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Electronic Devices Interview Questions

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Energy bands and carrier concentration

1. Why does a solid have energy bands instead of the discrete levels of a single atom?

When many atoms sit close together, their outer-electron levels interact and split. With around 10^{23} atoms the split levels lie so close that they form nearly continuous bands. In a semiconductor or insulator at 0 K, the filled valence band and the empty conduction band are separated by a forbidden gap E_g.

2. What is the difference between an intrinsic and an extrinsic semiconductor?

An intrinsic semiconductor is pure, so electrons and holes are equal in number, $n = p = n_i$, and the Fermi level lies near mid-gap. An extrinsic one is doped with donors or acceptors, so one carrier type dominates and the Fermi level moves toward the conduction band (n-type) or valence band (p-type).

3. Silicon at 300 K has $n_i = 1.5 \times 10^{10}\ \mathrm{cm^{-3}}$. It is doped with $10^{16}\ \mathrm{cm^{-3}}$ of fully ionised donors. Find the hole concentration.

The hole concentration is about $2.25 \times 10^{4}\ \mathrm{cm^{-3}}$.

WORKING

1. Donors dominate, so $n \approx N_D = 10^{16}\ \mathrm{cm^{-3}}$.
2. Mass-action law: $np = n_i^2$, so $p = n_i^2 / n$.
3. $p = (1.5 \times 10^{10})^2 / 10^{16} = 2.25 \times 10^{20} / 10^{16}$.
4. $p = 2.25 \times 10^{4}\ \mathrm{cm^{-3}}$.

4. What is the difference between a direct and an indirect band-gap semiconductor, and why does it matter for light emission?

In a direct gap the conduction-band minimum and valence-band maximum occur at the same crystal momentum, so an electron can recombine with a hole and emit a photon directly. In an indirect gap (silicon, germanium) a phonon must also take part, so recombination is mostly non-radiative. Direct-gap materials such as GaAs suit LEDs and lasers.

5. Why does the intrinsic carrier concentration rise sharply with temperature?

Because $n_i \propto T^{3/2} e^{-E_g/2kT}$. A higher temperature gives more electrons enough thermal energy to cross the band gap, and the exponential term dominates the change. Each extra degree adds many more electron-hole pairs, so n_i roughly doubles for every 10 degrees or so in silicon near room temperature.

Carrier transport

6. What is the difference between drift current and diffusion current?

Drift current flows when an electric field pushes carriers, and it is proportional to the field, the carrier density and the mobility. Diffusion current flows when carriers move from a region of high concentration to low concentration, and it is proportional to the concentration gradient and the diffusion coefficient. Diffusion needs no field: it flows wherever a concentration gradient exists.

7. Electrons in silicon at 300 K have a mobility of $1350\ \mathrm{cm^2/V \cdot s}$. Taking the thermal voltage as 0.0259 V, find their diffusion coefficient.

The diffusion coefficient is about $35\ \mathrm{cm^2/s}$.

WORKING

1. Einstein relation: $D/\mu = kT/q$.
2. $D = \mu\,(kT/q)$.
3. $D = 1350 \times 0.0259$.
4. $D \approx 35\ \mathrm{cm^2/s}$.

8. What does a Hall effect measurement tell you about a semiconductor sample?

With a magnetic field applied perpendicular to the current in a sample, a transverse Hall voltage appears. Its sign shows whether the carriers are electrons or holes, and its size gives the carrier concentration through $R_H = -1/(qn)$ for electrons or $R_H = 1/(qp)$ for holes. Combined with the measured conductivity, it gives the mobility, $\mu = \sigma|R_H|$.

9. Electrons are the minority carriers in a p-type silicon sample. Their diffusion coefficient is $35\ \mathrm{cm^2/s}$ and their lifetime is $10\ \mu\mathrm{s}$. Find the diffusion length.

The diffusion length is about $187\ \mu\mathrm{m}$. It follows from $L = \sqrt{D\tau}$ with $D = 35\ \mathrm{cm^2/s}$ and $\tau = 10^{-5}\ \mathrm{s}$, and it is the average distance an excess electron diffuses before it recombines.

WORKING

1. $L = \sqrt{D\tau}$.
2. $L = \sqrt{35 \times 10^{-5}}\ \mathrm{cm}$.
3. $L = \sqrt{3.5 \times 10^{-4}}\ \mathrm{cm} \approx 0.0187\ \mathrm{cm}$.
4. $0.0187\ \mathrm{cm} = 187\ \mu\mathrm{m}$.

10. What does the continuity equation for carriers state?

It is a carrier balance. The rate of change of carrier density at a point equals generation minus recombination, plus the net inflow of carriers carried by the drift and diffusion currents. In steady state with no field and no generation, excess carriers injected at one end of a long sample decay exponentially with distance, with the diffusion length $L = \sqrt{D\tau}$ as the decay length.

P-N junctions and Zener diodes

11. How does the depletion region of a p-n junction form, and what sets the built-in potential?

Electrons diffuse from the n side to the p side and holes the other way, leaving uncovered ionised donors and acceptors. These fixed charges create a field that opposes further diffusion, until drift balances diffusion. The built-in potential is $V_{bi} = (kT/q)\ln(N_A N_D/n_i^2)$.

12. A silicon p-n junction at 300 K has acceptor doping of $10^{17}\ \mathrm{cm^{-3}}$ on the p side and donor doping of $10^{16}\ \mathrm{cm^{-3}}$ on the n side. Take $n_i = 1.5 \times 10^{10}\ \mathrm{cm^{-3}}$ and $kT/q = 0.0259\ \mathrm{V}$. Find the built-in potential.

The built-in potential is about 0.754 V.

