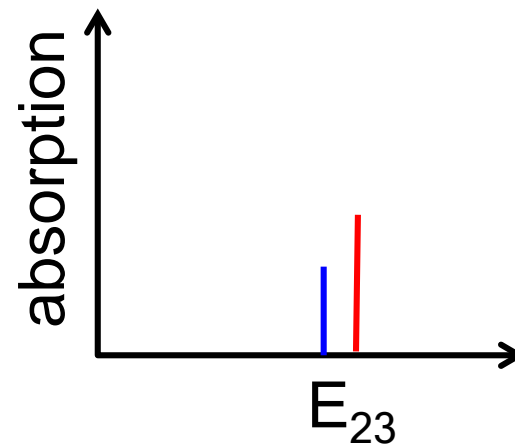
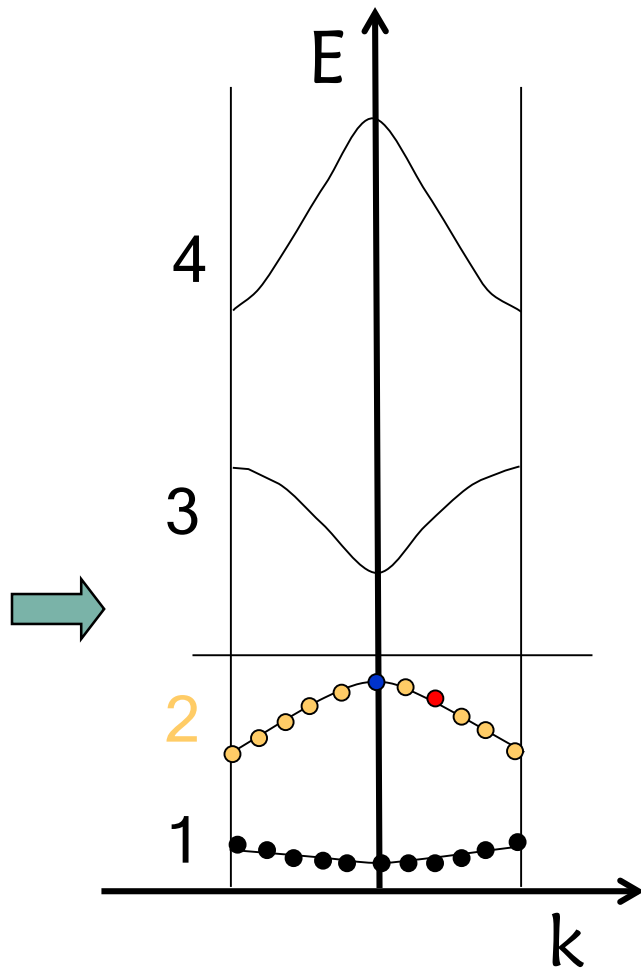


# Direct Bandgaps

Photons are only absorbed between bands that have filled and empty states

Particle-particle interaction –  
Energy and momentum must be conserved

Photon momentum negligible compared to electron momentum  
Electron transition is “vertical”



