Semiconductor Fundamentals

Presented to

EE2187 class in Semester 1 2019/20

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Lecture 10

Course information

- Semiconductors Materials - Types of Solids, Space lattice, Atomic Bonding,
- Introduction to quantum theory, Schrodinger wave equation, Electron in free space, Infinite well, and step potentials, Allowed and forbidden bands
- Electrical conduction in solids, Density of states functions, Fermi-Dirac distribution in Equilibrium,
- Valence band and Energy band models of intrinsic and extrinsic Semiconductors. Degenerate and non degenerate doping
- Thermal equilibrium carrier concentration, charge neutrality
- Carrier transport – Mobility, drift, diffusion, Continuity equation.

Reference

Text Book:

1. Physics of Semiconductor Devices, *S. M. Sze*, John Wiley & Sons (1981).
2. Solid State Electronics by *Ben G. Streetman and Sanjay Banerjee,* Prentice Hall International, Inc.
3. Semiconductor Physics and Devices, Donald A. Neamen, Tata Mcgraw-Hill Publishing company Limited.
4. Advanced Semiconductor Fundamentals by Pirret

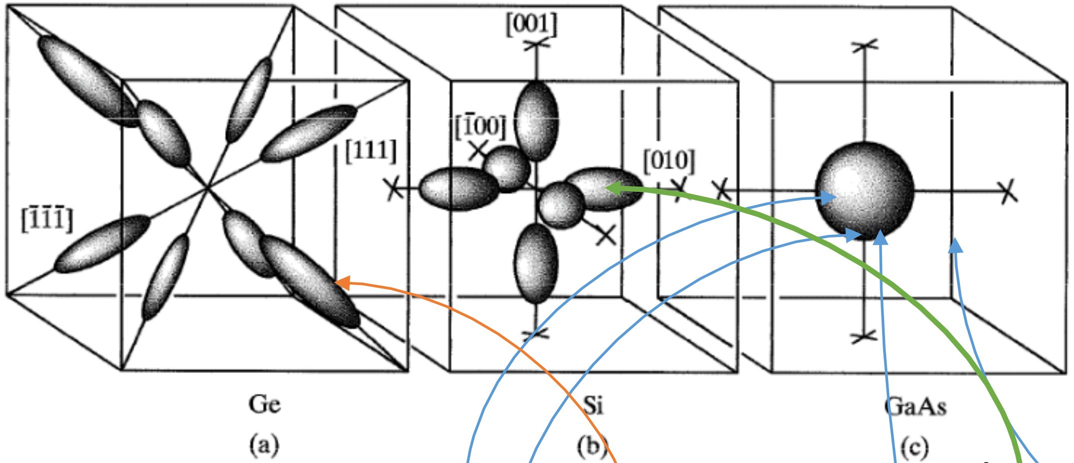
Reference Book:

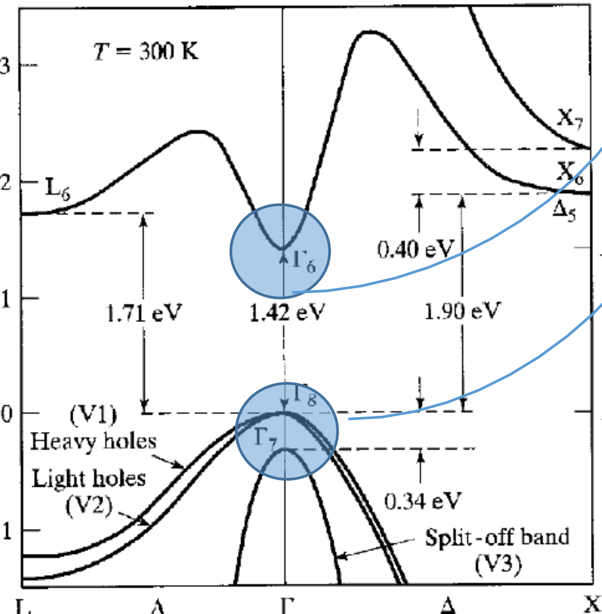
1. Fundamentals of Solid-State Electronic Devices, *C. T. Sah*, Allied Publisher and World Scientific, 1991.
2. Complete Guide to Semiconductor Devices, *K. K. Ng*, McGraw Hill, 1995.
3. Solid state physics, Ashcroft & Mermins.
4. Introduction to Solid State Electronics, *E. F. Y. Waug*, North Holland, 1980.

Recap

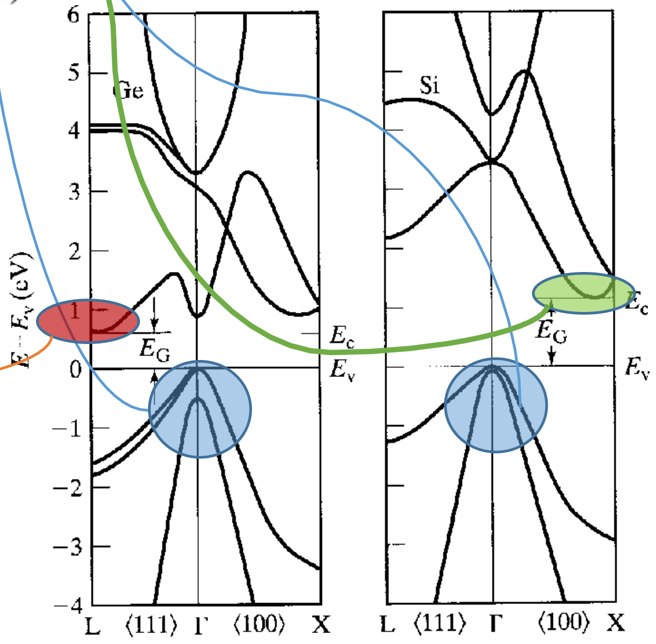
Constant-Energy Surfaces: Conduction Band

