Characteristic curves of semiconductors with Cobra4

(Item No.: P2410960)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physik	Hochschule	Elektrizität und Magnetismus	Gleichstromkreise	Characteristic curves of semiconductors with Cobra4

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	10 Minutes	20 Minutes	2 Students

Additional Requirements:

- Computer with XP or higher

Experiment Variations:

Keywords:

Semiconductor, p-n junction, Energy-band diagram, Acceptors, Donors, Valence band, Conduction band, Transistor, Operating point

Overview

Short description

Principle

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

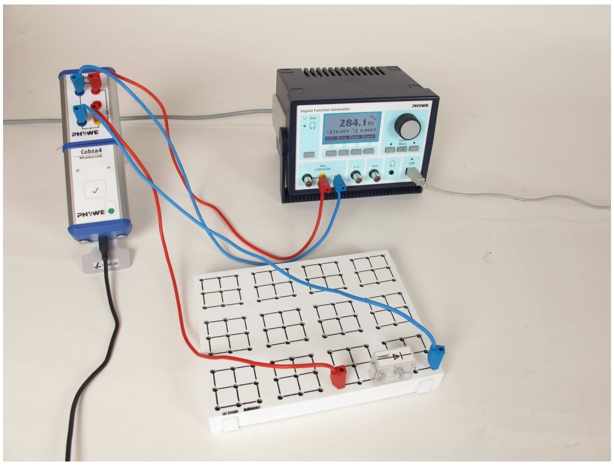

Fig.1:Experimental setup

Equipment

Position No.	Material	Order No.	Quantity
1	Cobra4 Wireless/USB-Link	12601-10	1
2	Cobra4 Sensor-Unit Energy: Current, voltage, work, power	12656-00	1
3	PHYWE Digital Function Generator, USB, incl. Cobra4 software	13654-99	1
4	PHYWE power supply DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
5	DMM with NiCr-Ni thermo couple	07122-00	1
6	Potentiometer 1 kOhm, 0.4W, G2	39103-04	1
7	Plug-in board,4mm plugs	06033-00	1
8	Transistor BC337, base left, G3	39127-20	1
9	Resistor 47 kOhm, 1W, G1	39104-38	1
10	Semiconduct.diode/si/1 N 4148,G1	39106-03	1
11	Semiconduct.diode/si/1 N 4007,G1	39106-02	1
12	Connecting cord, 32 A, 250 mm, red	07360-01	2
13	Connecting cord, 32 A, 250 mm, blue	07360-04	2
14	Connecting cord, 32 A, 500 mm, red	07361-01	2
15	Connecting cord, 32 A, 500 mm, blue	07361-04	3
16	Software measureLAB	14580-61	1
Additional material			
	PC with USB-Interface, Windows XP 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 to your computer.
- Connect the Cobra4 Wireless/USB-Link via USB-cable to the USB interface of the computerand plug the Cobra4 Sensor-Unit Energy on the Cobra4 Wireless/USB-Link.
- Connect the Wireless/USB-Link to your computer. Set up the equipment according to Fig. 1 and 2.
- Start the "measureLAB" program on your computer and load the "Characteristic curves of semiconductors" experiment. (Experiment > Open experiment). All pre-settings that are necessary for value recording are now carried out. Click on to start the measurement.

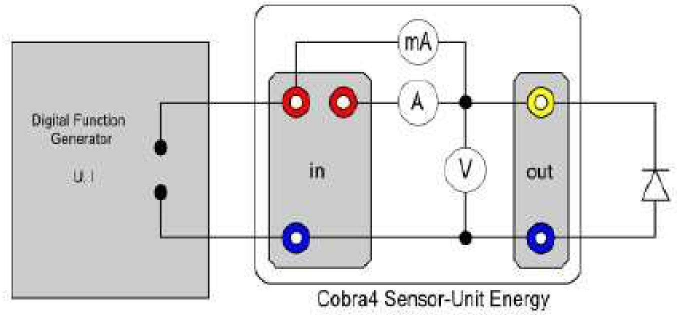

Fig. 2: Schematic setup to determine the characteristic curves of diodes.