# Direct Bandgaps

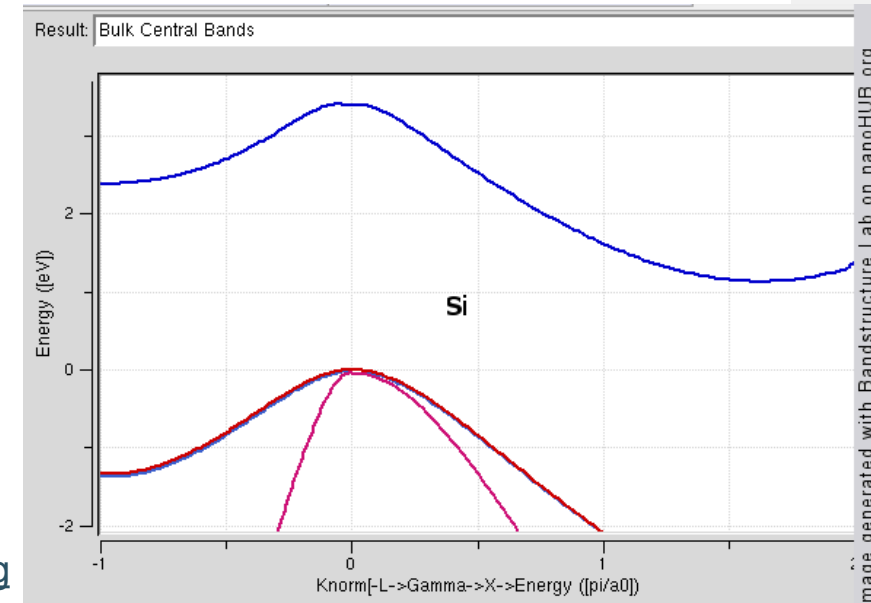
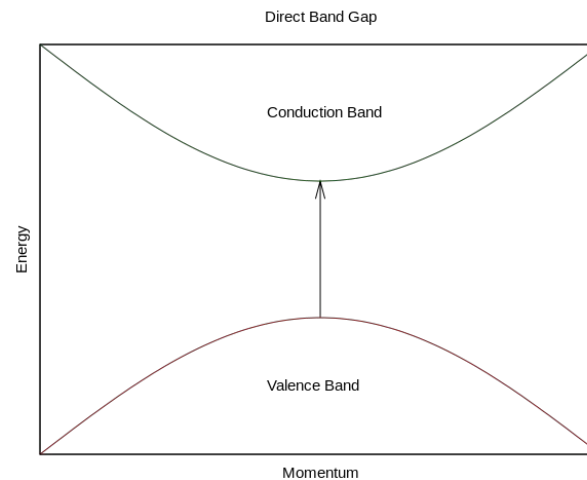
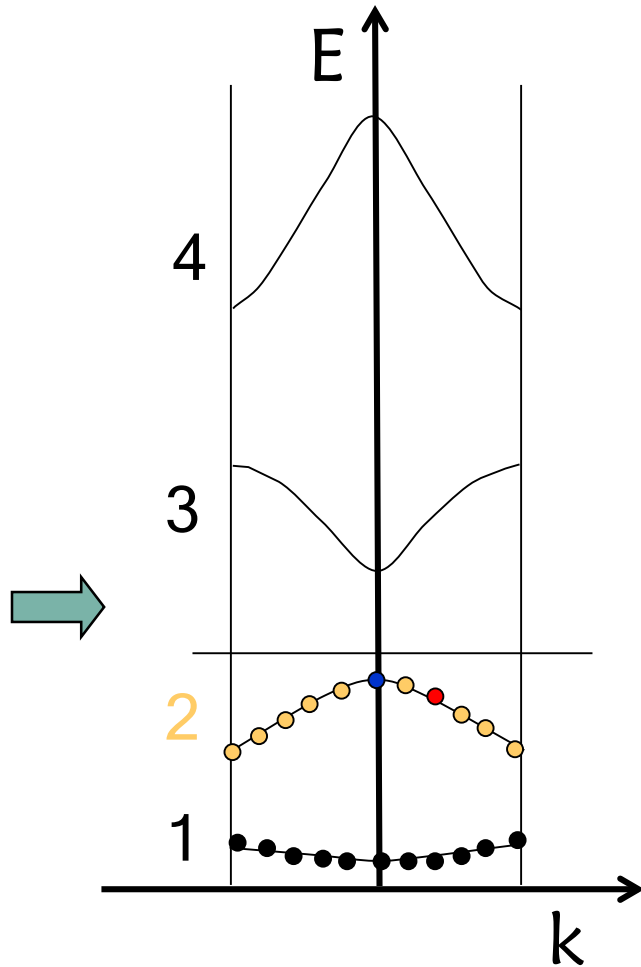
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In Si and Ge the smallest bandgap is not at  $\Gamma$

nanoHUB result on wikipedia



[https://en.wikipedia.org/wiki/Direct\\_and\\_indirect\\_band\\_gaps](https://en.wikipedia.org/wiki/Direct_and_indirect_band_gaps)

<https://upload.wikimedia.org/wikipedia/commons/thumb/7/7a/Direct.svg/600px-Direct.svg.png>

