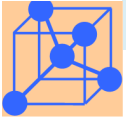


Semiconductor diodes

1. Methods of making junctions
2. Rectifying diodes
3. Zener diodes
4. High frequency and MW diodes
5. Variable capacitance diodes
6. Switching diodes
7. Tunnel and backward diodes





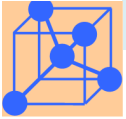
Semiconductor diodes (according to structure and technology)

- 1 Point contact (taškiniai)
- 2 Junction diodes (plokštiniai)
3. Small area (mažo ploto)
4. Schottky diodes (Šotkio diodai)

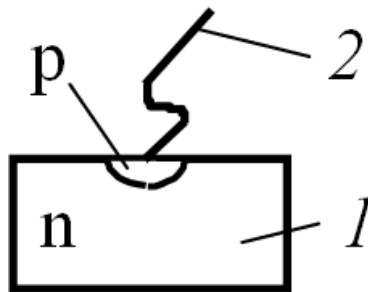
- Alloy junction (lydytiniai)
- Diffused junction (difuziniai)
- Epitaxial (epitaksiniai)
- Epitaxial-diffusional (epitaksiniai-difuziniai)

- Mesadiodes (mezadiodai)
- Planar diodes (planarieji)





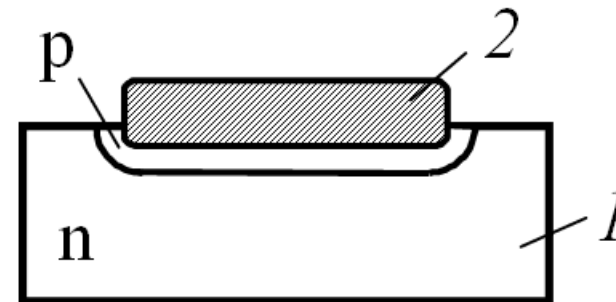
Methods of making junctions



Point contact diode:
1 – semiconductor crystal; *2* – metal wire

Properties:

- small junction area,
- good frequency properties

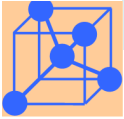


Alloyed junction:
1 – semiconductor crystal;
2 – aluminium tablet

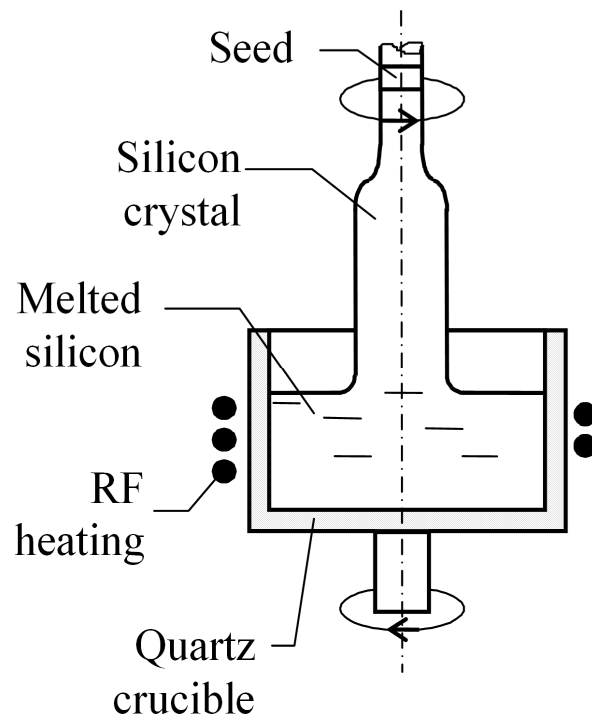
Properties:

- step junction,
- large junction area





Methods of making junctions

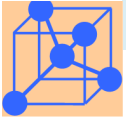


Grown junctions are formed during the Czochralski crystal pulling process.

Single crystals around 2 m long and with diameters up to 300 mm can be grown using this method based on the pulling of a single crystal from a molten semiconductor. If impurities of p and n-type are alternately added to the molten semiconductor material during the pulling process, a pn junction appears.