Geometrical shapes for given Energy are called CES





Valence Band E-k and constant energy surfaces all look similar



So Energy E in Conduction band

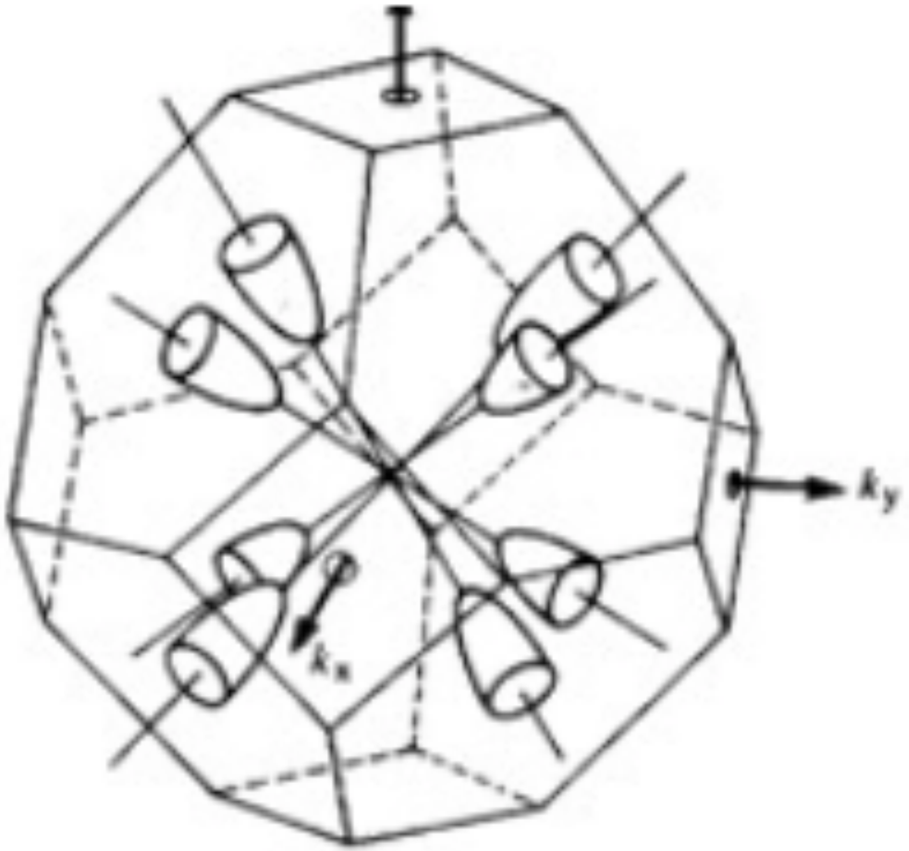
$$E = Ec + \mathrm{A}k_1^2 + \mathrm{B}k_2^2 + \mathrm{C}k_3^2$$

k,, k2, k3 are k space coordinate measured from center of band minimum along the principle axis for example Ge it will be center on L point and one of the axis say k_1 would directed along kx, ky, kz in [111} direction