<https://en.wikipedia.org/wiki/File:Bulkbandstructure.gif>

# Direct and Indirect Bandgaps

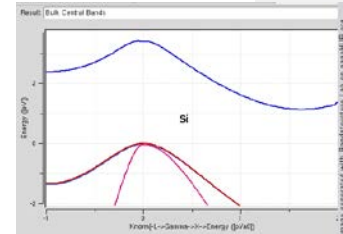
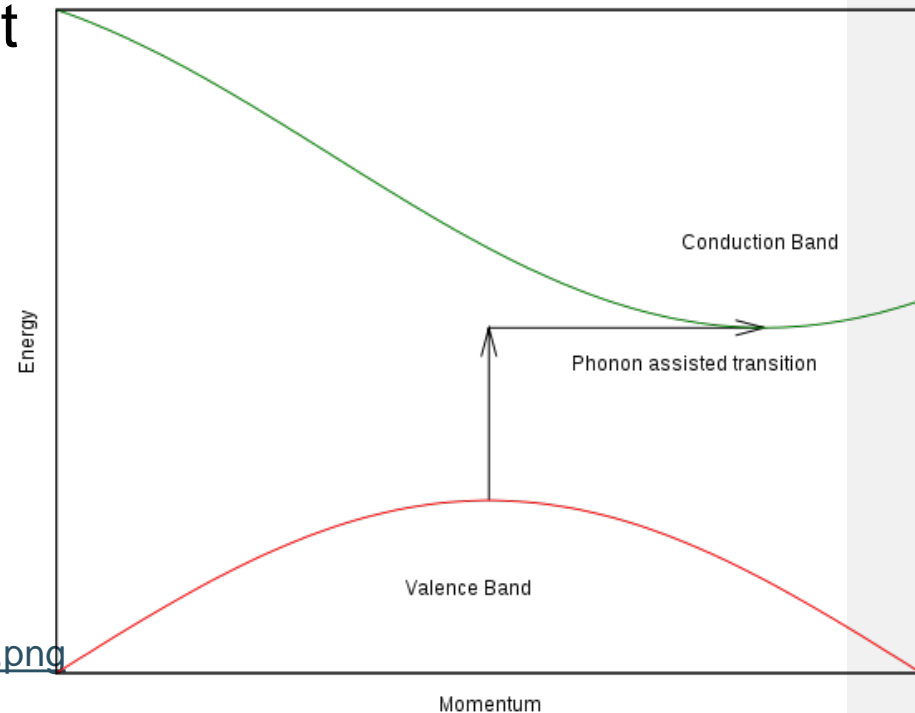
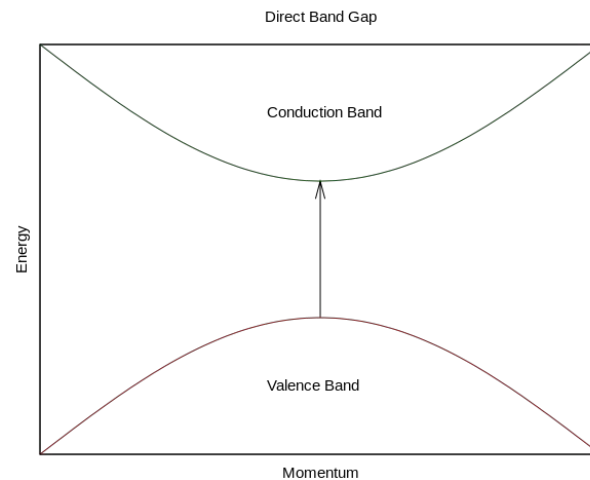
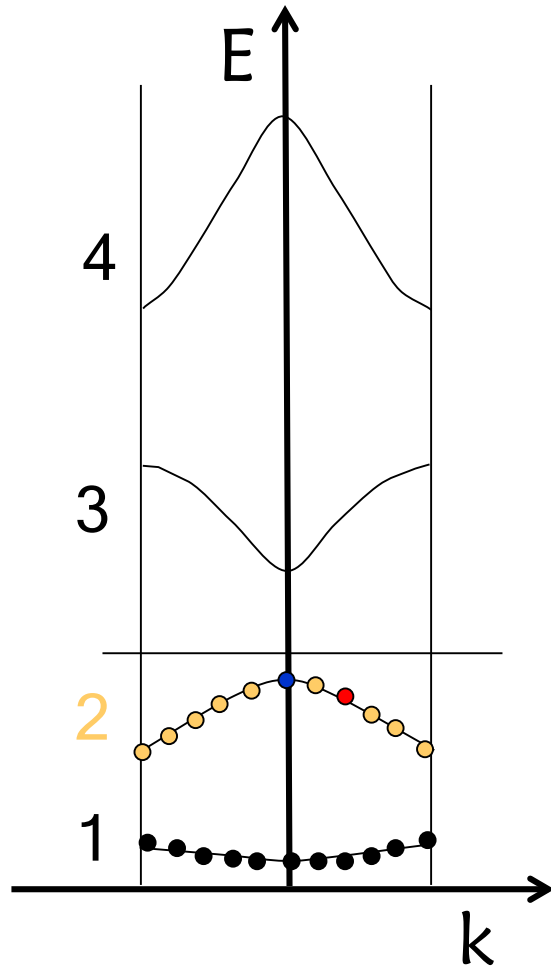
Particle-particle interaction –  
Energy and momentum must be conserved

