Nanoelectronic devices III.

Dr. Miklós Berta

bertam@sze.hu

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SZÉCHENYI ISTVÁN EGYETEM
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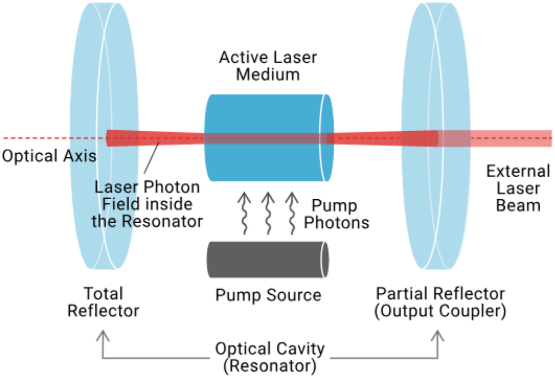
Fizika és Kémia Tanszék

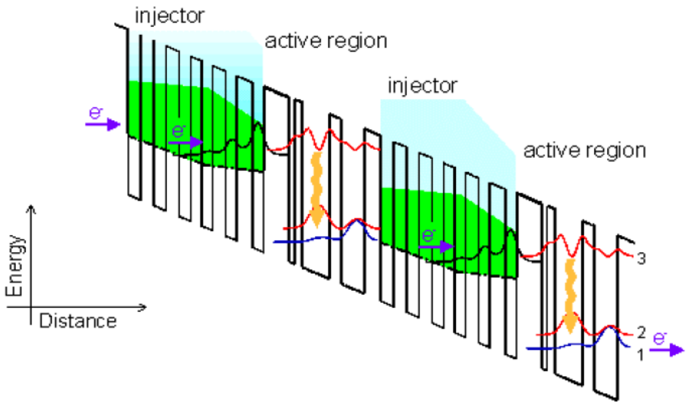
Basics of the lasers



- inverse population
- photon creation mainly by stimulated (induced) emission
- optical cavity – resonator

Quantum cascade laser

Consider a system made of many thin layers to which, if an external voltage is applied, the following energy level – structure is produced:



- injector - this domain consists of a multitude of artificial atoms (quantum dots) - artificial crystal lattice with energy bands!
- active region - this region has the dimension, that the electrons of the injector with the appropriate energy tunnel to the excited energy level in the middle layer $\longrightarrow$ inverse population is realized in the active region
- under the influence of an external photon (with stimulated emission), the laser effect is realized
- an electron with an energy corresponding to the ground state energy of the active region can tunnel into the injector following the active region (electron will find a corresponding energy in the energy band)
- this process can be repeated many times thanks to the set external voltage (in a $\mathbf{10\,\mu m}$ thick layer, up to 100 domains - a few nanometers thick - can be formed one after the other)
- 1 electron passing through the layers can take part in up to 100 induced transitions, i.e. 100 coherent photons can be generated
- by grinding the covering layers of the structure enough smooth, the optical resonator can also be realized

Josephson – switch

If the temperature of crystal lattices drops below a certain critical temperature (this value is different for every material), a surprising phenomenon occurs → the material's resistance decreases to zero → superconductivity phenomenon .

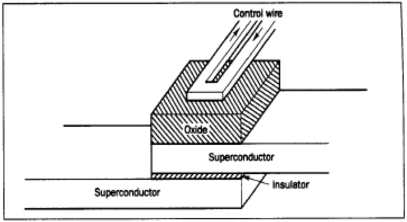
This phenomenon can be explained trhrough the very weak quantum mechanical effect, which arranges electrons with opposite spins into so-called Cooper – pairs, these pairs behave like zero-spin particles (bosons) and pass through the superconductor without resistance.

Cooper – pairs disintegrate into single electrons at temperatures higher than the critical one.

Experience shows that Cooper pairs disintegrate into individual electrons even in a magnetic field with a flux higher than the critical one. We use this in the so-called in Josephson – switches.