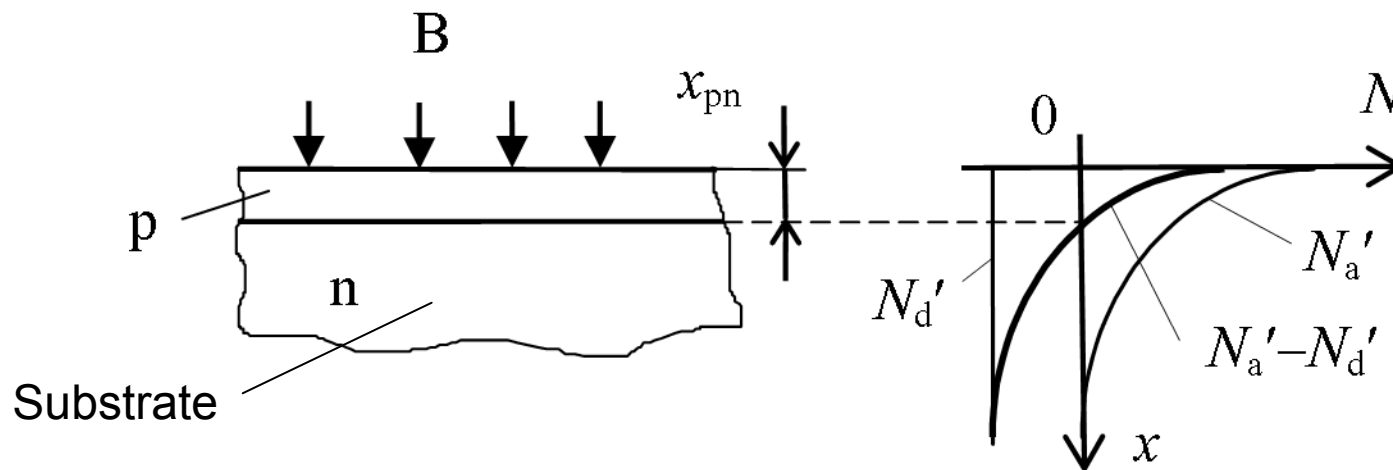
After slicing the large-area device can be cut into a large number (thousands) of smaller-area semiconductor diodes. Usually wafers are made in this way. In practice the Czochralski method is used to obtain high quality doped semiconductor crystals (... Substrates for ICs).





Methods of making junctions

Diffused junctions are formed using the thermal diffusion of impurity atoms.

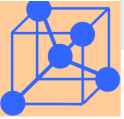


Diffused pn junction and impurity distribution

... As a result the major portion of the original semiconductor plate (*base*) is unchanged, but the surface layer becomes doped with the diffused impurity.

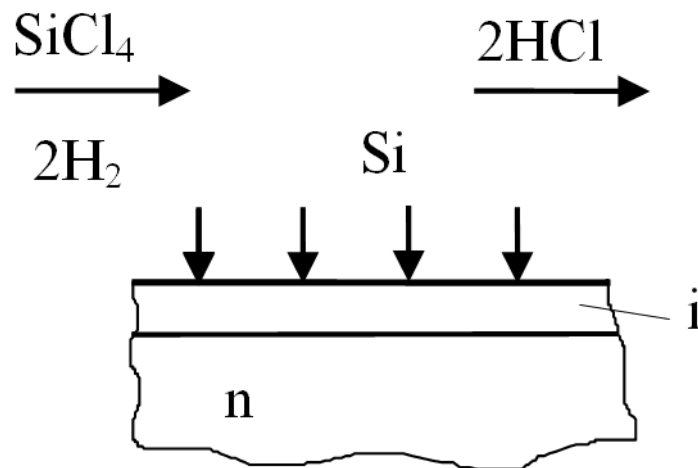
A junction is thus formed directly under the surface. The diffusion process requires more time than the alloy process, but it is relatively inexpensive and can be very **accurately controlled**.