Electron transition is “vertical”

In Si and Ge the smallest bandgap is not at  $\Gamma$

Need a “phonon” to compensate momentum conservation

3-particles - less efficient



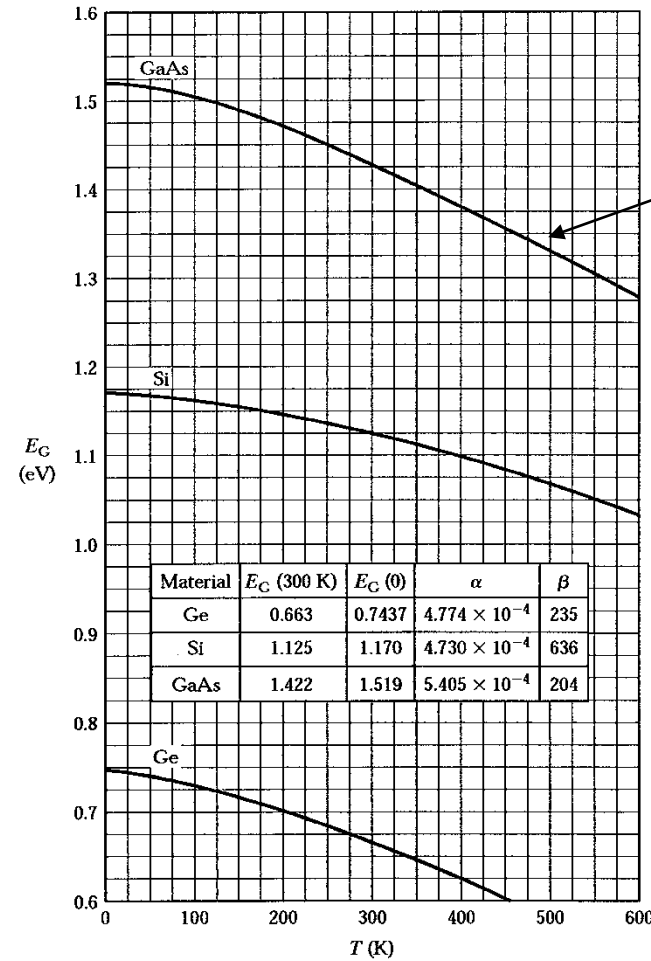
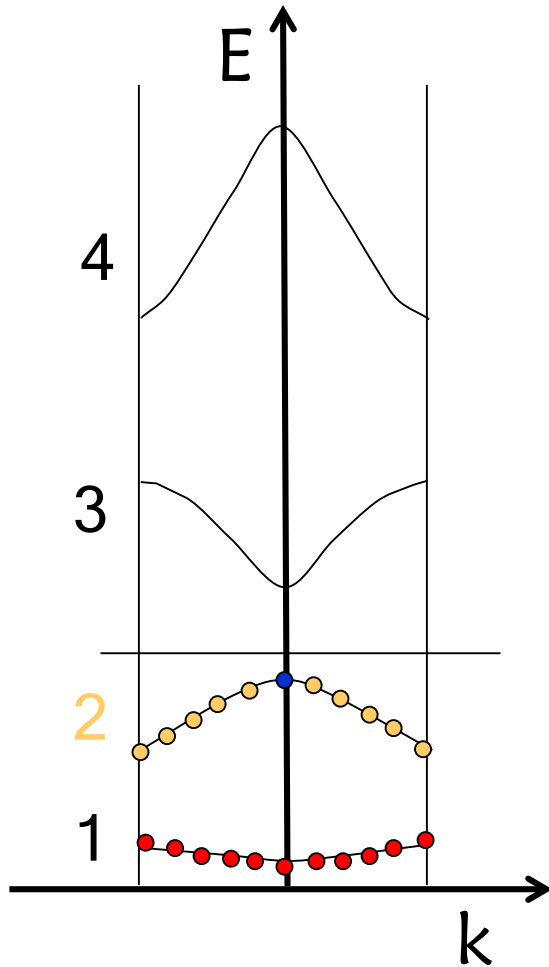