The obtained data may look like Fig. 3 after combining the curves of the 1N4007 and the 1N4148 silicon diodes with the "Data pool" > Diagram function. You can see that both diodes begin at the same voltage to conduct but have different resistances. At higher positive (forward) voltages *U*, the funcion generator's current reaches saturation – the voltage U_2 does not rise any more. The function generator reaches up to 500 mA. Also measure higher reverse voltages e.g. –10000 mV to +1000 mV.

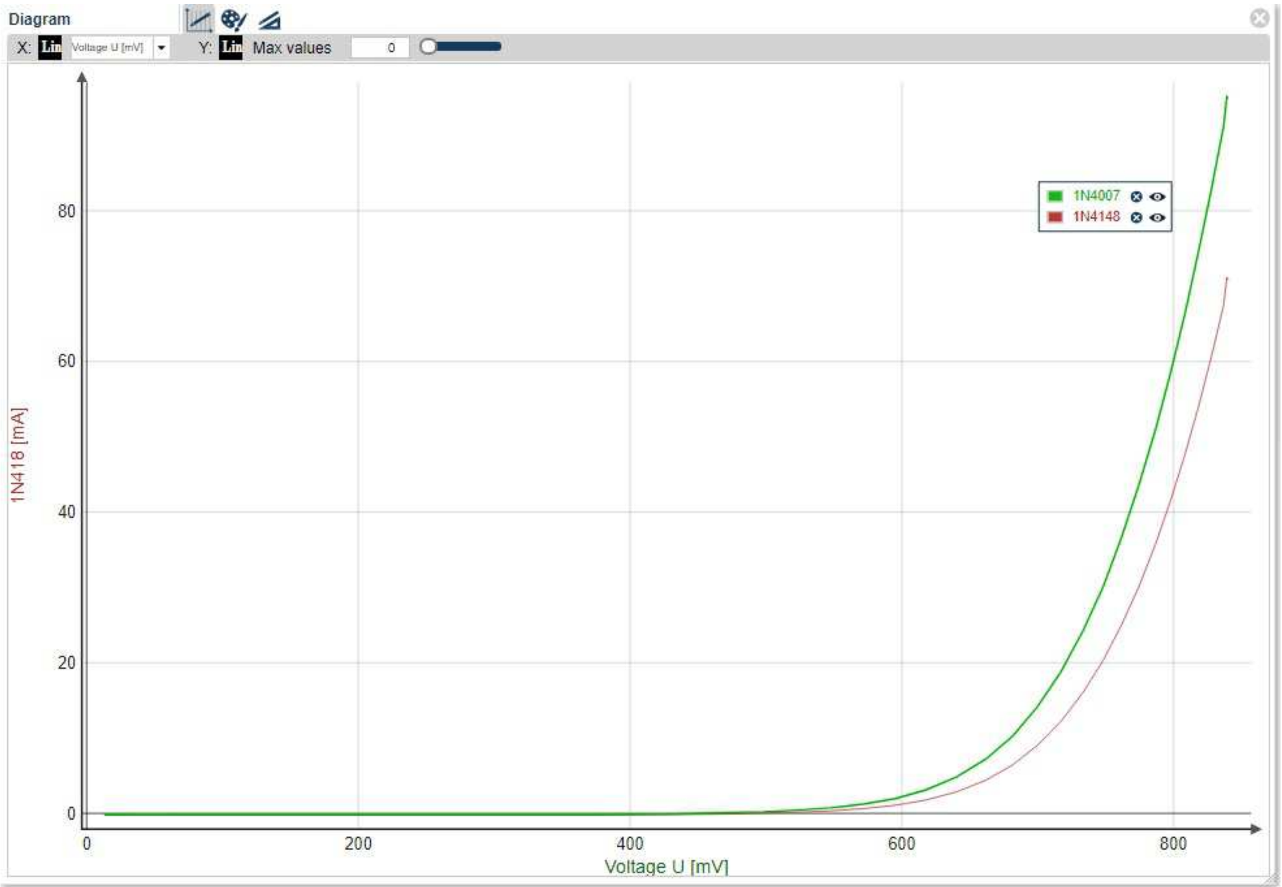

Fig. 3: Characteristic curves of silicon diodes.

