Nanoelectronic devices I.

Dr. Miklós Berta

bertam@sze.hu

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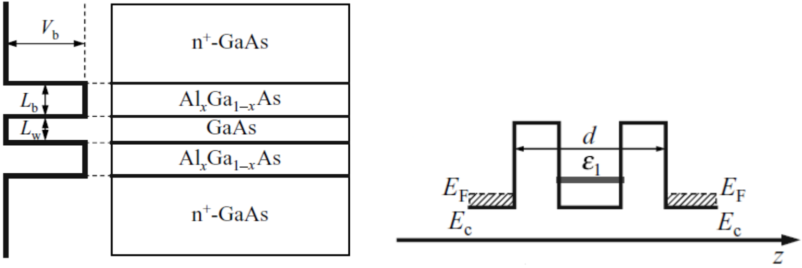
SZÉCHENYI ISTVÁN EGYETEM SZE - GYŐR

Fizika és Kémia Tanszék

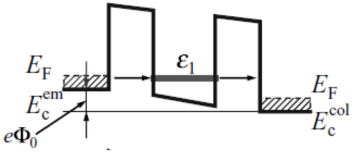
Resonant tunnel diode

Let's examine the behavior of the layer structure shown in the figure below from the point of view of electron transport!

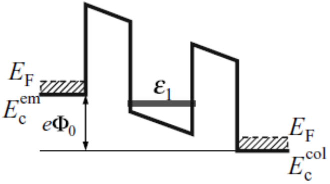


- Between doped GaAs contacts, the potential structure on the right is formed for the conduction electrons in the contacts.
- Dimensions L_b, L_w ensure the collision-free movement of electrons, i.e. they are significantly smaller than the average free path of electrons in these layers.

- In the intermediate (non-doped) GaAs layer (quantum wells), electrons can only occur with discrete energies $\varepsilon_{\boldsymbol{k}}$.
- Electrons can pass through from the contacts to the quantum wells only via the tunnel effect, but only those whose energy matches one of the quantum well's discrete energy level. There are no such ones.
- Let's see what happens if we connect a voltage Φ_0 between the contacts!

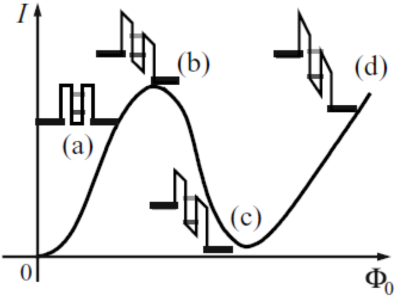


- As a result of the external voltage, the bottom of the conduction band and the Fermi levels in the contact shift as a result of the electrical potential energy.
- A voltage Φ_0 can be chosen such that the contact containing conduction electrons whose energy is the same as one of the energy levels of the quantum well, so that they can pass through the layer structure via a tunnel effect. In this case, we talk about resonant tunneling.



- By further increasing the Φ_0 voltage, we can achieve that the energy of the electrons in the contact rises above the former resonance level in the quantum well, and the resonant tunneling stops.
- The layer structure will be closed for electrons until the value of the external voltage Φ_0 is such that the resonant tunneling does not start again at a higher energy level in the quantum well!

It can be seen that such a layer structure practically behaves like a diode! It conducts at certain external voltage values, but not at voltages other than these.



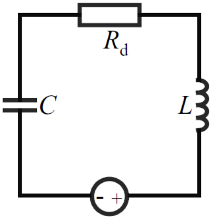
The dynamic resistance of a diode is the following quantity in electronics:

$$R_d = \left(\frac{dI}{d\Phi}\right)^{-1}$$

- It can be seen that the V-A characteristic of a resonant tunnel diode has regions where the dynamic resistance of the diode is negative!

Resonant tunnel diode as a microwave generator

Consider the following circuit with a resonant tunnel diode with dynamic resistance $\boldsymbol{R_d}$:



The impedance of the circuit:

$$Z(\omega) = R_d - i\left\{\omega L - \frac{1}{\omega C}\right\}$$

The resonant frequency of the circuit is defined by the condition $Z(\omega_0) = 0.$.

From this condition:

$$\omega_0 = -i\frac{R_d}{2L} \pm \sqrt{\frac{1}{LC} - \left(\frac{R_d}{2L}\right)^2}$$

And the damping factor of the circuit is:

$$\beta = -Im(\omega_0) = \frac{R_d}{2L}$$

- If $\beta > 0$, then the circuit vibrates without power with damped vibration, (with a capacitor charged only once).
- What happens if $\beta < 0$? A circuit without external excitation, but with a once-charged capacitor, is not damped, but excited, i.e. it behaves as an oscillator!
- Since the dynamic resistance of a resonant tunnel diode can be negative, the above circuit can be set as an oscillator without damping. The circuit operating in this mode behaves like a microwave generator!

Köszönöm a figyelmet!