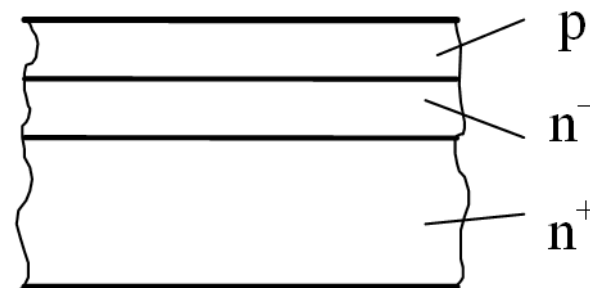


Methods of making junctions

The layer of a doped semiconductor can also be made by **epitaxial growth** technology.



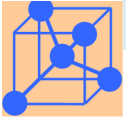
Epitaxial growth of a silicon layer



Epitaxial-diffusional structure

... i, n, p, n-, p-, n+ and p+ layers may be formed on the substrate and pn junctions may be manufactured by the technique of epitaxial growth.

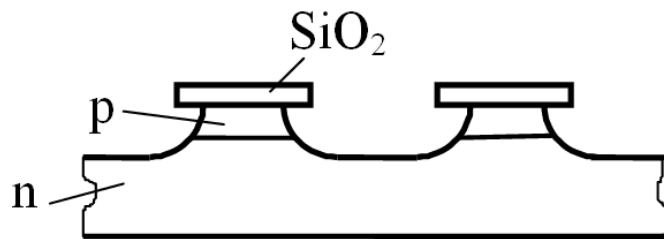




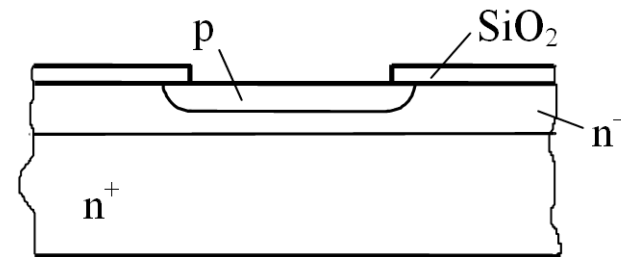
Methods of making junctions

The area of junction diodes must be large to handle high currents. However, capacitances of the junction increase with the area of the junction.

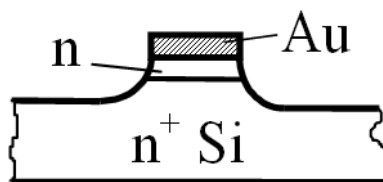
... Special **mesa** and **planar** technologies are developed for the fabrication of high frequency diodes with small areas of junctions



Mesodiode

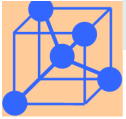


Epitaxial-diffusional
planar diode



Epitaxial Schottky (MS)
diode

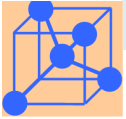




Semiconductor diodes

- Rectifying diodes (rectifiers, power diodes) for rectification of alternating current.
- Zener diodes – for voltage reference. Based on electrical breakdown.
- High frequency diodes – for applications (detection, mixing, ...) at high frequencies. Small base resistance, small barrier capacitance.
- Varicaps – variable capacitance diodes (electrically controlled capacitors).
- Switching diodes – for fast switching electronic circuits.
- Tunnel and backward diodes.





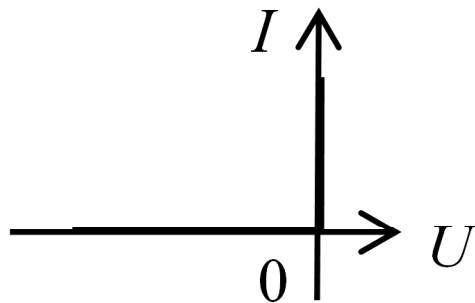
Rectifying diodes (rectifiers, power diodes)

The majority of power diodes are constructed using silicon. Silicon diodes have higher current, temperature and peak inverse voltage ratings.

