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Quantum transistors

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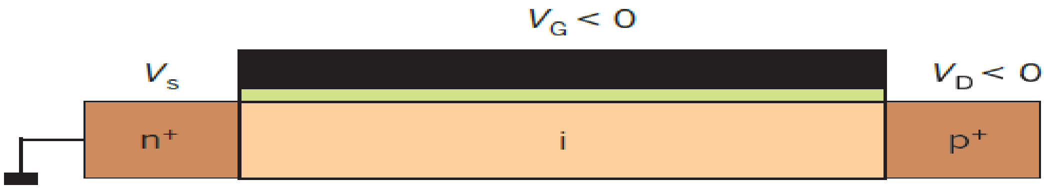
Transistors make our electronic world go round! Our lives are dominated by technological devices that are able to operate due to the incorporation of transistors. Dating back to early 1950's, these semiconductor devices came to replace the vacuum (electron) tubes widely used up until then in the electronic equipment. In discrete quantities they are used to create simple electronic switches, digital logic and signal amplifying circuits while they can get embedded into tiny chips in big quantities to create computer memories, microprocessors, and other devices. But nowadays there is a principle that has taken over and that is the smaller we are the better we perform, so quantum transistors have come now to replace the conventional ones. In this project our goal is to shed light on the principles behind the operation of quantum transistors and highlight the benefits occurring in electronic circuits because of them.

Even though more established types of transistors such as FETs (field-effect transistors), MOSFETs (metal–oxide–semiconductor field-effect transistors) or CMOS (Complementary metal–oxide–semiconductor) incorporate interesting physics, quantum transistors are truly fascinating. One example of such a device is the single-electron transistor, or sometimes called the quantum dot transistor while quantum well transistors are developing which could lead to more powerful, less power-hungry computers within the next decade. In this project we will examine the case of the tunnel field effect transistor or TFET as it is abbreviated.

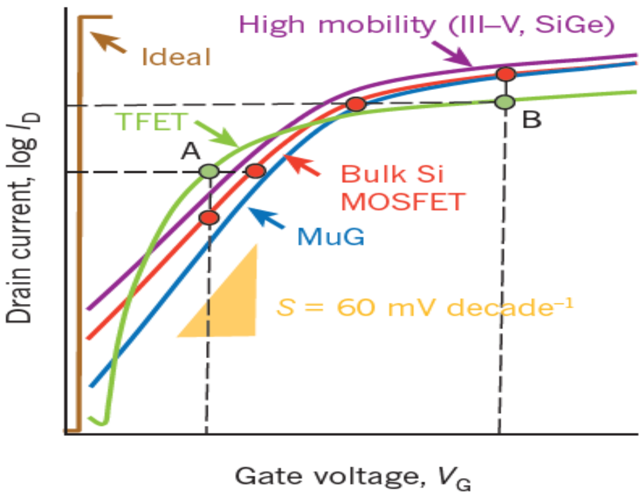
TFETs, as their full name suggests, exploit the effect of tunneling which happens at the quantum scale typically corresponding to 100 nanometers or less. Essentially, a tunneling current occurs when electrons move through a barrier that they classically shouldn't be able to move through. However, electrons have wavelike properties and these waves don't end abruptly at a wall or barrier, but taper off quickly, so if the barrier is thin enough, the probability function may extend into the next region, through the barrier. As far as the TFET's structure is concerned there is the source and drain terminals which are doped of opposite type. Essentially it consists of a P-I-N (p-type, intrinsic, n-type) junction, in which the electrostatic potential of the intrinsic region is controlled by a gate terminal.



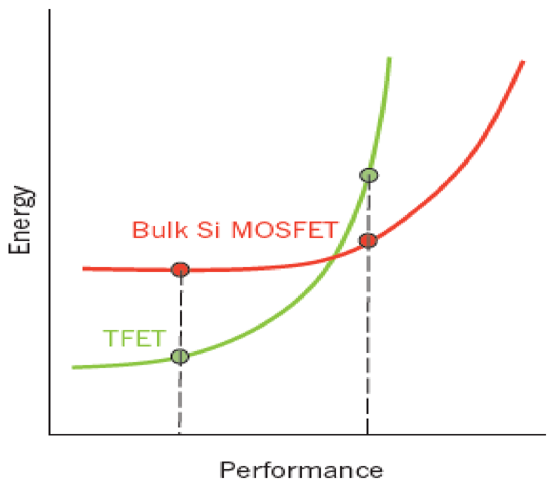
(a) Schematic cross-section of p-type TFET with applied source (V_S), gate (V_G) and drain (V_D) voltages. [1]

The nano-thick barrier here is located above the intrinsic area for V_G<0 as it is suggested in the picture above.

As for the main characteristics that we will analyze in the transistor is the gate voltage, the drain current and the energy efficiency given by the transistor. The two diagrams below show the relations connecting the V_G and the I_D as well as the energy efficiency occurring from the switching energy and performance plot.



(a) Qualitative comparison of three engineering solutions to improve the characteristics of the bulk silicon MOSFET switch (red): a multigate device (MuG, blue) for improved electrostatics; a high-mobility channel (purple) using group III–V and SiGe materials; and a TFET (green), which has a steep off–on transition and the lowest I_{OFF}. [1]



(b) Comparison between switching energy and performance for a MOSFET and a TFET. The steep-swing TFET offers better energy efficiency at lower or moderate performance level. [1]

When all these characteristics have been evaluated we can move on to briefly take a look into the future development of intriguing devices which include more complex physics. One is the double-electron-layer tunneling transistor (Deltt) which is still in the early stages of exploration and exploits the same effect as the TFETs but in a more complex way as in this case there are two two-dimensional quantum wells which act as source and drain. Furthermore, double-gate thin-body quantum well-to-quantum well TFET structures have been proposed but they are still in the earliest stage of development and they are an open subject for the future.

We realize that in today's world one-of-a-kind devices of many quantum-transistor varieties have been built and operated, but their so critical role as a control source in just about every modern circuit is pushing researchers to make them even more efficient, more reliable even more practical. So by the end of this presentation we will have delved into the physics and all these potentials of quantum transistors and in particular those of TFETs.

References

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- [3] https://en.wikipedia.org/wiki/Tunnel_field-effect_transistor.

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