

ECE 440: Lecture 4

Energy Bands, Temperature, Effective Mass

Typical semiconductor band gaps (E_G) between 0-3 eV

- **Si $E_G = 1.1$ eV**
- **See Appendix III in book**

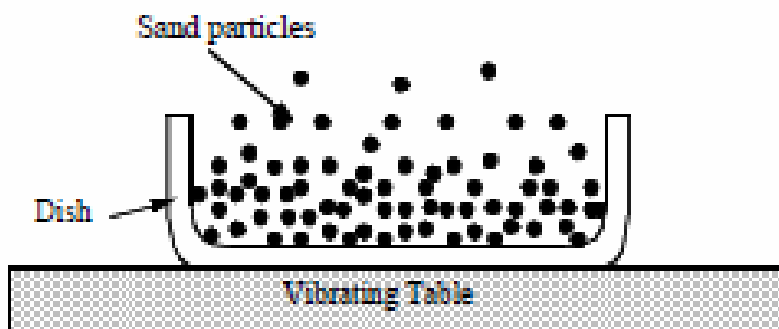
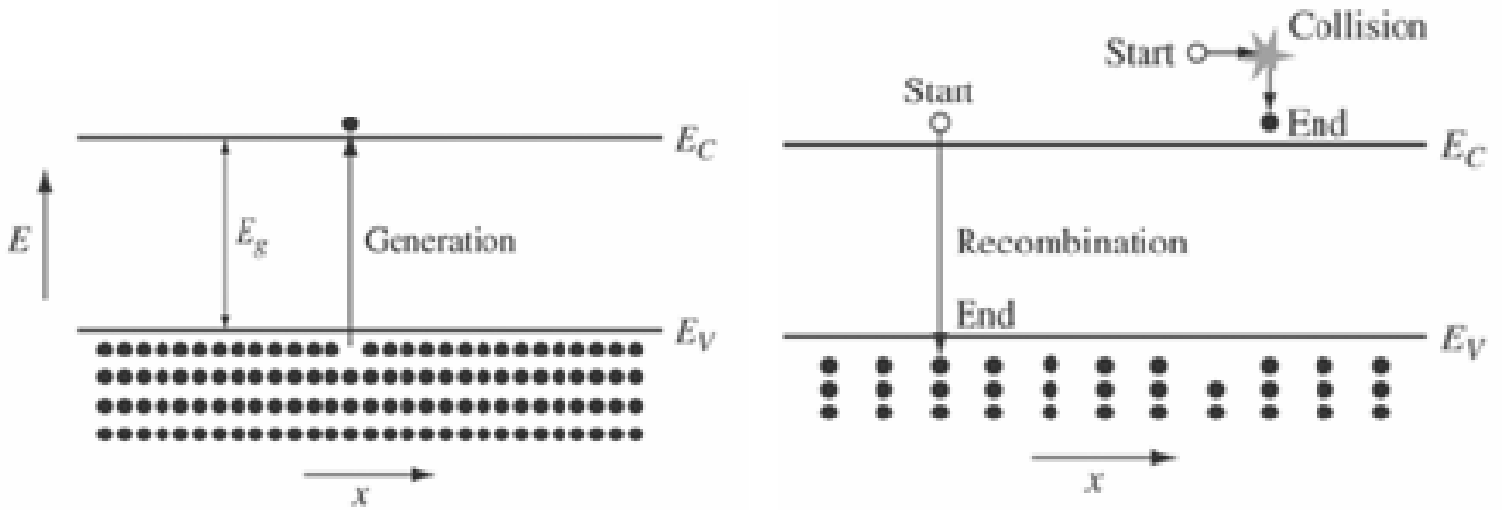
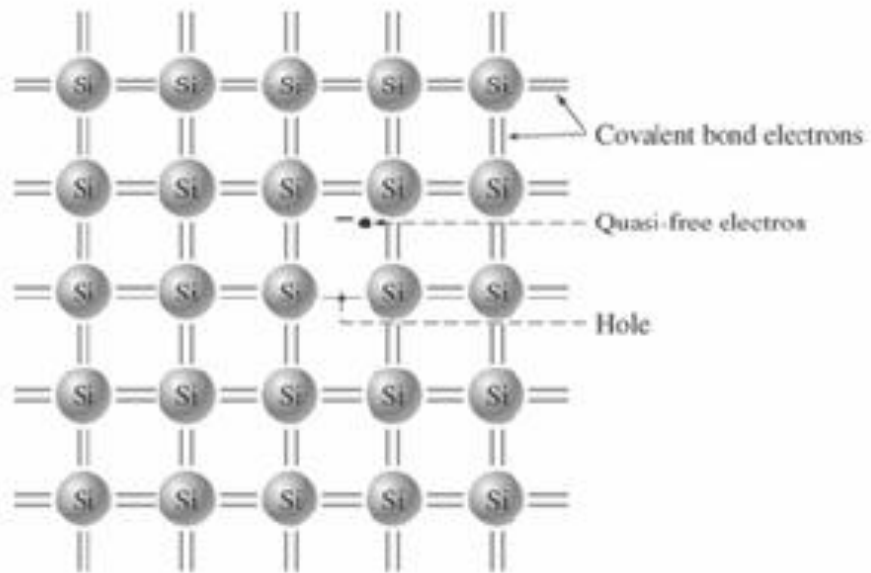
Insulator band gaps above 5 eV