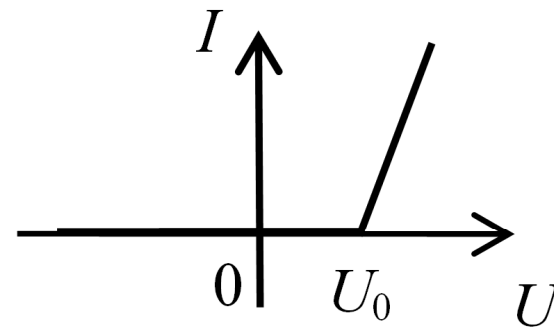
The current capability of power diodes can be increased (1) increasing the junction area or placing two or more junctions in parallel, and (2) the peak inverse voltage rating can be increased by using pn junctions in series.

In order to reduce the junction temperature, the heat sinks are used to draw the heat away from the element.

In the rectifying process a diode is used as a valve or a switch.



(a)



(b)





Rectifying diodes

The important parameter of a rectifying diode is the **knee** or **offset voltage**. It is dependent on the semiconductor used for a diode. Two terms are introduced to characterize diode resistance in a given point of the I - U characteristic.

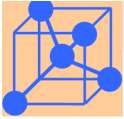
Static resistance is the ratio of the dc voltage across a device to the dc current through the device:

$$R_s = U / I$$

Dynamic resistance is the ratio of the change in voltage across a device to the change in current through the device:

$$R_d = dU / dI \cong \Delta U / \Delta I$$





Zener diodes

Silicon diodes, especially made to operate in the breakdown region, are used as voltage references in rectification and control circuits.

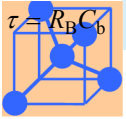
The Zener or avalanche breakdown is used in these diodes.

They are historically called **Zener diodes**.

Reference diodes with near to zero temperature coefficient can be achieved using compensation methods, for example, by connecting a positive coefficient reference diode in series with a forward-biased pn junction which temperature coefficient is negative.

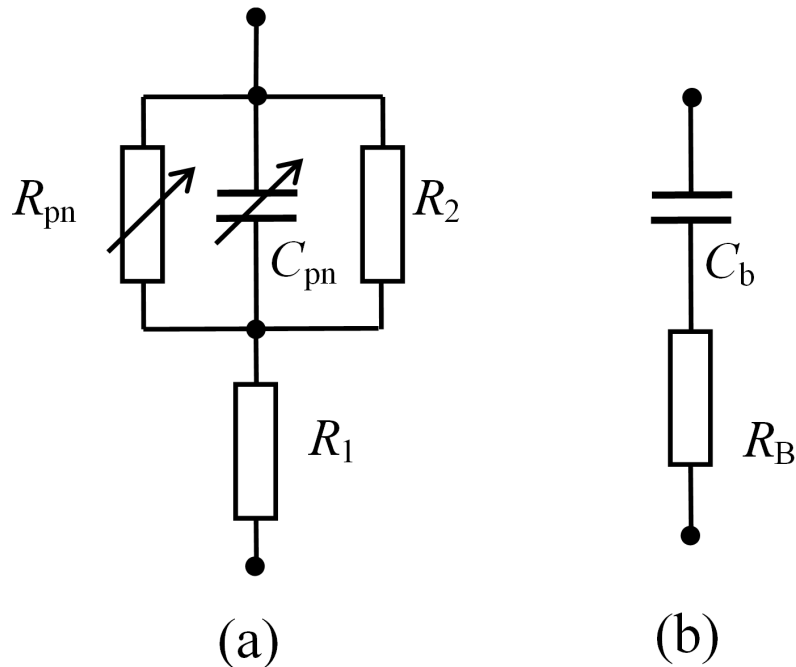
Forward biased semiconductor diodes can be used as the small-voltage reference diodes due to nonlinearity of the forward branches of current-voltage characteristics. Such diodes are sometimes called **stabistors**.





High frequency diodes

Diodes used for detection, mixing, frequency multiplication, ... Work at high frequencies.



The small signal models of a junction diode: R_1 – base resistance, R_2 – leakage resistance

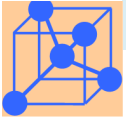
In most applications the reverse bias is applied to a high frequency diode. Then the frequency properties of a diode are dependent on the time constant

$$\tau = R_B C_b$$

Point-contact, mesa, planar epitaxial structures and Schottky diodes are suitable for high frequency applications.

