Semiconductor devices

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Doping

Silicon is the most common substrate for semiconductor devices. It is from group IV (14) of the periodic table.

Si is *tetravalent*—4 valence electrons. Doping with materials of a different valence frees up energy levels near the conduction and valence bands. This makes *impurity semiconductors* which can have much higher currents than intrinsic semiconductors made of pure materials.

Semiconductor types

If doped with a pentavalent material (As, Sb) 4 valence e's participate in bonding and the leftover is nearly free in an energy level just below the conduction band.

This makes an *n*-type semiconductor—one with negative charge carriers.

If doped with trivalent atoms (In, Al, B), an electron deficiency or *hole* is produced with an electron energy just above the valence band. This is easy to fill with electrons, freeing the hole to move about.

This is a *p*-type semiconductor.

The p-n junction

If a *p*-type and an *n*-type semiconductor are brought into contact, electrons diffuse into the *p* region and holes diffuse into the *n* region, where they recombine.

This leaves a **depletion layer** which has few carriers and the fixed ionic charges in the crystal lattice produce an $\vec{\mathbf{E}}$ field and corresponding voltage step across the depletion layer. See figure 12.29.

The figures at Hyperphysics on this are excellent:

`http://hyperphysics.phy-astr.gsu.edu`
`/hbase/solids/pnjun.html#c1`

If we apply a positive voltage to the *p*-type region, it lowers the potential energy step so that electron in the *n*-type region can combine with holes in the *p*-type region and current flows.

If the bias is applied in the opposite direction, the barrier is raised.

This leads to the *p*-*n* **diode.** See figure 12.30

The bipolar junction transistor (BJT)

Consists of layers of *pnp* or *npn* materials, with the central layer very thin. A lead is connected to each region: for an *pnp* transistor the *emitter* and *collector* leads are to *p*-type material, and the *base* to the narrow *n*-type region. See figures 12.32–33.

With proper bias voltages, a small current from the base modifies recombination of holes in the base, and will control a much larger current of holes from emitter to collector. This acts as a **current amplifier.***

*This is a simplified model!

When all is set up correctly

$$I_c = \beta I_b$$

where the current gain $\beta \sim 100$ depending on the particular transistor. A small I_b can control a large I_c. See fig 12.33 for one possible bias circuit arrangement for a time-varying signal.

BJTs are still superior for many linear signal amplification applications. For high-speed, low-power switching and logic, FETs now dominate.

Field-effect transistors (FETs)

FETs work by using an electric field to control the width of a depletion region. One type of semiconductor is used to induce a depletion layer in another, and then an $\vec{\mathbf{E}}$ field is used to control the width of this layer. This modifies the width of an adjacent thin conducting channel. See figure 12.34 and nearby text.

FETs have many advantages for fast switching, low current and power dissipation,and high input impedance.