- **SiO₂ $E_G = 9$ eV**

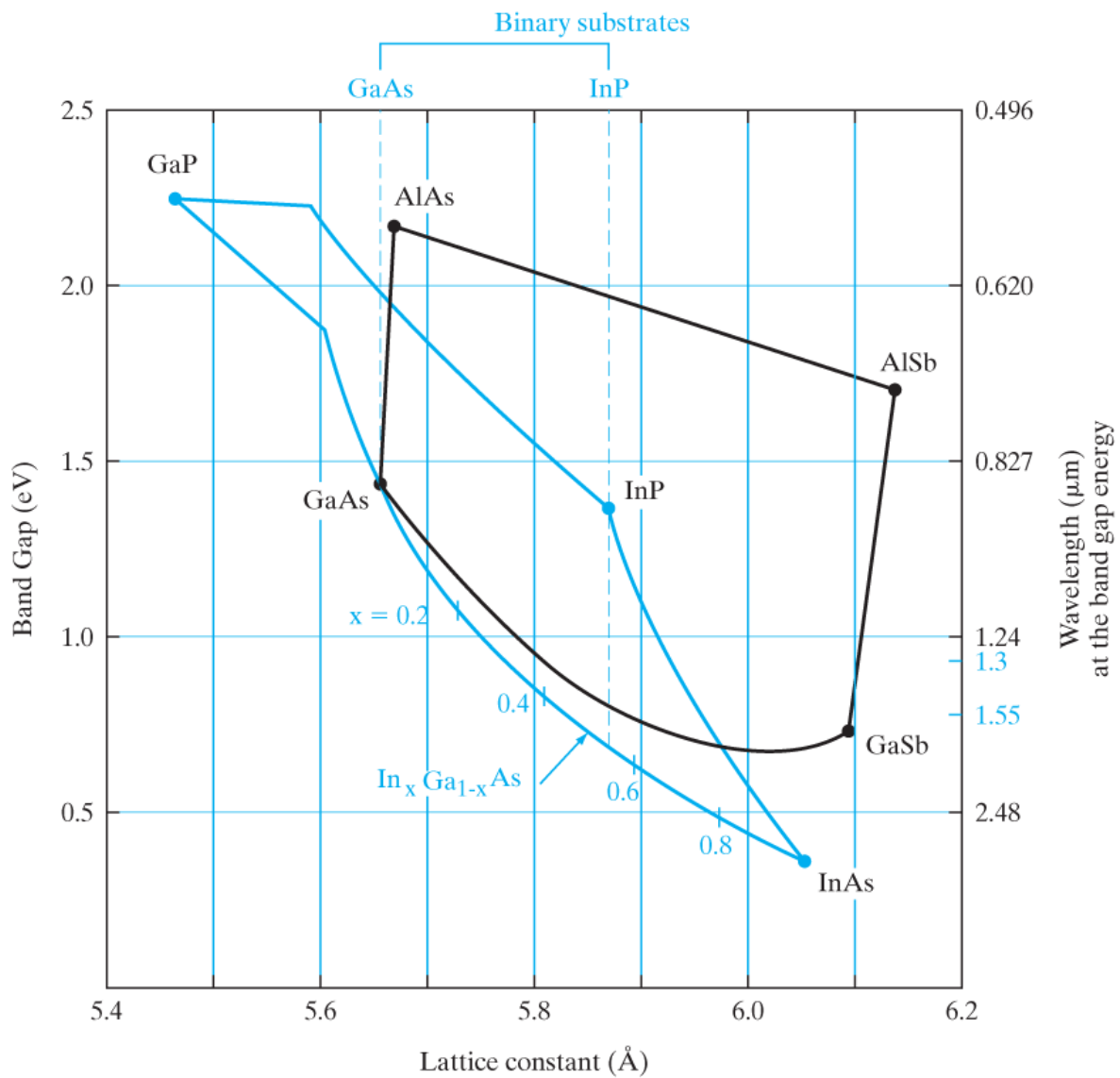
Where are all electrons at $T=0$ K?

Do either insulators or semiconductors conduct at 0 K?

What about at $T=300$ K?