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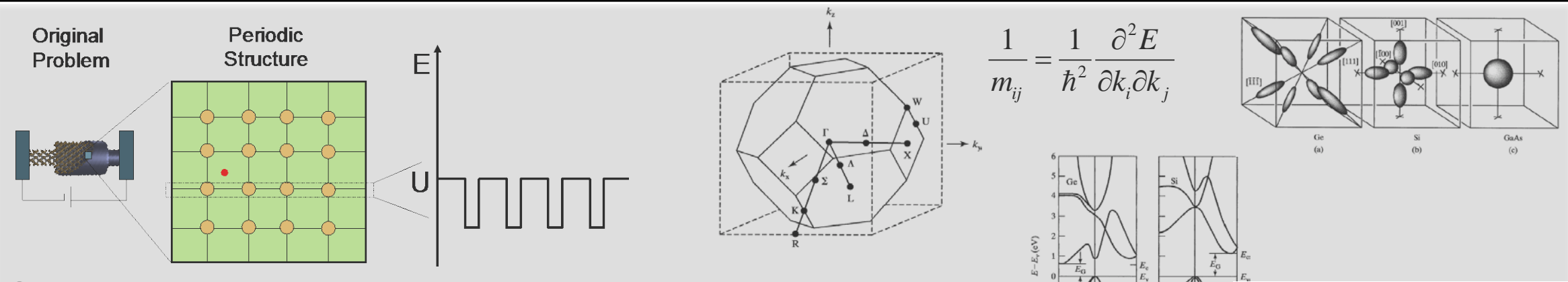


# Temperature-dependent Band Gap



$$E_G(T) = E_G(0) - \frac{\alpha T^2}{T + \beta}$$

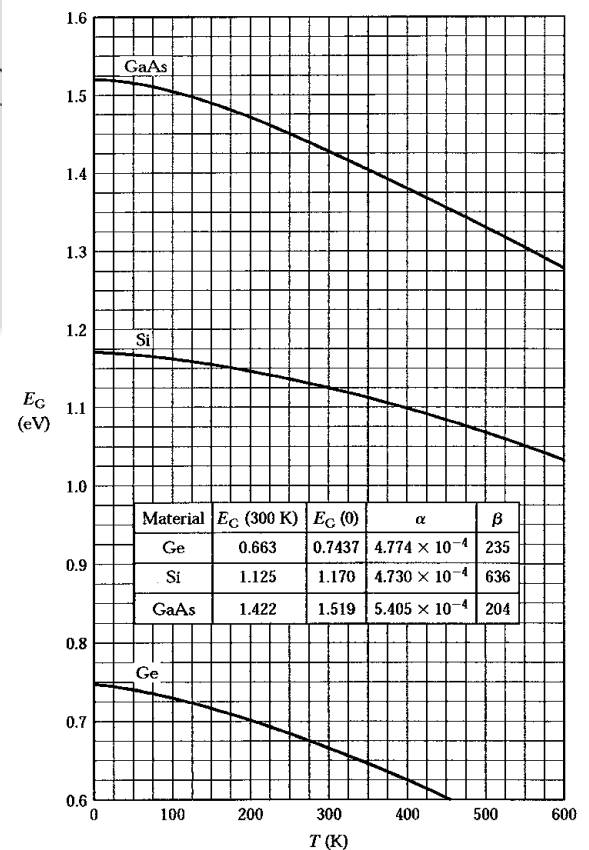
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Bandstructure Measurements **test and validate the theories**