2. Collector current characteristics for different base currents

Now set up the gear according to Fig. 4 and Fig. 5.

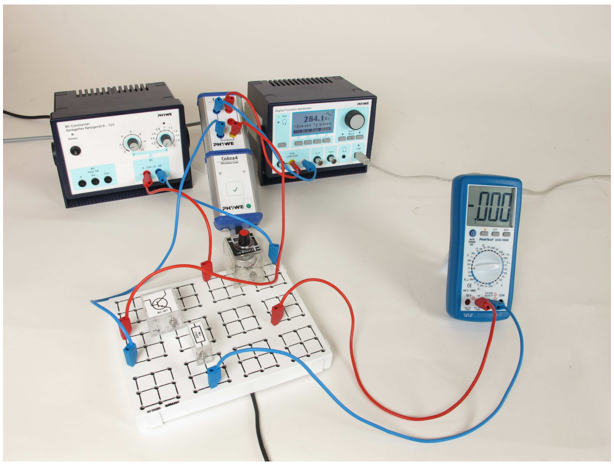

Fig.4: Setup for characteristic transistor measurement

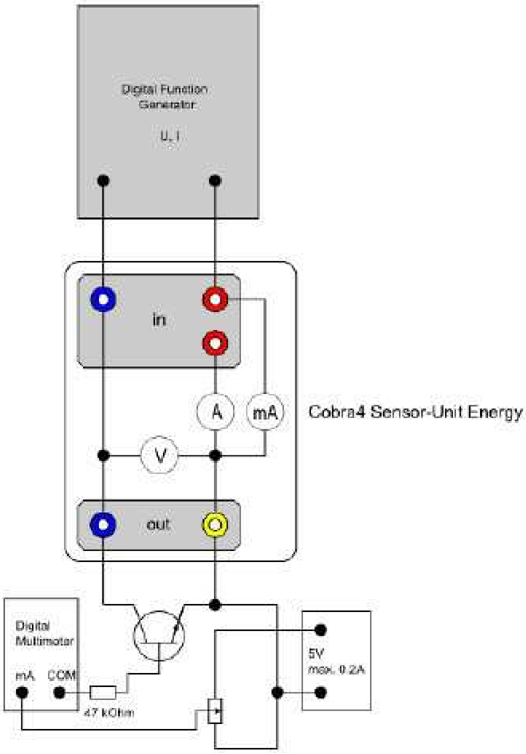

Fig. 5: Schematic setup for transistor characteristic measurement.

After connecting the Digital Function Generator t the computer, go to [icon] to set a voltage ramp from -500 to 9500 mV, c.f. Fig. 6 for all necessary settings. Be sure to insert the 47 kOhm resistor properly so the base current is not too high.

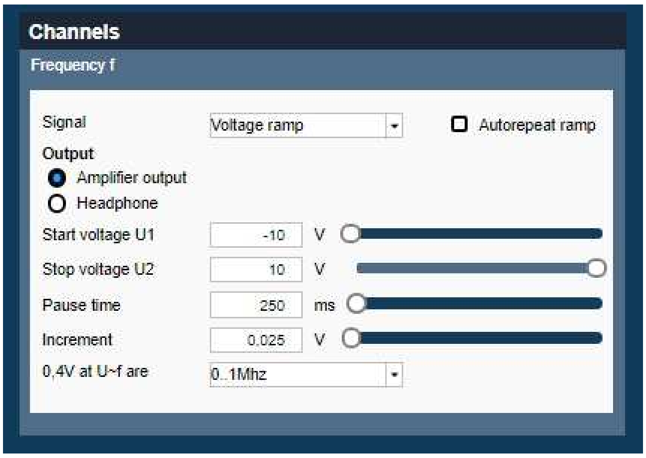

Fig. 6: Function Generator settings.