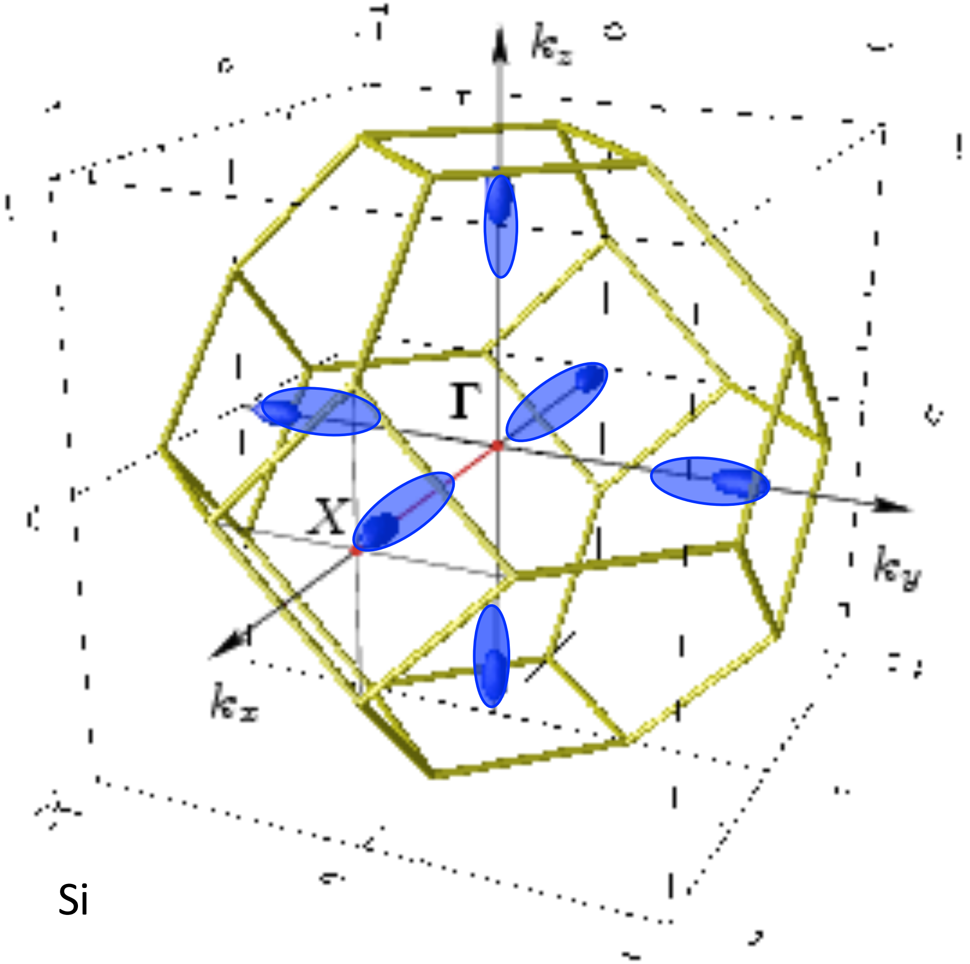
For GaAs A=B=C

And for Si, and Ge, B=C

Constant-Energy Surfaces at BZ Boundaries

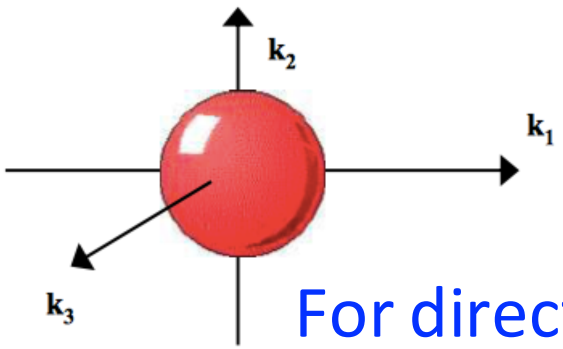


Ge

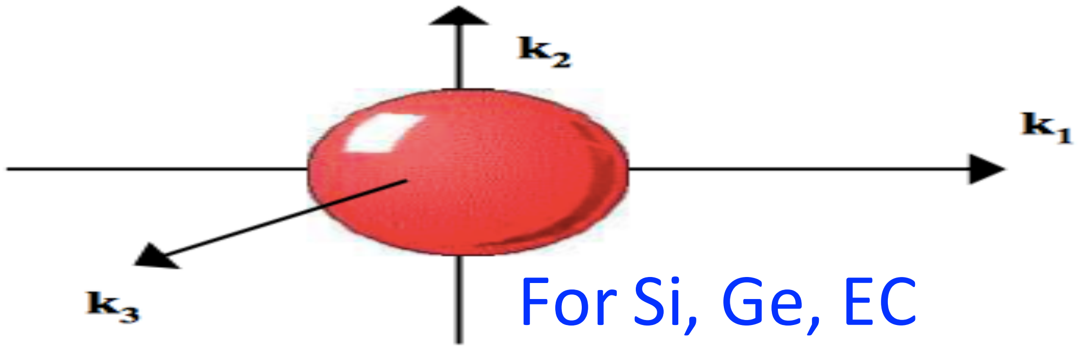


Si

Effective Mass in 3D Crystal



For direct band gap or Ev



For Si, Ge, EC

$$m^* a = F$$

for 3D crystals $\quad \frac{dv}{dt} = \frac{1}{m*} F \quad$ $where, \frac{1}{m*} = \begin{pmatrix} m_{xx}^{-1} m_{xy}^{-1} m_{xz}^{-1} \\ m_{yx}^{-1} m_{yy}^{-1} m_{yz}^{-1} \\ m_{zx}^{-1} m_{zy}^{-1} m_{zz}^{-1} \end{pmatrix}$

$$E - Ec = A(k_x^2 + k_y^2 + k_z^2)$$

$m_{ij}^{-1} = \frac{1}{\hbar^2} \frac{\partial^2 E}{\partial k_i \partial kj}$ for i, j =x, y& z

$$E - Ec = A(k_x^2) + B(k_y^2 + k_z^2)$$

$$E - Ec = A(k_x^2 + k_y^2 + k_z^2)$$

$$E - Ec = A(k_x^2) + B(k_y^2 + k_z^2)$$

$$m_{ij}^{-1} = \frac{1}{\hbar^2}\frac{\partial^2 E}{\partial k_i \partial kj} \text{ for i, j =x, y\& z}$$

$$m_{11}^{-1} = m_{22}^{-1} = m_{33}^{-1} = \frac{2A}{\hbar^2} \quad m_{ij}^{-1}\text{=0 if i}\neq j$$

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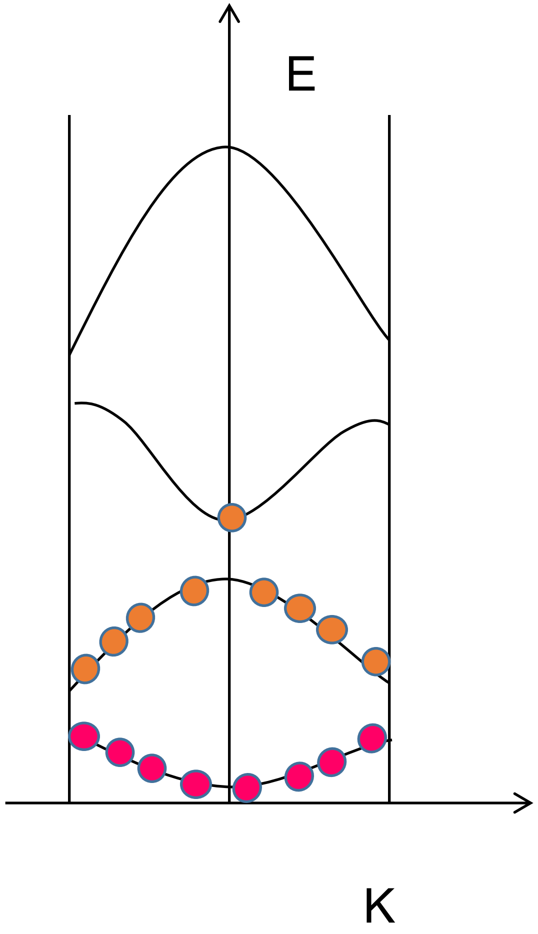
$$where, \frac{1}{m*} = \begin{pmatrix} \frac{2A}{\hbar^2} & 0 & 0 \\ 0 & \frac{2A}{\hbar^2} & 0 \\ 0 & 0 & \frac{2A}{\hbar^2} \end{pmatrix}$$

$$where, \frac{1}{m*} = \begin{pmatrix} \frac{2A}{\hbar^2} & 0 & 0 \\ 0 & \frac{2B}{\hbar^2} & 0 \\ 0 & 0 & \frac{2B}{\hbar^2} \end{pmatrix}$$