How do band gaps vary with lattice size? (is there a trend?)



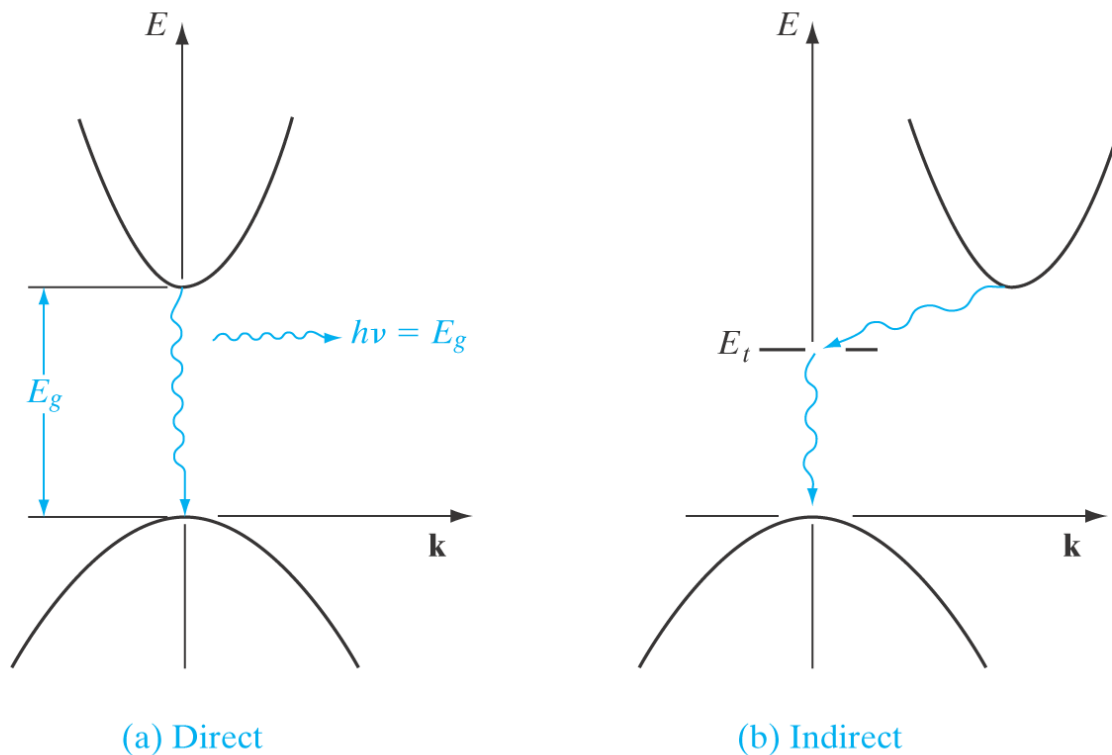
How do band gaps vary with temperature?

“Direct” and “indirect” band gap:

- Remember, in a periodic crystal: $\psi_{n\mathbf{k}}(\mathbf{r}) = e^{i\mathbf{k}\cdot\mathbf{r}} u_{n\mathbf{k}}(\mathbf{r})$.
- Where \mathbf{k} is wave vector (momentum):
- Related to electron energy as:
- Don't forget wave/particle duality!!!

So, if we can plot E bands vs. x or r (distance)...

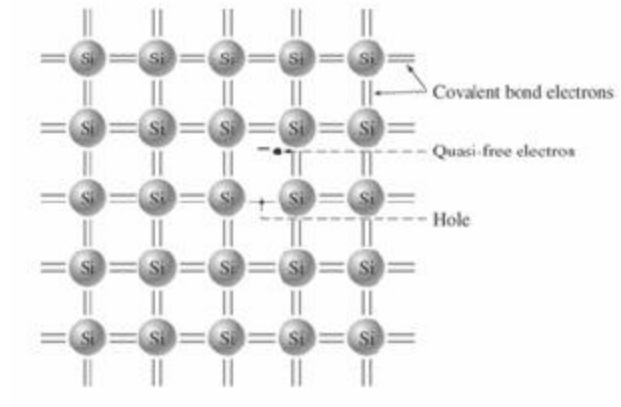
What about vs. k (momentum)?



Which material would you choose for light emitting devices (LEDs)? Or Lasers?