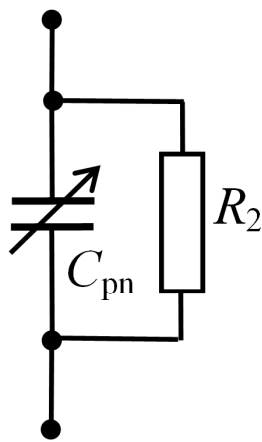
Special point contact diodes are used in the very high frequency (microwave) range. They must have a very small junction area and small parasitic inductance and capacitance.



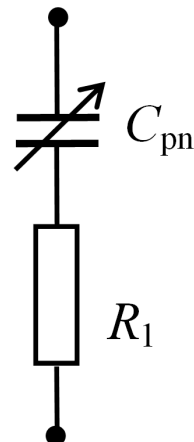


Variable capacitance diodes

Reverse-biased junction diodes are often used as small signal capacitors which capacitance can be electrically controlled by their dc bias. Diodes made especially for this purpose are called *tuning diodes*, *varactors*, *variable capacitance diodes*, or **varicaps**.



(a)



(b)

The simplified models of a varicap

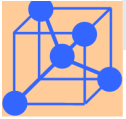
Besides capacitance, **electrical quality** is the very important parameter of a varicap.

$$Q = X_e / R_e$$

$$Q = \omega C_{pn} R_2 \quad Q = 1 / \omega C_{pn} R_B$$

... The quality increases with the frequency in the low frequency range and decreases with the frequency in the high frequency range. So the quality has a maximum value in the middle frequency range.



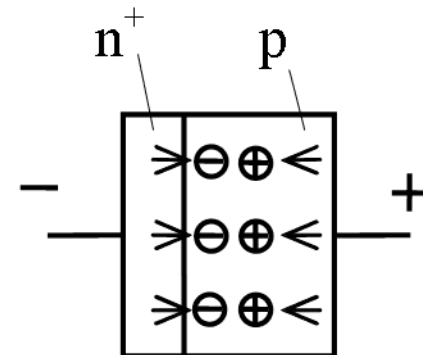


Switching diodes

At switching an interval of time elapses before the diode reaches its new steady state.

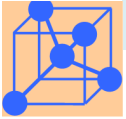
To reduce the switching time and increase the operation speed, high frequency diodes are used. This condition must be satisfied but is not enough to ensure high operation speed.

Let us consider a n+p junction diode.

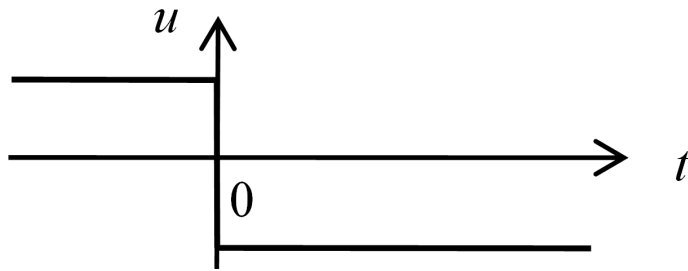


At forward bias, the injected carriers exist during a certain lifetime before they recombine with the majority carriers. The charge of the excess electrons and the charge of the excess holes exist at the pn junction under a constant forward bias. Thus, at a forward bias **the diffusion capacitance of the pn junction is charged** and the forward current flows through the diode.

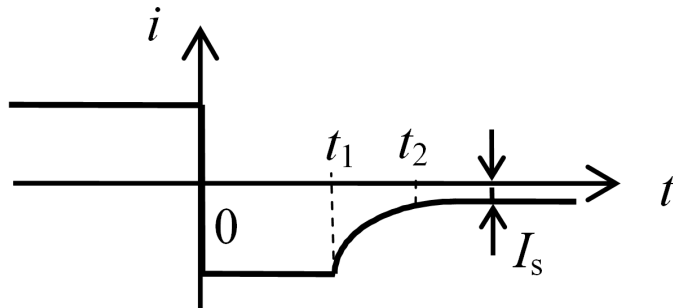




Switching diodes



(a)



(b)

If voltage becomes reverse, the reverse current is limited only by external resistance...