Measurement of effective mass



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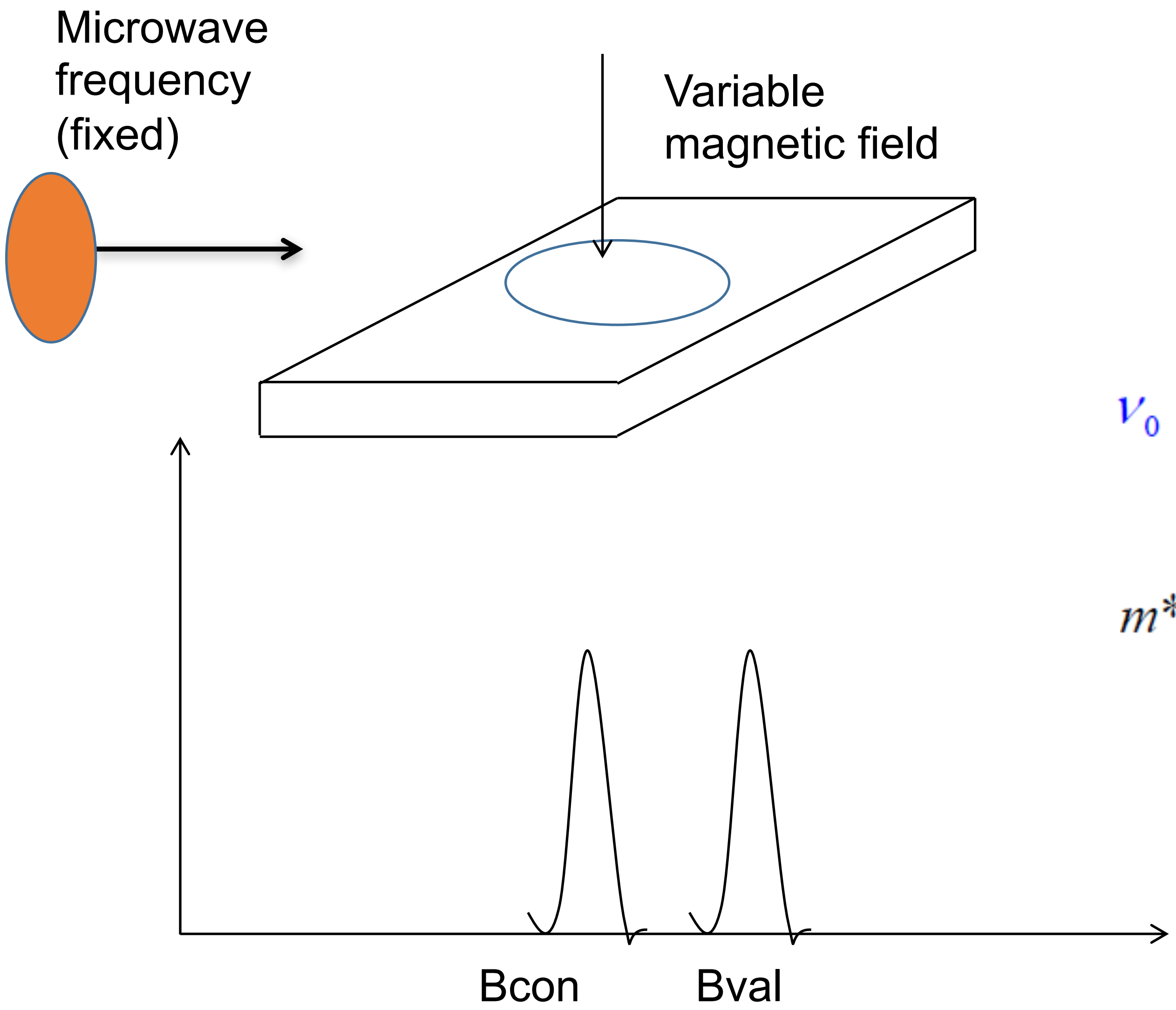
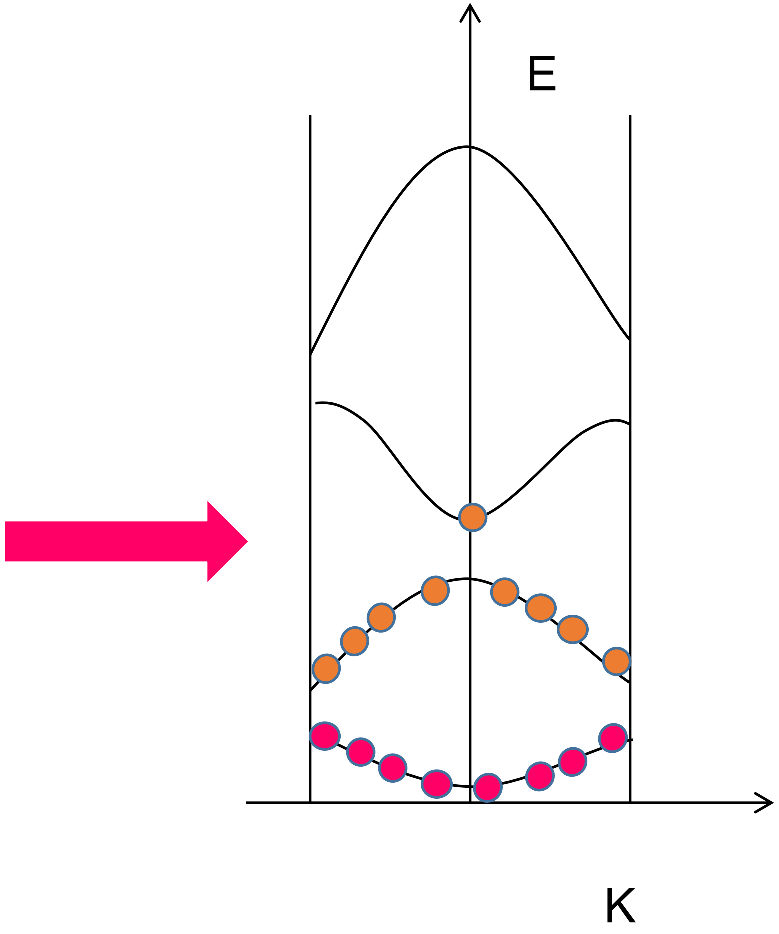
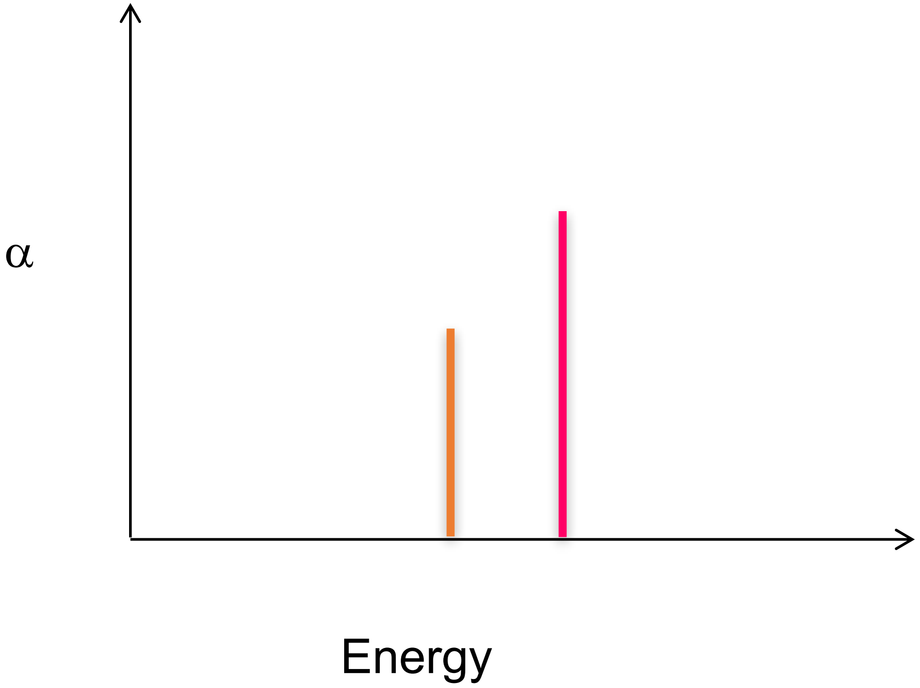


