Lecture 3: Semiconductor physics

Questions for extra credit:

1)Atoms in insulators have a conduction band and valence band. (T or F)

2)Intrinsic semiconductors are different from extrinsic semiconductors in what way?

3)What is the self-inductance Emf voltage that is produced by a sudden surge in current I when a transistor is suddenly switched on or off in a circuit of resistance R with inductance L.

4a)By considering the electrons in a solid as a free electron gas, that is, the electrons are free to wander around the crystal without being influenced by the potential of the atomic nuclei, we can obtain a relationship for the number of available states in a solid. A free electron has a velocity v and a momentum p=mv with only kinetic energy. Therefore, what is the energy of the free electron expressed in terms of its velocity?

4b)If the electron is considered to be a wave-like particle with wave number **k**, what is the relation between its momentum, energy, and wave number?

5)What does MOSFET stand for and list one major advantage and one major disadvantage with it compared to a bipolar transistor?

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Answers:

1)True. All atoms have these bands; in insulators the bands are prohibitively separated from each other making it difficult for thermal energy or other exited particles to energize electrons to jump from one band to the other.

2)Extrinsic semiconductors are doped with external impure atoms to create holes (ptype) or extra electrons (ntype) in the conduction band.

Note: The density of electrons in the conduction band or valence band is :

$$n = \frac{N}{V} = \frac{1}{V}\int_{E_g}^{\infty} f(E)g(E)dE$$

$$= \frac{(2m_e)^{3/2}}{2\pi^2\hbar^3}\int e^{-(E-\mu)/k_bT}\left(E - E_f\right)^{1/2} dE$$

$$= 2\left(\frac{2\pi m_e k_b T}{\hbar^2}\right)^{3/2} e^{-(\mu-E_g)/k_bT}$$

where the exponential becomes positive for the valence band and is negative in the conduction band.

3)Self induction produces an EMF which opposes the change in current - if I is increasing, the induced voltage tends to drive a negative current. The total voltage drop around the circuit is

V - IR-LdI/dt = 0 => dI/dt = -(R/L)I +V/L. This differential equation has the solution

$I(t) = (V/R)(1-e^{-t/T})$ where T=L/R is the characteristic time constant. The current rises from zero, exponentially approaching the steady state value V/R.

Note: The power required to establish the current working against the back EMF and the resistance is $dW/dt = IV = I^2R + ILdI/dt$. Neglecting the resistive losses, we have

$dW = LIdI = d[LI^2/2]$. So the stored energy is $U_B = (1/2)LI^2$.

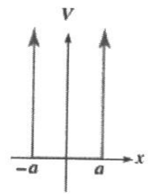
4a) By considering the electrons in a solid as a free electron gas, that is, the electrons are free to wander around the crystal without being influenced by the potential of the atomic nuclei so that it only has only kinetic energy:

$$E = \frac{1}{2}m\mathbf{v}^2 = \frac{|\mathbf{p}|^2}{2m}.$$

4b)Prince Louis De-Broglie hypothesized that if waves could exhibit particle-like properties, then might particles also exhibit wave-like properties? Thus the electron can be represented by a vector in velocity, momentum or k-space. Finally, the relationship between the electron's energy, momentum, and its wave number is $E = \frac{1}{2} mv^2 = h^2\mathbf{k}^2/2m$ and $\mathbf{k} = \frac{\mathbf{p}}{\hbar}$.

5)MOSFET: metal-oxide semiconductor field effect transistor. It has very high switching speed but also has high conductive losses associated with it.

Lecture 3: Semiconductors (cont.)



Consider the solution to the Schrödinger equation

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi(x) = E\psi(x), \tag{1}$$

where $\hbar$ is h-bar, *m* is the mass of a particle, $\psi(x)$ is the wavefunction, and *E* is the energy of a given state. For an infinite one-dimensional square potential well, the potential is given by

$$V(x) = \begin{cases} 0 & \text{for } |x| < a \\ \infty & \text{for } |x| > a, \end{cases} \tag{2}$$

so Schrödinger equation becomes

$$\frac{d^2\psi}{dx^2} = -\frac{2m}{\hbar^2}E(x)\psi(x) = -k^2\psi(x) \tag{3}$$

for $|x| < a$, where

$$k \equiv \frac{\sqrt{2mE}}{\hbar}. \tag{4}$$

But this is just the equation of a simple harmonic oscillator, which has as a most general solution:

$$\psi(x) = A\cos(kx) + B\sin(kx).$$