# Characteristic curves of semiconductors with FG-Module



## Related Topics

Semiconductor, P-N junction, Energy-band diagram, Acceptors, Donors, Valence band, Conduction band, Transistor, Operating point

## Principle

The current-voltage characteristic of a semiconducting diode is measured.
The collector current in dependancy on the emitter-collector voltage is measured for different values of base current strength through a NPN transistor.

## Equipment

| | | |
|---|---|---|
| Cobra3 Basic Unit | 12150.00 | 1 |
| Power supply, 12 V- | 12151.99 | 2 |
| RS232 data cable | 14602.00 | 1 |
| PowerGraph | 14525.61 | 1 |
| Cobra3 Function generator module | 12111.00 | 1 |
| Digital multimeter | 07122.00 | 1 |
| Potentiometer, 1 kΩ. | 39103.04 | 1 |
| Plug-in board, 4 mm jacks | 06033.00 | 1 |
| Transistor in plug-in box, BC337 | 39127.20 | 1 |
| Resistor in plug-in box, 47 kΩ | 39104.38 | 1 |
| Silicon diode 1N4007 | 39106.02 | 1 |
| Silicon diode 1N4148 | 39106.03 | 1 |
| Connecting cord, $l$ = 250 mm, red | 07360.01 | 2 |
| Connecting cord, $l$ = 250 mm, blue | 07360.04 | 2 |
| Connecting cord, $l$ = 500 mm, red | 07361.01 | 2 |
| Connecting cord, $l$ = 500 mm, blue | 07361.04 | 3 |
| PC, Windows® 95 or higher | | |

## Tasks

1. Measure the current – voltage curve for 1N4007 and 1N4148 silicon diodes.
2. Measure the collector current – emitter-collector voltage curve for different values of base current.

## Set up and procedure

*1. Characteristic curves of diodes*

Connect the Function Generator Module to the Cobra3 unit. Connect the Cobra3 unit to your computer to port COM1, COM2 or to USB port (for USB computer port use USB to RS232 Converter 14602.10). Connect both Cobra3 and Function Generator Moule to their 12 V supplies. Set up the equipment according to Fig. 1. Start the “measure” program on your computer. Select the “Gauge” “PowerGraph”.

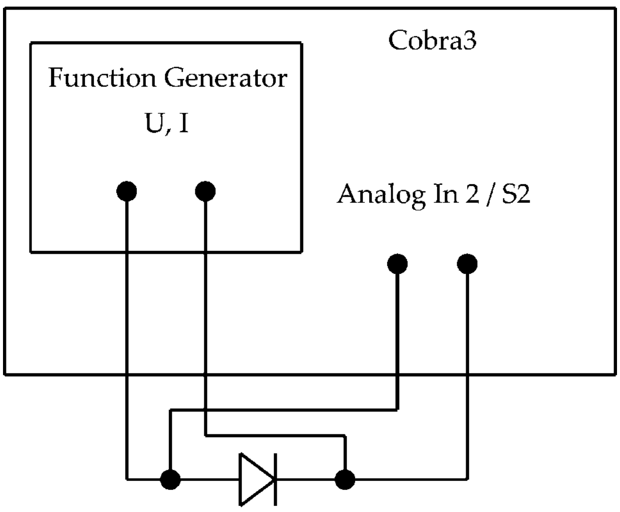


Fig. 1

On the “Setup“ chart click on the “Analog In 2 / S2“ symbol and configure the sensor like this:

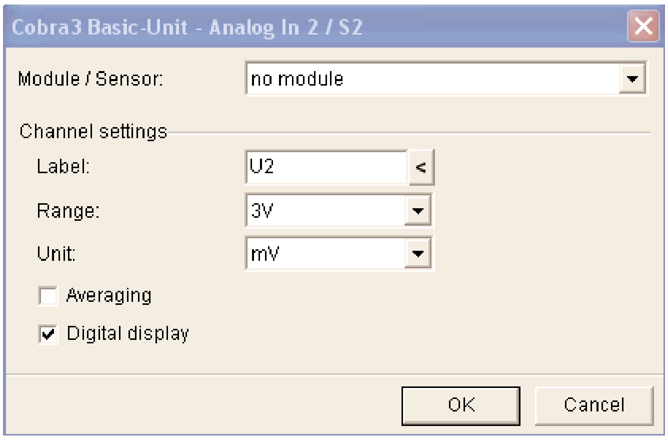


Fig. 2

Then click the “Function Generator“ symbol and set the parameters like this:

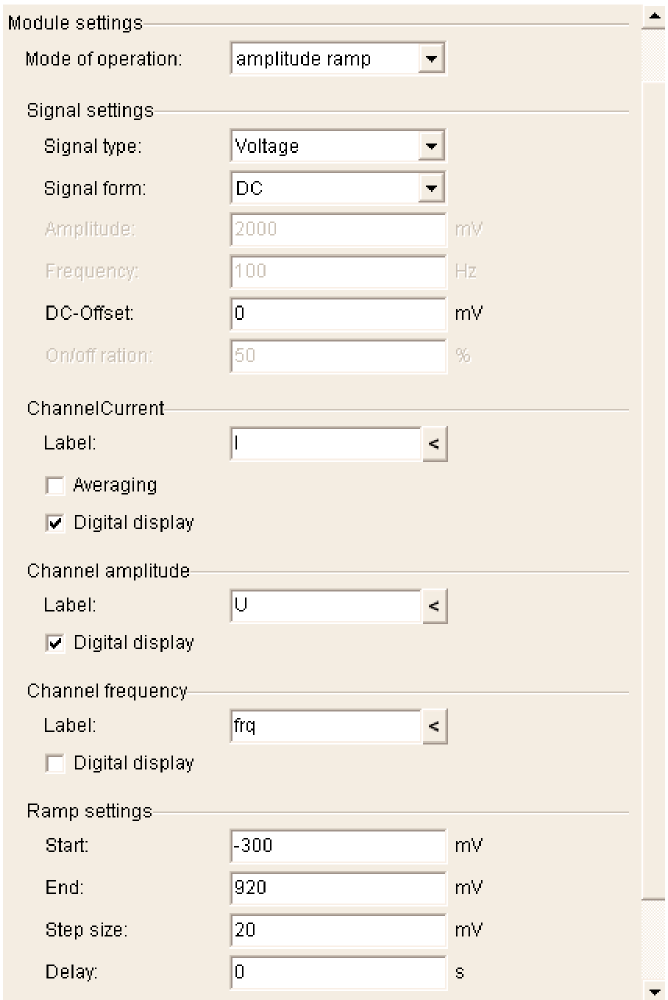


Fig. 3: FG module settings

On the “Settings“ chart of PowerGraph set the parameters like this:

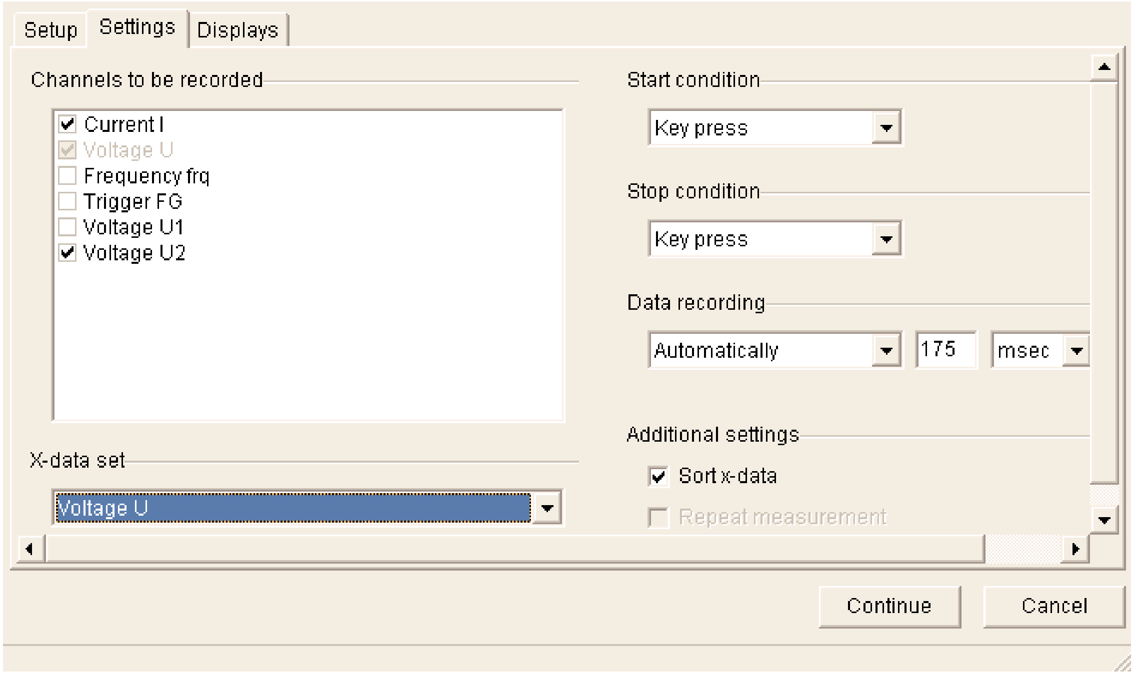


Fig. 4: PowerGraph settings

And the “Displays“ chart may look like this after adding a diagram:

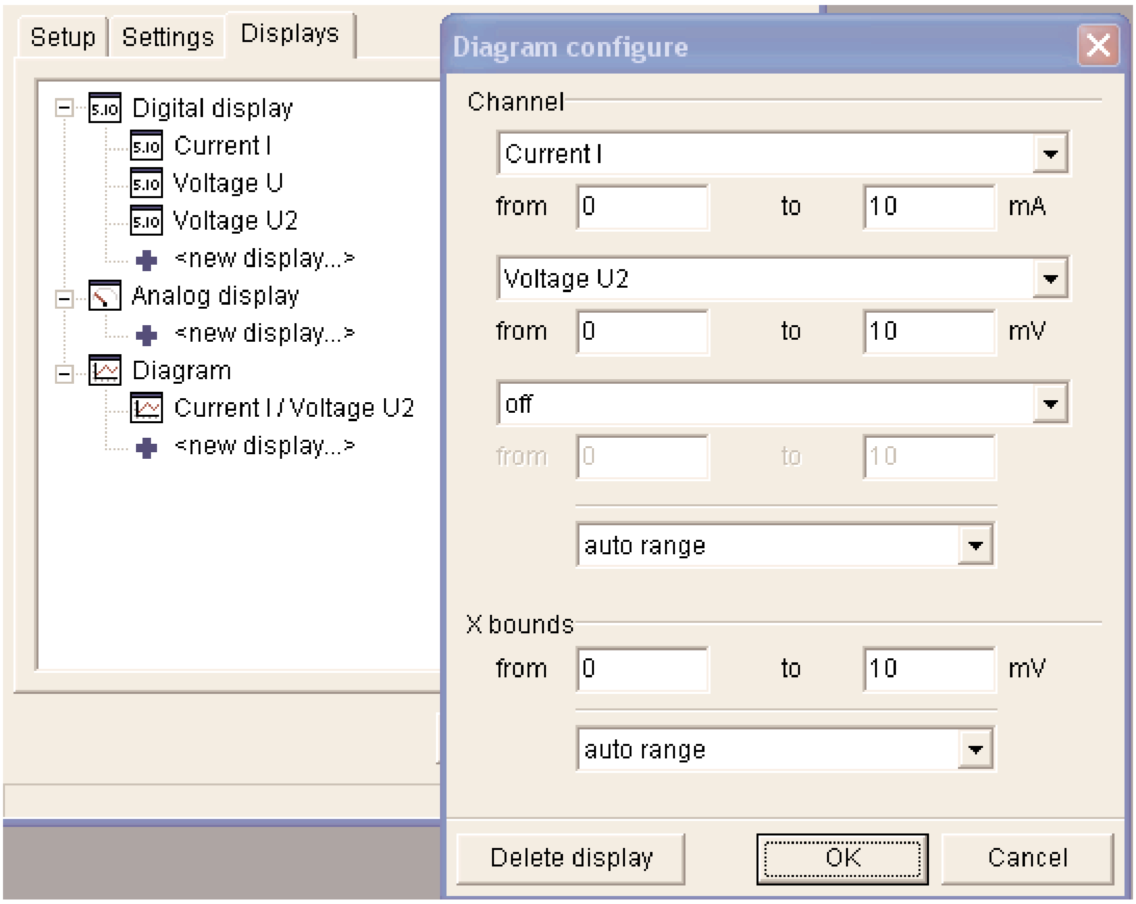


Fig. 5: PowerGraph displays settings

Start the measurement with the “Continue“ button. The obtained data may look like Fig.6 after combining the curves of the 1N4007 and the 1N4148 silicon diodes with the “Measurement“ > “Assume channel“ function. You can see that both diodes begin at the same voltage to let the current through but have different resistances. At higher positive (forward) voltages U the funcion generator’s current reaches saturation – the voltage U2 does not rise any more. The function generator is linear up to 200 mA and reaches up to 230 mA. Also measure higher reverse voltages e.g. –10000 mV to +1000 mV but using bigger step sizes for shorter measurement duration.

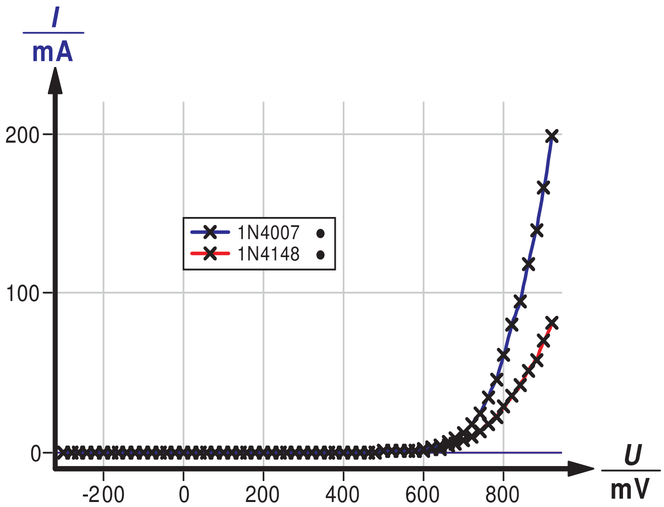


Fig. 6: Characteristic curves of silicon diodes

*2. Collector current characteristics for different base currents*

Now set the gear up according to Fig. 7 and Fig. 8.