WORKING

1. $V_{bi} = (kT/q)\ln(N_A N_D / n_i^2)$.
2. $N_A N_D / n_i^2 = 10^{33}/(2.25 \times 10^{20}) = 4.44 \times 10^{12}$.
3. $\ln(4.44 \times 10^{12}) \approx 29.12$.
4. $V_{bi} = 0.0259 \times 29.12 \approx 0.754$ V.

13. What is the difference between Zener breakdown and avalanche breakdown?

Zener breakdown is band-to-band tunnelling in a heavily doped junction with a very thin depletion region, and occurs at low voltages, below about 5 V. Avalanche breakdown is impact ionisation by carriers accelerated in the field of a lightly doped junction, and occurs above about 7 V. Zener breakdown has a negative temperature coefficient, avalanche a positive one.

14. A silicon diode at 300 K has a saturation current of 1 pA. It is forward biased at 0.65 V. Taking the thermal voltage as 0.0259 V, find the diode current using the ideal diode equation.

The diode current is about $79\ \mathrm{mA}$. With $V/V_T \approx 25.1$, the exponential term is about 7.9×10^{10}, so the -1 in the ideal diode equation is negligible and $I \approx I_S e^{V/V_T}$.

WORKING

1. $I = I_S\,(e^{V/V_T} - 1)$.
2. $V/V_T = 0.65/0.0259 \approx 25.1$.
3. $e^{25.1} \approx 7.9 \times 10^{10}$, so the -1 is negligible.
4. $I \approx 10^{-12} \times 7.9 \times 10^{10} \approx 0.079$ A.

The bipolar junction transistor as a device

15. Why is the emitter of a BJT heavily doped and the base thin and lightly doped?

The heavy emitter doping makes most of the base-emitter current come from carriers injected into the base, which gives high injection efficiency. A thin, lightly doped base lets those carriers cross to the collector before they recombine, which gives a base transport factor near 1. Together they make I_C almost equal to I_E.

16. What is the difference between the current gains α and β of a BJT, and how are they related?

The gain $\alpha = I_C/I_E$ is slightly below 1, while $\beta = I_C/I_B$ is large, often 100 or more. They are linked by $\beta = \alpha/(1-\alpha)$. Because $1-\alpha$ is tiny, a small change in α causes a large change in β, which is why β varies so much between devices.

17. What is the Early effect in a BJT, and what does it do to the output resistance?

In active mode, a larger collector-base reverse voltage widens the collector depletion region and narrows the neutral base. A narrower base raises the collector current slightly as V_{CE} increases. This makes the output characteristic slope upward, so the output resistance is finite, $r_o \approx V_A/I_C$, where V_A is the Early voltage.

18. Why does punch-through limit the maximum collector voltage of a BJT with a very thin base?

As the collector-base reverse bias rises, the depletion region widens into the base. If it reaches across the whole base and touches the emitter junction, the base no longer separates emitter from collector. The

collector current then rises sharply with little control from the base, so the device cannot be used beyond that voltage.

MOS capacitor, MOSFET and scaling

19. What is the threshold voltage of an NMOS transistor?

It is the gate voltage at which the surface of the p-type body becomes strongly inverted, so that the electron density at the surface equals the hole density in the bulk (surface potential $2\phi_F$). Above it a conducting n-channel exists. It depends on oxide thickness, body doping, the work-function difference and the body bias.

20. What happens in a MOS capacitor on a p-type body as the gate voltage is swept from negative to positive?

A negative gate voltage pulls holes to the surface, which is accumulation. A small positive voltage pushes holes away and uncovers negative acceptor ions, which is depletion. Beyond the threshold voltage, electrons collect at the surface and form an inversion layer. The depletion width stops growing at strong inversion.

21. Why does the drain current of a MOSFET in saturation still rise slightly with drain voltage?

Because of channel-length modulation. As the drain voltage rises, the pinch-off point moves toward the source and the effective channel gets shorter. Since drain current varies as $1/L$, it increases, which is written as $I_D = \frac{1}{2}k(V_{GS} - V_T)^2(1 + \lambda V_{DS})$ in the square-law model.

22. Why can the subthreshold swing of a MOSFET not be made smaller than about 60 mV per decade at room temperature?

Below threshold the current is a diffusion current that depends exponentially on the surface potential, with the thermal voltage setting the scale. The swing is $S = (kT/q)\ln 10\,(1 + C_d/C_{ox})$, and since the bracket is at least 1, $S \geq 60\ \mathrm{mV/decade}$ at 300 K for a conventional MOSFET.

LEDs, photodiodes and solar cells

23. Why is a photodiode usually operated under reverse bias?

Reverse bias widens the depletion region, so more light is absorbed where the field is strong. The field sweeps photogenerated carriers out quickly, which speeds up the response, and the wider region lowers the junction capacitance. The photocurrent is then proportional to the light power, on top of a small dark current.

24. An LED is made from GaAs, which has a band gap of 1.42 eV. Using $hc/q \approx 1240\ \mathrm{eV \cdot nm}$, find the wavelength of the light it emits, assuming the photon energy equals the band gap.

The emitted wavelength is about 873 nm, in the infrared.

WORKING

1. Photon energy equals the gap: $E = E_g = 1.42\ \mathrm{eV}$.
2. $\lambda = hc/E$.
3. $\lambda = 1240\ \mathrm{eV \cdot nm}/1.42\ \mathrm{eV}$.
4. $\lambda \approx 873\ \mathrm{nm}$.

25. How are the fill factor and efficiency of a solar cell defined?

The fill factor is $FF = P_{max}/(V_{oc}I_{sc})$, the ratio of the maximum power point to the product of open-circuit voltage and short-circuit current. It measures how square the I-V curve is. The efficiency is $\eta = P_{max}/P_{in}$, the electrical power delivered at the best operating point divided by the incident light power.

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