$$\nu_0 = \frac{qB_0}{2\pi m^*}$$

$$m^* = \frac{qB_0}{2\pi \nu_0}$$

Measurement of Band Gap





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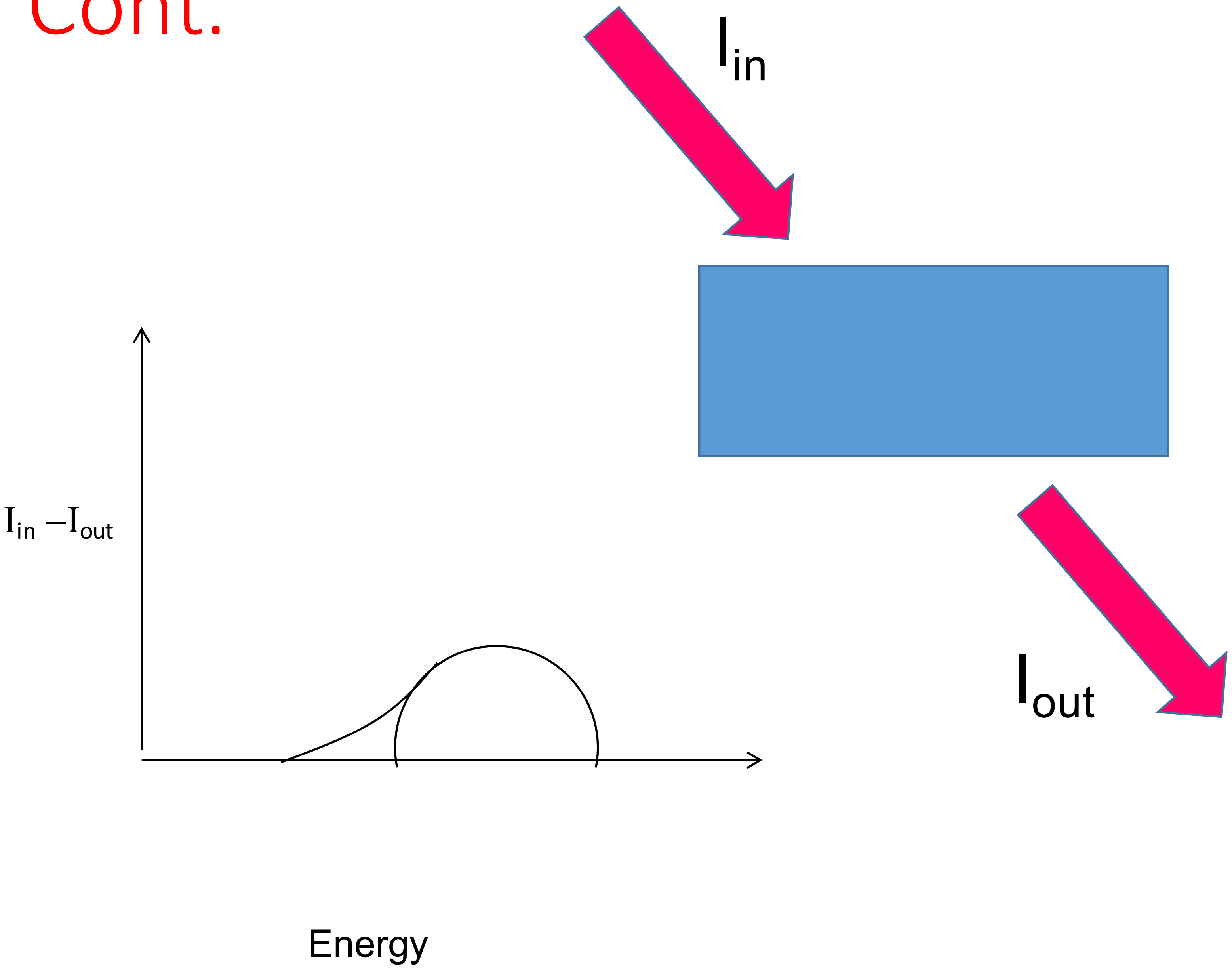