The period of time during which the excess carriers are extracted from the vicinity of the junction is called the **storage time**.

... The recovery interval becomes completed when the diffusion capacitance is recharged and the junction barrier capacitance is charged.

A diode has switch properties if its *reverse recovery time* is much less than the pulse period.

... If we want to increase speed of operation, we must **reduce the recovery time**.





Switching diodes

The reverse-recovery time is dependent on forward and reverse currents. So it is a function of the external circuitry. But it is also determined by diode parameters.

The stored charge and consequently the switching time can be greatly reduced **reducing the carrier lifetime**. The lifetime may be reduced by introduction of gold impurities into the junction diode by thermal impurity diffusion. The gold atoms create a series of recombination centers. Due to this the stored carriers recombine more quickly because of the increased recombination rate.

The reverse recovery time can also be reduced **shortening the length of the base region** or reducing the thickness of the layer where the minority carrier charge is stored. This layer is thin in the diodes made by the **diffusion technology** due to the existence of the internal electrical field at the junction and in the diodes formed using **epitaxial-diffusion method**.

In a Schottky diode the current is transported by majority carriers. So there is no minority charge, and **Schottky diodes** are preferred components for fast switching applications.





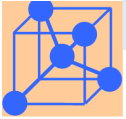
Switching diodes

Point-contact diodes, mesa diodes, epitaxial-diffusion planar diodes, Schottky mesa diodes are used most frequently as high speed switching diodes.

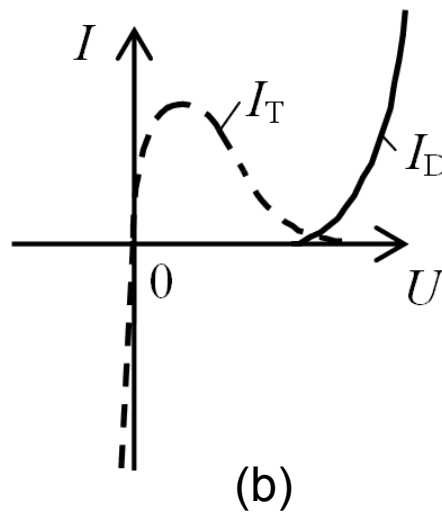
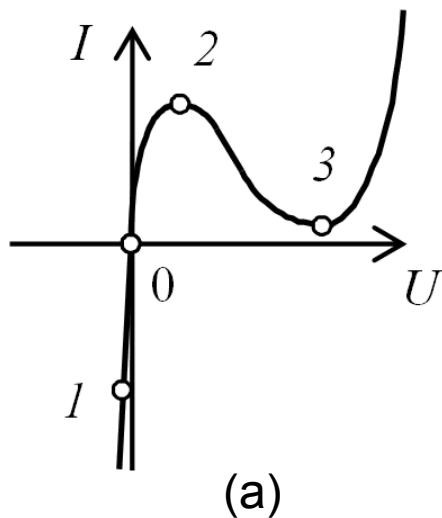
... There is a group of pn junction diodes in which carrier storage is the major factor contributing to the operation of the device. These diodes are called **charge-storage diodes**, or **step recovery diodes**. They are designed so that most of the injected minority carriers under forward bias are stored near the junction and are immediately available for conduction when the reverse bias is applied.

Charge-storage diodes are therefore used as **pulse formers**. Most charge-storage diodes are fabricated in silicon with relatively long carrier lifetimes ranging from 0.5 ms to microseconds.