Short recap, so far we keep switching between:

- **Bond picture**



- **Band picture vs. x**

- **Band picture vs. k**

Let's combine energy bands vs. k and vs. x :

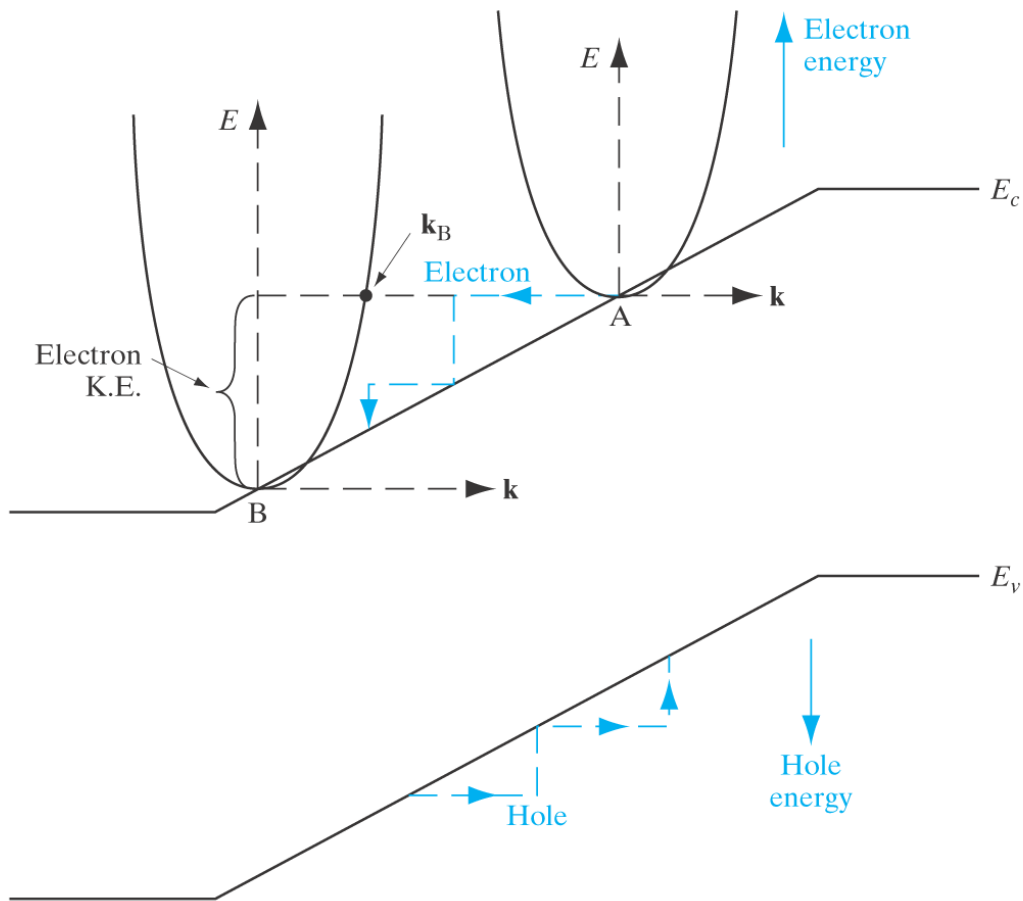
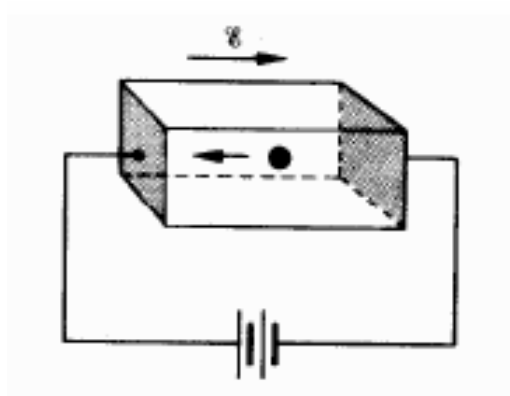


Figure 3.9

Superimposition of the (E, \mathbf{k}) band structure on the E -versus-position simplified band diagram for a semiconductor in an electric field. Electron energies increase going up, while hole energies increase going down. Similarly, electron and hole wave vectors point in opposite directions and these charge carriers move opposite to each other, as shown.

Electrons (or holes) as moving particles:



Newton's law still applies: $F = m^*a$

Where m^* = the effective mass of the particle, which includes all the complex influences of the crystal potential on the motion of the electron (or hole).

Acceleration?

For electrons:

For holes:

Effective mass values? Fractions of m_0 . See Appendix III.

Sometimes depend on direction of motion in the crystal.

E.g. for electrons in Si: $m_l = 0.98m_0$, $m_t = 0.19m_0$

Or they depend of particle location in the band (bottom, top, edge, "light" band vs. "heavy" band). Values in Appendix III are given at the bottom of the bands for electrons, top of the bands for holes.

Effective mass in the energy band diagram vs. k picture:

- **Remember for waves: $p = \hbar k$**
- **But for particles: $E = mv^2/2 =$**
- **Take second derivative vs. k**

So effective mass is related to energy band *curvature* in the E-k band picture!

Q: What's the meaning of the energy band *slope* in the E-x band picture?