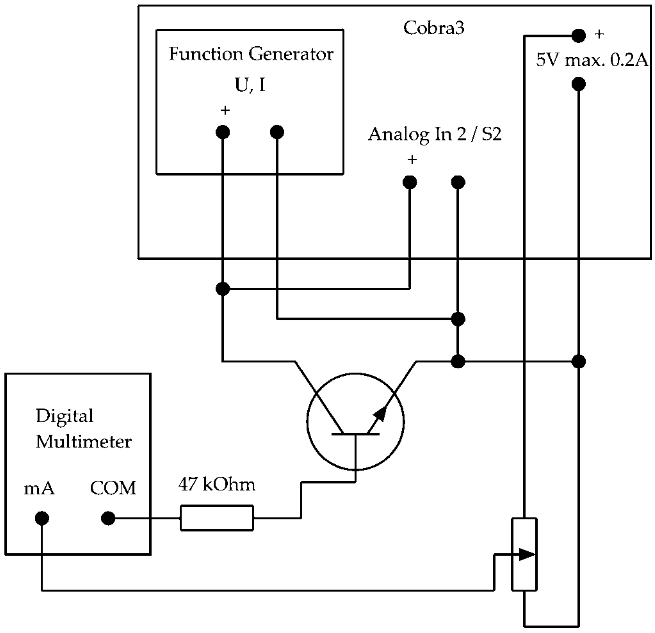


Fig. 8: Set up for transistor characteristics measurement

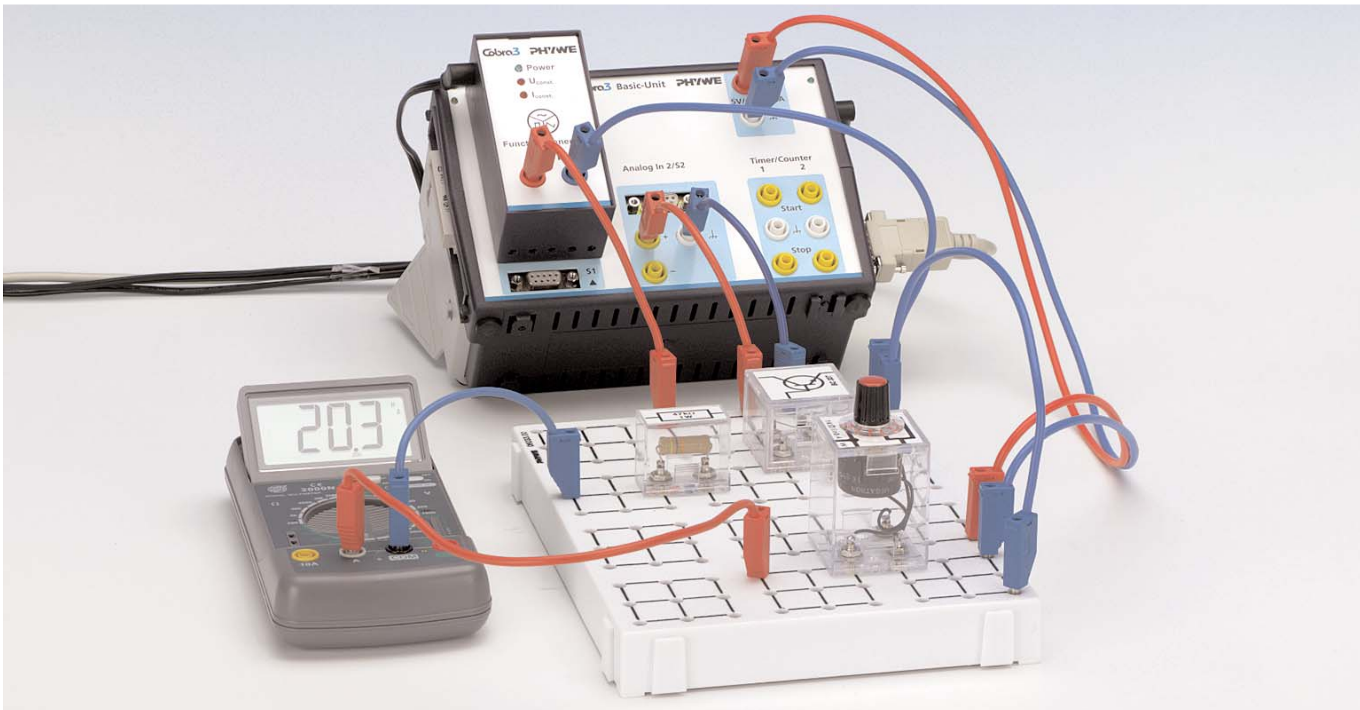

Fig. 7

Start the “PowerGraph“ gauge and set the values after clicking the function generator symbol on the “Setup“ chart like this:

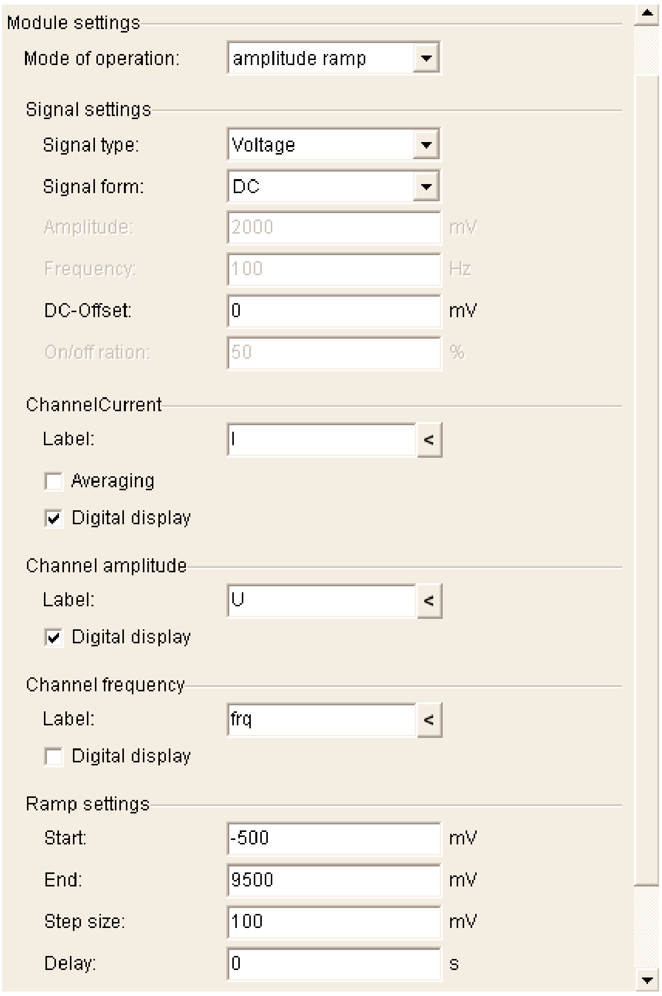


Fig. 9

Set the “Range“ on “Analog In 2 / S2“ to 10 V. Be sure to insert the 47 kOhm resistor properly so the base current is not too high. Set the potentiometer so that the multimeter reading has the desired value between 0 µA and 60 µA. Start the measurement with “Continue“ and note the multimeter reading after the collector current started flowing.

The obtained curves may look like this:

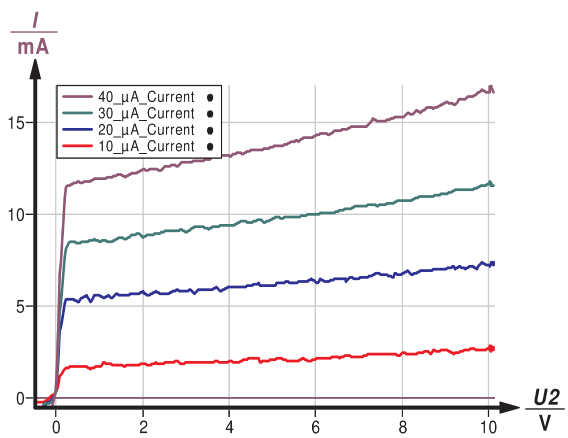


Fig. 10

## Theory and evaluation

A p-doped semiconductor contains impurities called acceptors whose energy level to catch an electron from the valence band is that near to the band edge, that at room temperature a considerable part of these levels is occupied thus forming holes in the valence band as mobile charge carriers and immobile “ons“ in the crystal lattice. A n-doped semiconductor contains impuritys called donors capable of delivering electrons by thermal exitation to the conduction band as mobile carriers (having energy levels near the band edge considerably occupied at room temperature). The Fermi level usually lies in between the band edge and the ionized impurity levels.

When a n-doped and a p-doped semiconductor are brought in contact, in the contact area some electrons from the donors of the n-doped semiconductor recombine with the acceptors of the p-doped semiconductor without creating mobile charge carriers but creating a space charge, a barrier layer, (more of a contact surface charge), until it’s field equalizes the Fermi levels of both parts. So the contact area is depleted of carriers – the depletion zone is formed.