Set the potentiometer so that the multimeter reading has the desired value between 0 µA and 40 µA. Start the measurement with and note the multimeter reading after the collector current started flowing. The measurement is terminated automatically when the voltage ramp is finished.

The obtained curves may look like Fig. 7. To aquire such a diagram as shown in Fig. 7, go to , select all desired curves and click to display all curves in one diagram.

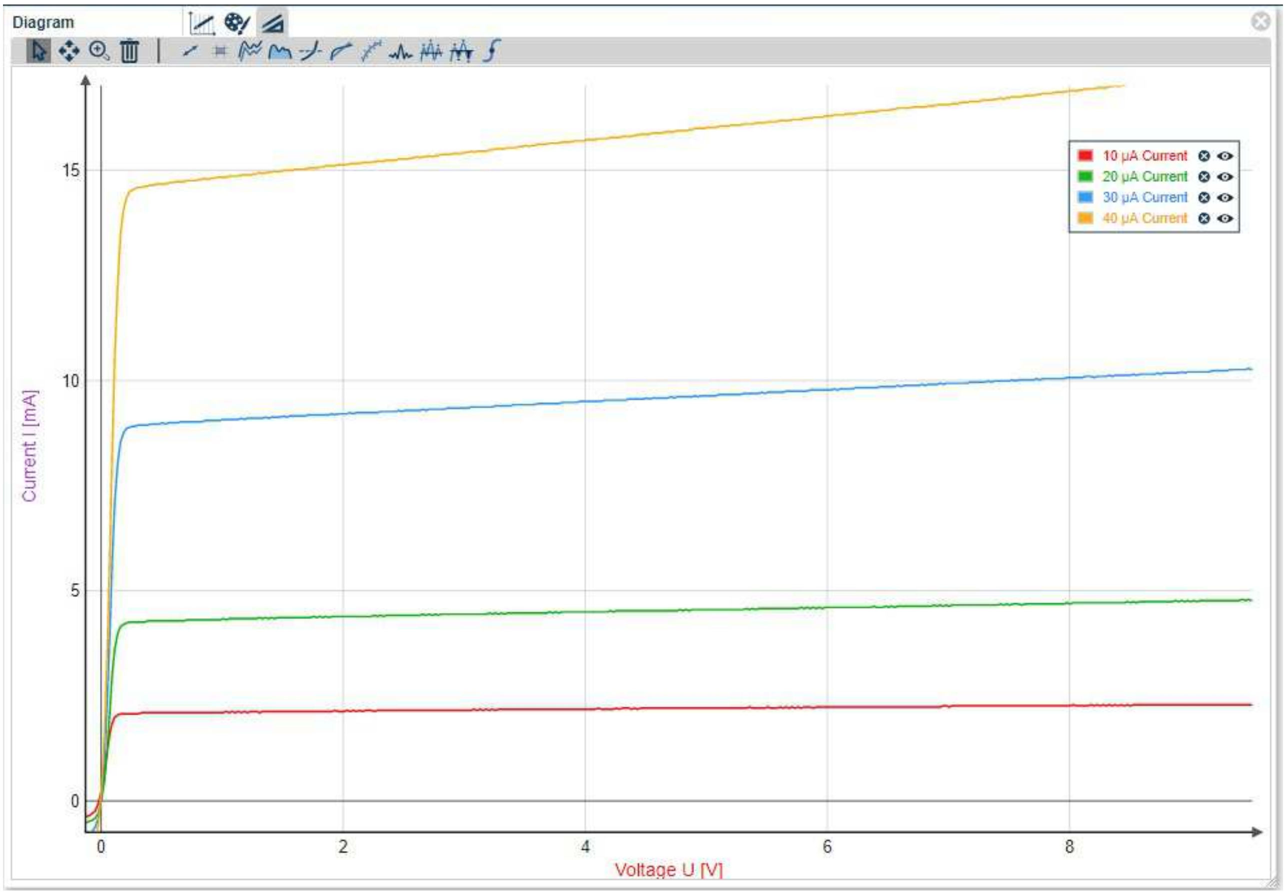

Fig. 7: Characteristic curves of a transistor.