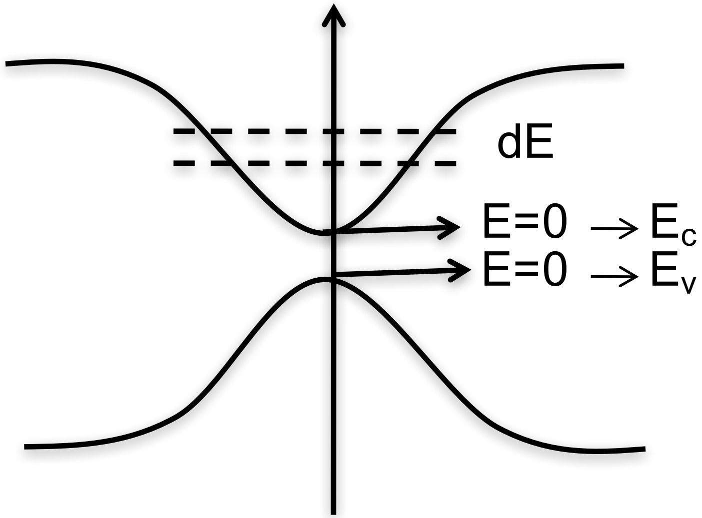
Carrier concentration

Density of electron/holes in energy interval dE-

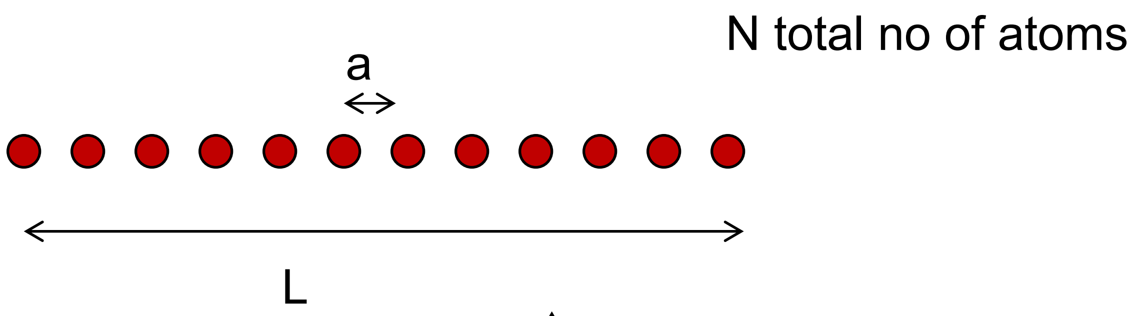
$$dn_o = f(E)g(E)dE$$

How do electrons and holes populate the bands?

$$n_o = \int_0^{E_{top}} f(E)g(E)dE$$

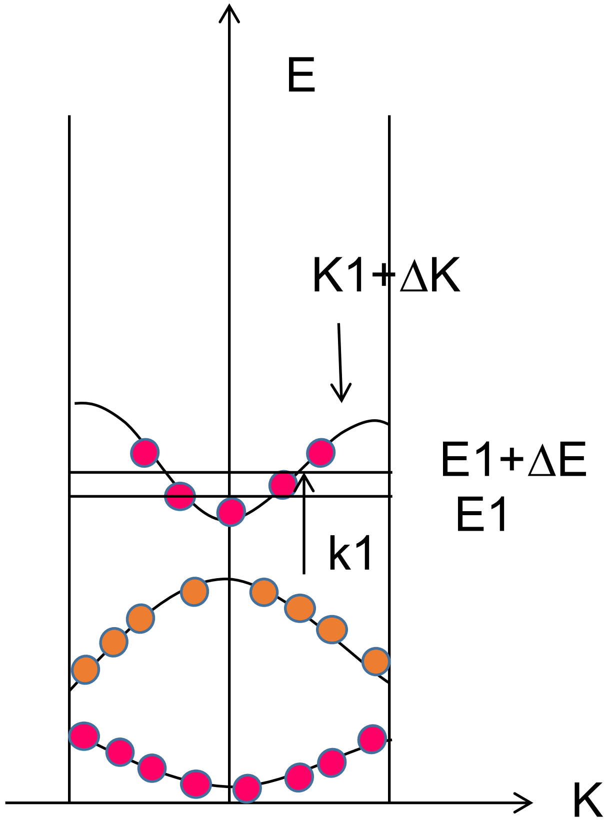


Density of states in band (1-D)



States between $E1+\Delta E$ and $E1=2X(\Delta k/\delta k)$

$$k = \pm\frac{2\pi n}{Np} = -\frac{N}{2}\ldots-1,01,\ldots N/2$$



$=2X\Delta k/(2\pi/Na)$

States per unit Energy=$(N.a.\ \Delta k)/(\pi.\Delta E)$

Cont.

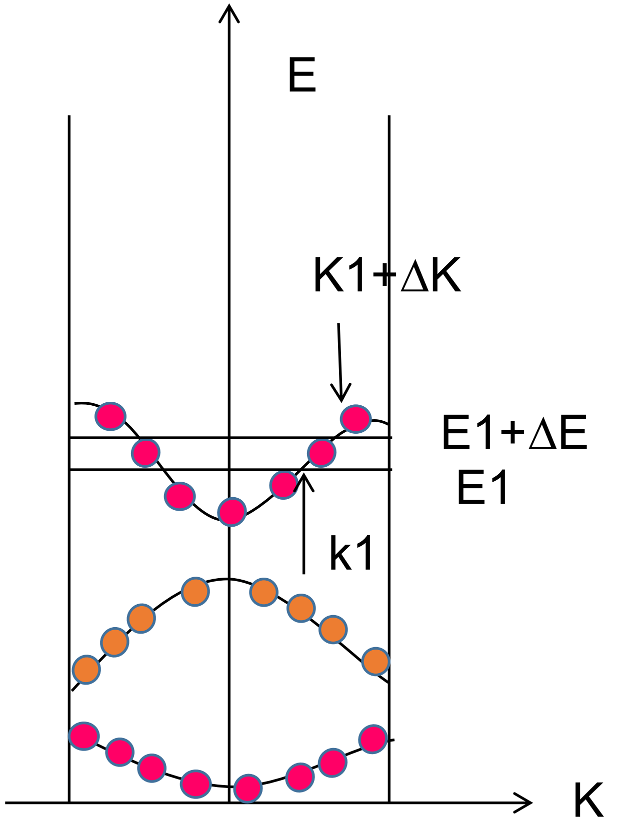
L

- States per unit Energy=(N.a. Δk)/(π.ΔE)

With free electron approximation

$$E-E_0=\frac{\hbar^2k^2}{2m^*}\Rightarrow k=\sqrt{\frac{2m^*(E-E_0)}{\hbar^2}}$$