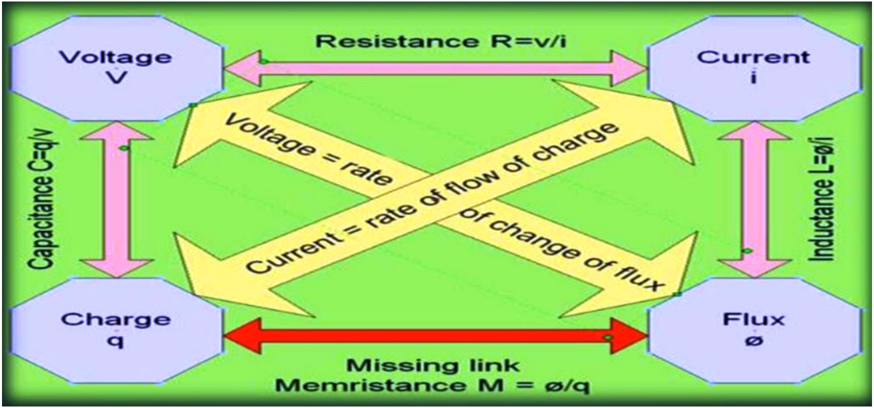
Place an insulating layer between two superconductors of a thickness through which the tunnel effect for Cooper –pairs is significant, i.e. the insulator will also be superconductive.

If a magnetic flux greater than the critical one is applied to this system (for example, with the help of a conducting loop placed above the system), then the Cooper – pairs in the insulator disintegrate, thus the resistance of the insulator increases dramatically!



This system is a two-state system, i.e. it is suitable to store information. Since the layer thickness is of the order of $\sim$ **nm**, fast and low-consumption memory elements can be formed on the base of this principle!

Memristor



In 1971, a theoretical prediction for the memristor! – by Leon O. Chua - Berkeley

$$d\Phi = M(Q).dQ$$

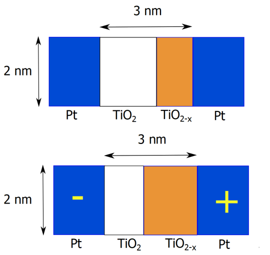
$$d\Phi = V(t).dt = M(Q).dQ = M(Q).I(t).dt$$

thus the VA characteristic of the memristor is:

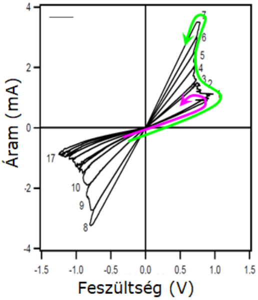
$$V(t) = M(Q).I(t) = M\Big(\int_0^t I(\tau)d\tau\Big).I(t).$$

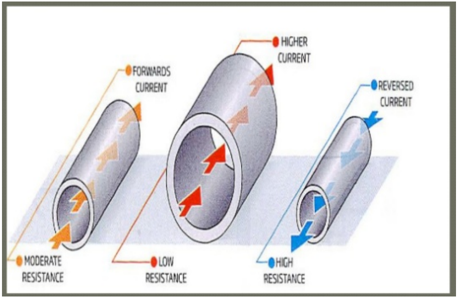
The slope of the characteristic depends on how much charge has been already passed through the memristor, i.e. the state of the memristor at a given moment depends on the charge that already passed through in the previous moments! This behavior is as if this circuit element has „memory"!

Nanoelectronic implementation



The orange region is contaminated with oxygen, so it is a p-type semiconductor region. If there is no external voltage, the white insulating region is relatively wide, so only a few electrons can tunnel through this insulating region. The higher the external voltage in the opening direction, the more the contaminated region widens, i.e. the electrons tunnel through the thinner insulating layer, the higher tunnel current will flow. And in the closing direction, the process is exactly the opposite.





It is important that the resistance formed after the flow of current remains there even after the electric field connected to the memristor is turned off!
→ MEMORY – effect

Memory elements that retain their state without power supply can be made in nano size!

Thank you!