Nanoelectronic devices II.

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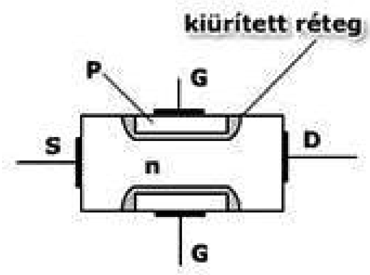
SZÉCHENYI ISTVÁN EGYETEM
SZE - GYŐR

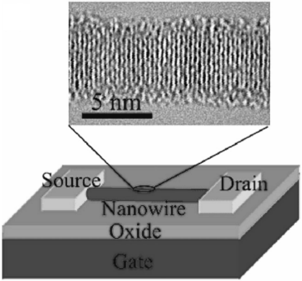
Fizika és Kémia Tanszék

Field – effect transistor (FET)



The potential of the G (GATE) contact can be used to change the thickness of the depletion region, i.e. the conductivity of the conduction channel between the S (SOURCE) and D (DRAIN) contacts can be controlled. → TRANSISTOR – EFFECT

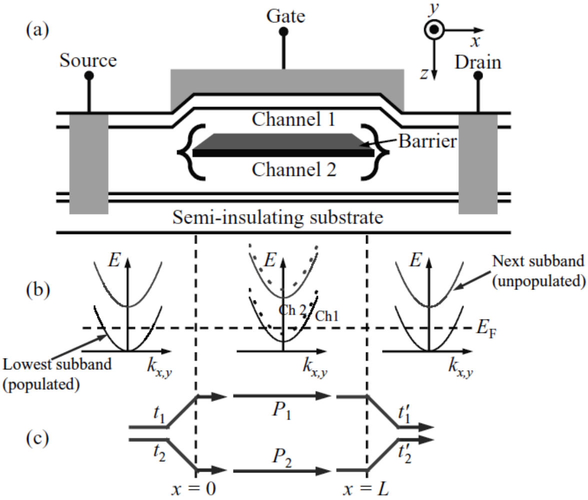
Quantum - wire transistor



- only electrons of a specific energy pass through the nanowire between the S and D contacts
- place a GATE contact above the nanowire - isolated from it and from the S and D contacts
- through the GATE potential, the discrete energy levels of the nanowire can be controlled, i.e. whether there is an open conduction channel and, if so, how many are open

- the quantized conductivity of the nanowire is regulated by the potential applied to the GATE, thus also the amount of current that flows between the S and D contacts
- recently, carbon nanotubes are often used as nanowires in this type of nanoFET transistors

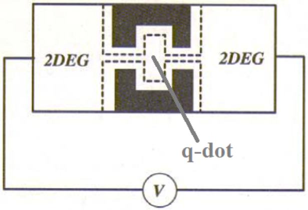
Quantuminterference - transistor (QUIT)



- imagine a FET transistor with a predefined size (L) so that the electron waves do not lose their coherence due to "collisions" ($L < l_{koh}$),
- the transversal (z - direction in the previous diagram) dimension of the conduction channel should already be in the ballistic range
- divide the conduction channel lengthwise (x - direction) into two subchannels using an insulating layer
- the potential of the GATE contact placed above the conduction channels (isolated from them) regulates the transmission (t_1, t_2) and phase shift (P_1, P_2) of the subchannels to different extents (as it is at different distances from each subchannel)
- the electron waves exiting the subchannels INTERFERE
- the interference image of the electrons depends on the phase difference between the individual subchannels, which in turn can be controlled externally with the GATE potential (all states between complete extinction and maximum amplification are available)

Quantum dot – transistor

We saw earlier that the discrete energy levels of electrons in a quantum dot depend only on the linear size of the quantum dot. („artificial atom”)
Consider the layout below:



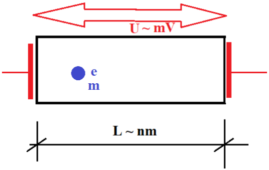
The 2DEG domains are connected to the quantum dot by contacts that are actually gaps, but due to their size, the electrons can significantly "tunnel" through them.

If we form a GATE contact separated by an insulator above the quantum dot, we can control the energy levels of the quantum dot with the external potential applied to the GATE, i.e. we can control the tunnel current that flows from one 2DEG region to the other 2DEG region.

Thanks to the tunnel effect in quantum dot - transistors we must also take into account the effect that the electron inside the dot has a repulsive effect on the following electron during conduction (Coulomb – inhibition). Thanks to this, it is possible for exactly one electron to mediate the tunneling current in the quantum dot region. (Single Electron Devices)

Estimation of the cutoff frequency of nano-transistors

The essence of nanodevices is that ballistic (non-collision) conduction is realized in them. For this, their dimensions are typically ***nm***. Let's determine how long it takes for an electron to pass through a range of length L without collision under the influence of a voltage U!



$$a = \frac{F}{m} = \frac{eE}{m} = \frac{eU}{mL}, L = \frac{1}{2}at_{tr}^2$$

Based on these:

$$t_{tr} = \frac{1}{f_{co}} = \sqrt{\frac{2m}{e}}\frac{L}{\sqrt{U}} \approx 10^{-13}\,\mathrm{s} \to f_{co} \approx 10\,\mathrm{THz}.$$

Thank you!