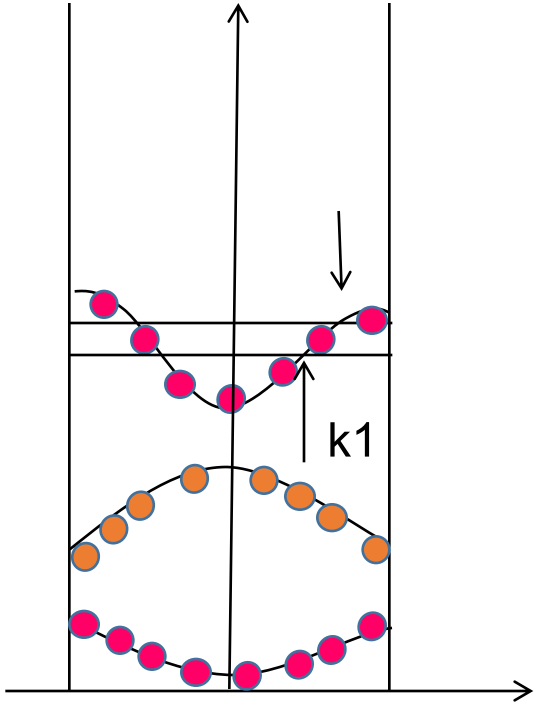
$$\frac{dk}{dE}=\sqrt{\frac{m^*}{2\hbar^2(E-E_0)}}$$

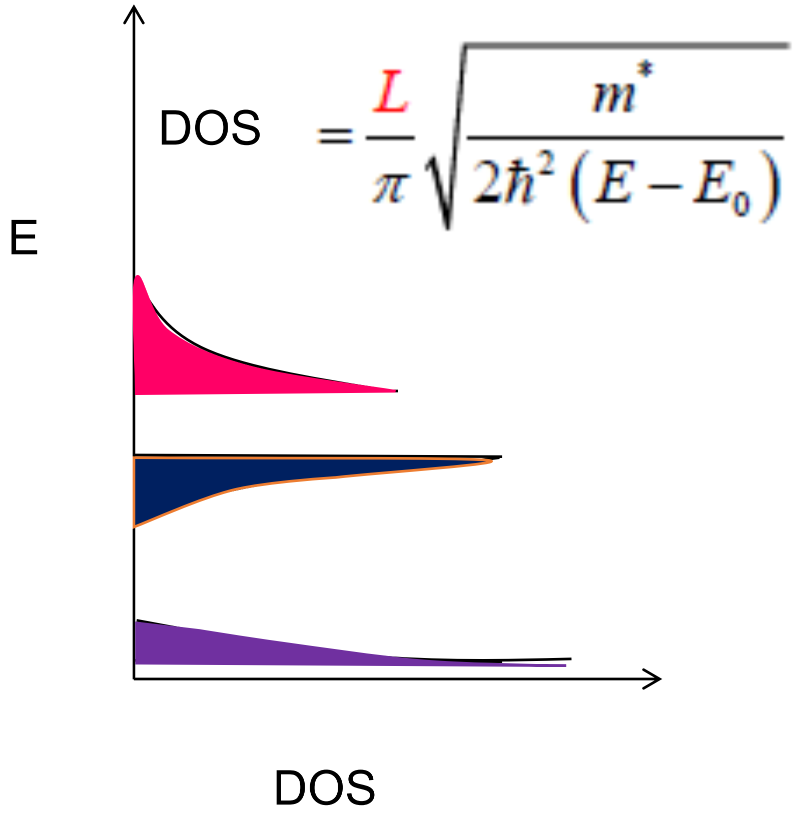


States per unit Energy @E $=\frac{L}{\pi}\sqrt{\frac{m^*}{2\hbar^2(E-E_0)}}$

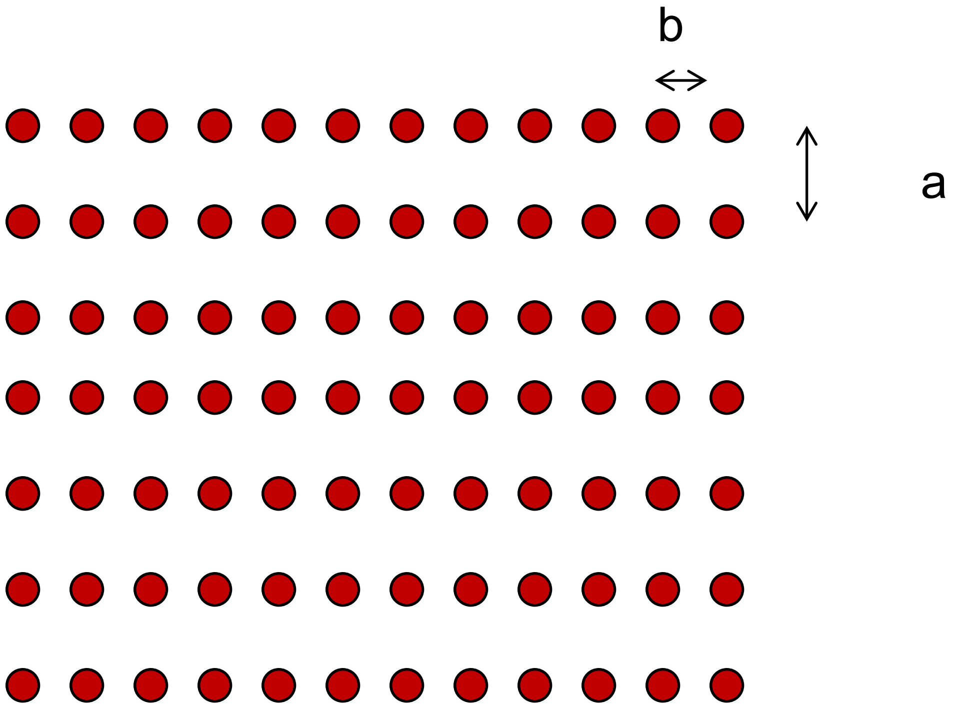
States per unit Energy per unit length @E $=\frac{1}{\pi}\sqrt{\frac{m^*}{2\hbar^2(E-E_0)}}$