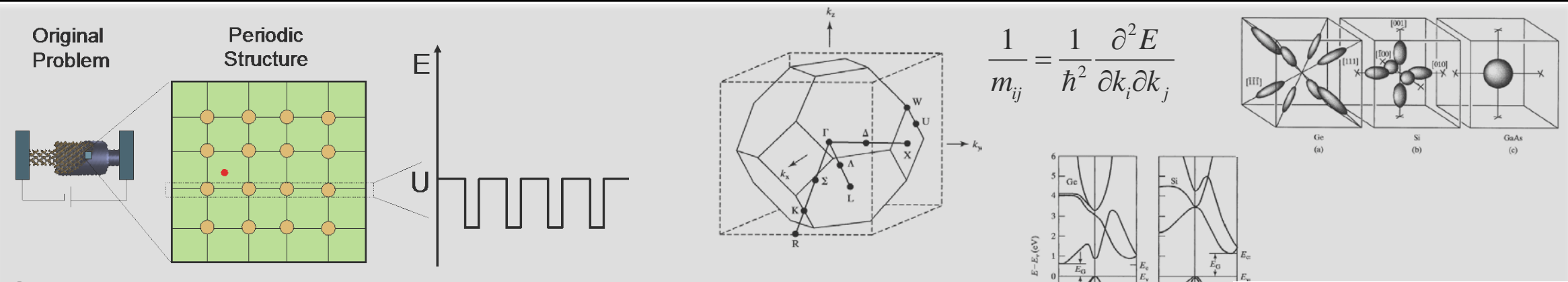
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Video Segment  
Video Segment

Reference: Vol. 6, Ch. 3

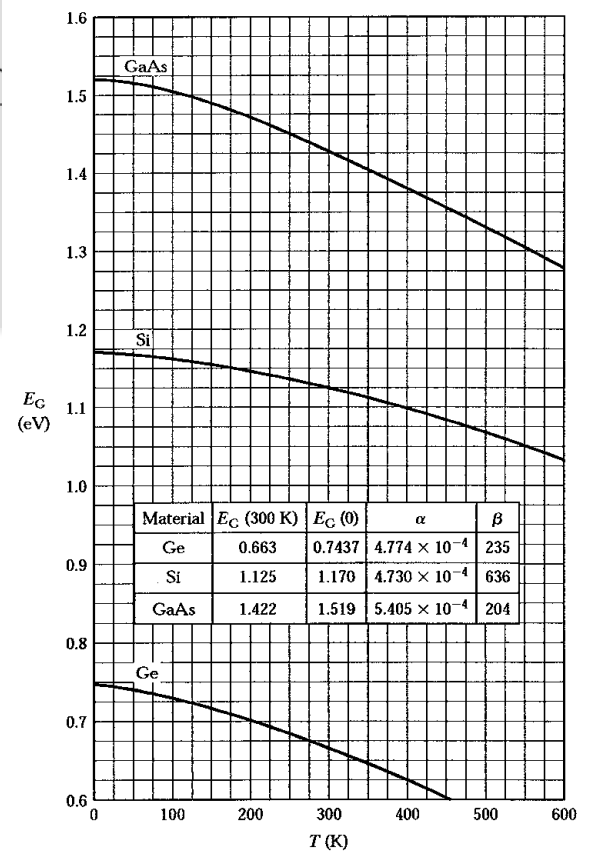
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Video Segment