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. 8).

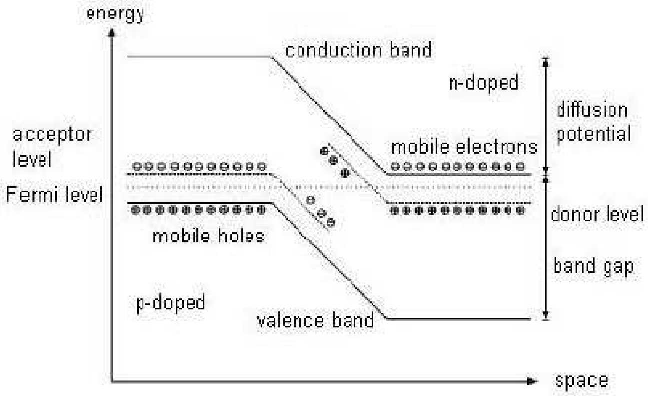

Fig. 8: pn-junction with equal carrier densities on both sides.

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 biasing 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. 9.

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 avalanche breakdown at high breakdown voltages. Since the temperature coefficients of avalanche and tunnel breakdown have opposite signs, tunnelling works better in the cold due to sharp band. Forward biasing 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 oppositely doped region and recombine there (In case of direct semiconductors – not silicon – that are emitting their energy difference not only thermally but also as photons, which is used in LEDs. 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.) The resistance of the pn-junction vanishes leaving only the normal resistance of the semiconductor material, see Fig. 10.

A transistor is formed by two opposite pn-junctions; a pnp or an npn device. Such a device will block current in either direction – one of the barrier layers will always be reverse biased – 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 an 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.

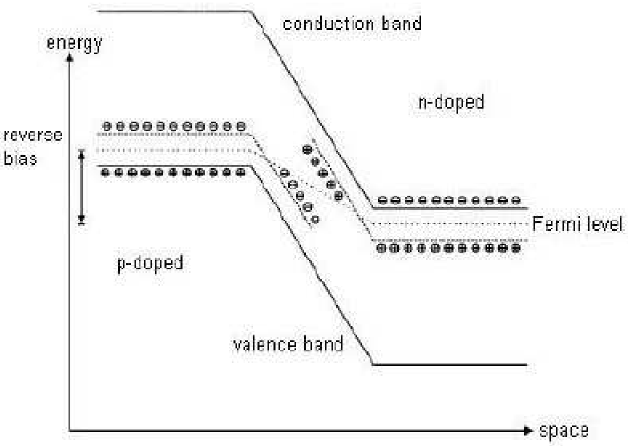

Fig. 9: Reverse biassing of a diode.

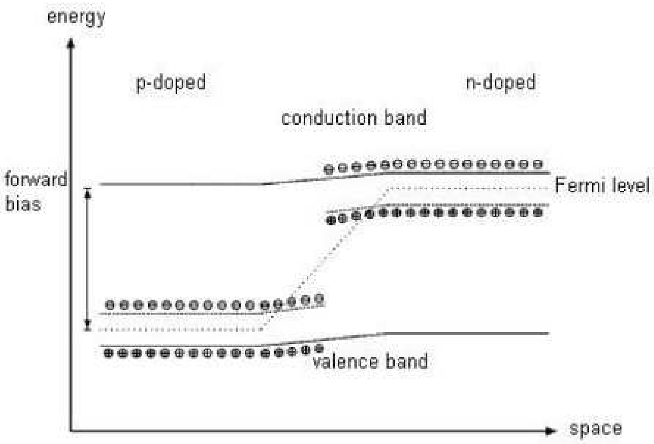

Fig. 10: Forward biassing of a diode.