Graphical Representation of DOS





Density of States in 2D Semiconductors



Interesting result :
DOS will be independent of Energy

DOS in 3-D semiconductor

Volume of single states in K-space is $(2\pi/L)^3$

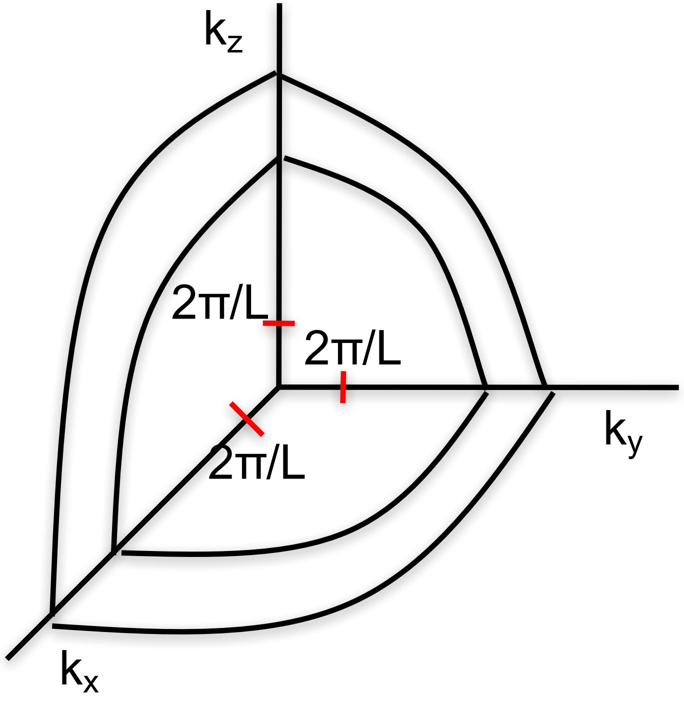
Volume of spherical cell of radius k and thickness k+dk $=4\pi k^2 dk$

States between E1+ΔE and E1

$=4\pi k^2 dk \,/\, (2\pi/L)^3$

$=Vk^2 dk \,/\, 2\pi^2$

States /energy $=(Vk^2 dk/dE)/2\pi^2$

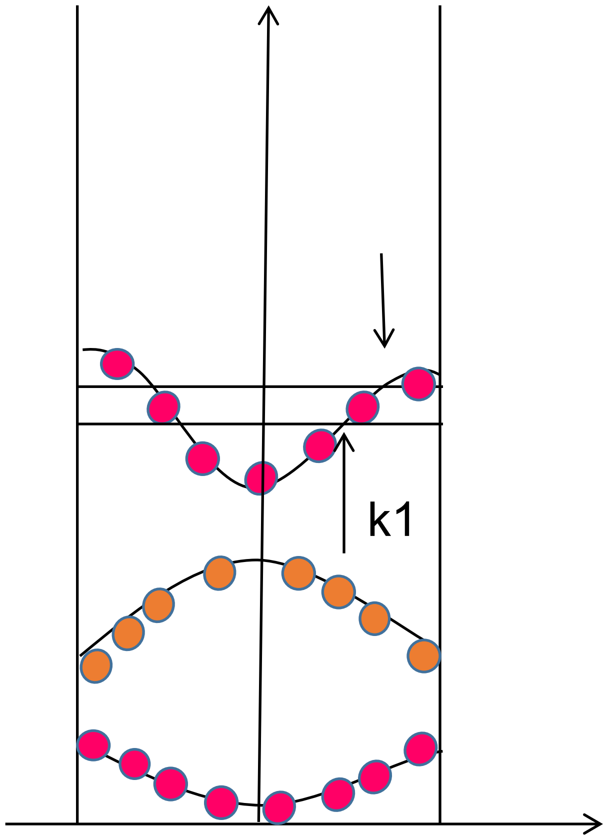


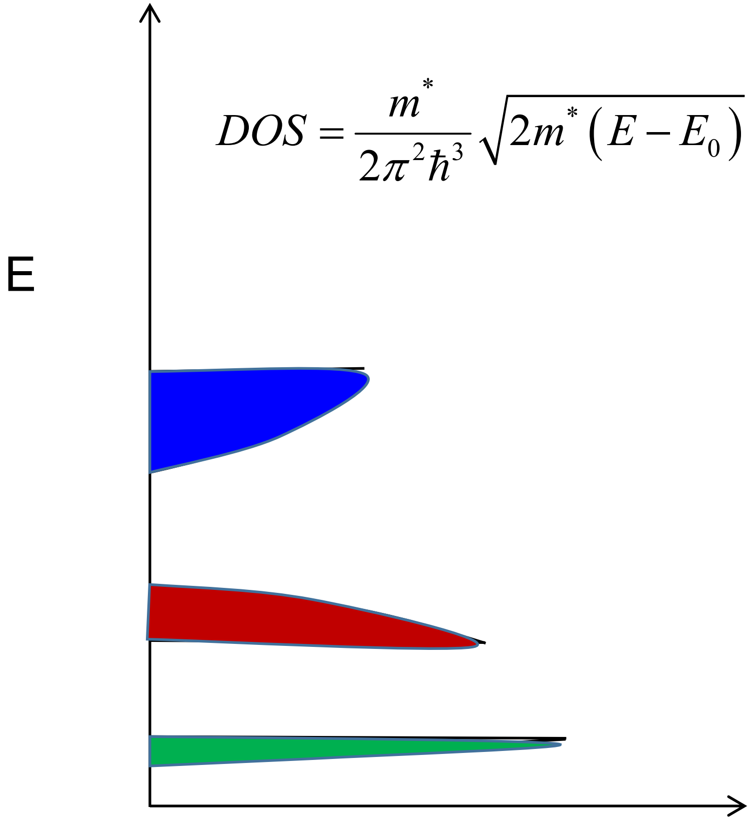
$$E - E_0 = \frac{\hbar^2 k^2}{2m^*} \Rightarrow k = \sqrt{\frac{2m^*(E-E_0)}{\hbar^2}} \Rightarrow \frac{dk}{dE} = \sqrt{\frac{m^*}{2\hbar^2 (E-E_0)}}$$

States/unit energy/unit volume @ E_1

$$DOS = \frac{m^*}{2\pi^2 \hbar^3} \sqrt{2m^*(E-E_0)}$$

Graphical representation





$$DOS = \frac{m^*}{2\pi^2\hbar^3}\sqrt{2m^*\left(E - E_0\right)}$$