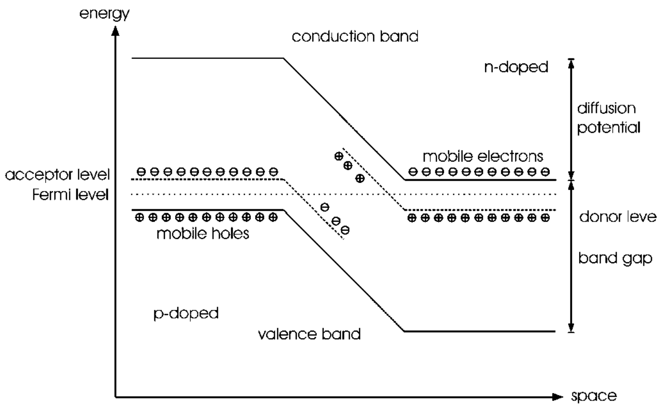


Fig. 11: pn-junction with equal carrier densitys on both sides

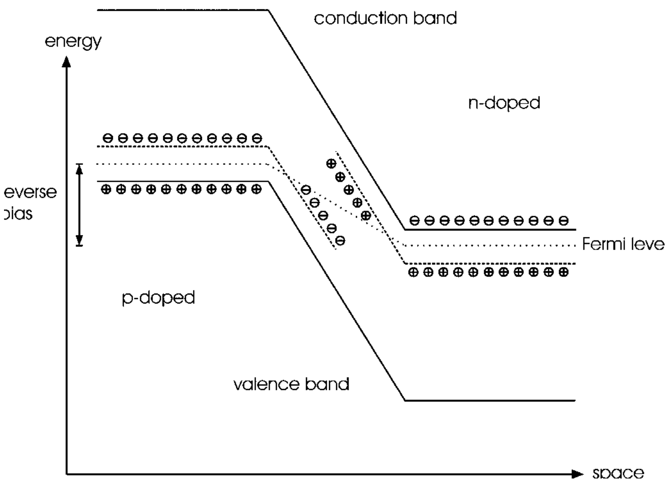


Fig. 12

If a voltage is applied to such a device the polarity makes a big difference:
If the negative terminal is connected to the p-doped part, this is called reverse biassing the diode. The energy level of the electrons is raised in the negatively charged part. The space charge increases creating a stronger field reverse to the applied outer field and the depletion zone gets larger. Electrons from the valence band of the p-doped part could lower their energy by entering the conduction band of the n-doped zone, but they can't do so because they may not cross the forbidden region unless it is that narrow (by heavy doping), that they can tunnel through it (tunnel diode). See Fig. 12. So no current can flow with reverse voltage. Applying high voltage will either result in finally an avalanche breakdown of the device, if the electrons get accelerated in the depletion region in a way, that they can ionize other atoms, or in a tunnel breakdown, depending on the doping circumstances. Diodes designed as rectifiers usually get destroyed by avalanche breakdown, zener diodes are especially made to break down at a certain reverse voltage and with them tunnel breakdown dominates at low and avalance breakdown at high breakdown voltages. Since the temperature coefficients of avalanche and tunnel breakdown have opposite signs (tunneling works better in the cold due to sharp band.
Forward biassing the diode means to put the positive terminal to the p-doped part. Then, at low voltages, still no current flows since the carriers would have to get over the diffusion potential to cross the depletion layer. Only if the voltage equals the diffusion potential, the band edges "get straight", the space charge and the depletion layer get dissolved and the current can flow freely. Holes and electrons can enter the oppositly doped region and recombine there (in case of direct semiconductors – not silicon – emitting their energy difference not only thermally but also as photons – useful for LED's. The band edges are not straight in momentum space but periodical. Direct semiconductors have their minimal band gap at zero momentum, indirect ones don't.) and the resistance of the pn-junction vanishes leaving only the normal resistance of the semiconductor material. See Fig. 13.

A transistor is formed by two opposite pn-junctions, a pnp or a npn device. Such a device will block current in either direction – one of the barrier layers will always be reverse biassed -, unless carriers are injected in the middle region destroying one of the depletion zones or barrier layers making the device permeable to current. So the middle region is electrically contacted and this contact is called base. To make such a device a good amplifier, the other regions are asymmetrically doped and also of asymmetrical geometry and thus making one contact the emitter and the other the collector. E.g. with a npn transistor like the BC337 there is only current gain, if the emitter is connected to the negative terminal, the collector to the positive terminal and the base is made a little positive injecting holes into the barrier layer between base and collector and thus weakening it.

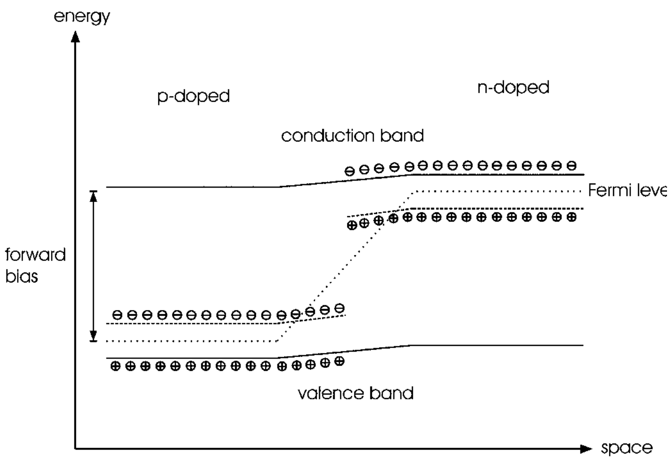


Fig. 13