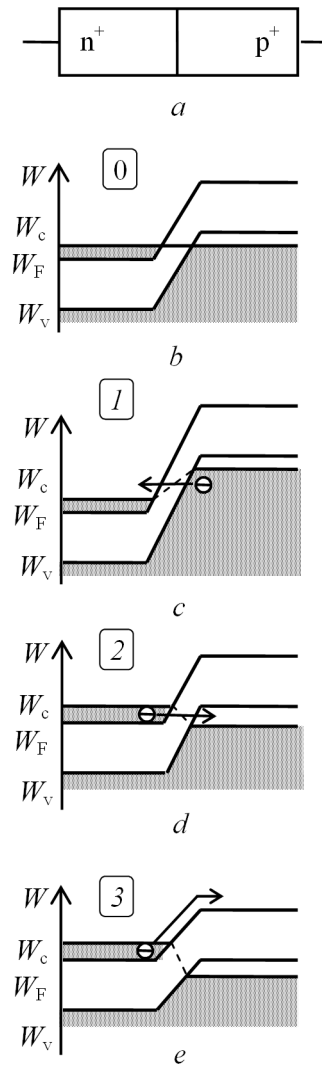


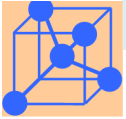


Tunnel diodes



I-U characteristic of a tunnel diode
and its current components





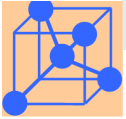
Tunnel diodes

The current of a tunnel diode consists of diffusion and tunnel currents.

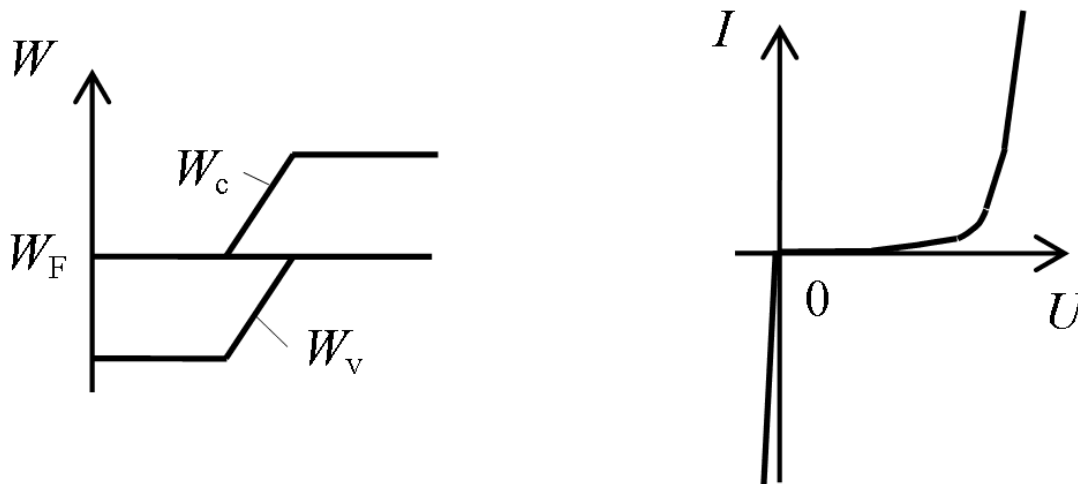
The I - U characteristic contains a part where the current decreases as the voltage increases – **the dynamic resistance is negative**. Therefore tunnel diodes can be used for amplification of small electrical signals and for generation of oscillations and pulses.

The tunnel current is carried by majority carriers – junction capacitance is small. Therefore **tunnel diodes are suitable for processing of very high frequency (microwave) signals**.





Backward diodes

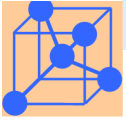


Energy band model
(a) and $I-U$
characteristic (b) of
a backward diode

The reverse resistance is less than forward resistance.

The $I-U$ characteristic is non-linear – diodes are suitable for processing (rectification, detection) of high frequency (microwave) small signals.





Semiconductor diodes

1. Sketch the $I-U$ characteristic of an ideal switch.
2. An ideal silicon junction diode has a reverse saturation current of 100 mA at the temperature of 300 K. Find the static resistance and dynamic resistance of the diode for a bias voltage of 0.2 V in the forward and reverse directions.
3. Sketch the equivalent circuit of a high frequency diode.
4. Derive the expressions for electrical quality of a variable capacitance diode.
5. Describe the operation of a switching diode and methods used to improve operation speed.

