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Popular science abstract

The rapid development of modern electronics begins to encounter fundamental limitations and faces new challenges. For example, the sizes of transistors reach few nanometers sizes (several dozen atoms) and cannot be further reduced, and thus the memory capacity in our electronic devices cannot grow significantly. Energy efficiency is another problem, especially important for mobile devices. Alternative ways of data storage and processing are sought. One of the more promising directions of research is spintronics, which uses not only charge but also spin (magnetic feature) of electron as an information carrier. The rapid development of this field in recent years has brought about discoveries that affect everyone's everyday life. The discovered effect of the giant magnetoresistance (GMR), and then the tunnel magnetoresistance effect (TMR) in the ferromagnetic tunnel junction (MTJ) was used in the heads of hard drives for readout. The resistance of the MTJ junction depends on the relative direction of the electrodes magnetization (parallel or antiparallel - fig. 1 a). Another milestone was the discovery of the Spin Transfer Torque (STT) phenomenon, which uses current rather than magnetic field (from a magnet or coil) to change the magnetization direction of the magnetic layers. This avoids the use of an external magnetic field (no moving parts as opposed to a hard disk). MTJs are the base for commercial magnetic free access memories (MRAMs) cells. There are also ferroelectric tunnel junction (FTJ) exploiting the phenomenon of TER - tunnel electro-resistance. In FTJ is a ferroelectric layer between the electrodes. Ferroelectric is similar to a ferromagnetic or a magnet, with the difference that instead of preserving the magnetization it retains voltage and charge. It acting as a barrier for the current. Its resistance depends on the direction of electrical polarization (Fig. 1 b). Nowadays attempts are made to create a ferroelectric random access memory FeRAM cell based on FTJs.

The MTJs and FTJs have already good properties, i.e. they exhibit very different resistance for different directions of magnetization and electrical polarization, respectively. In order to increase the capacity of data storage devices, attempts are made to combine MTJ and FTJ into one device in which twice as much bits can be saved (four different states). Previous studies have focused on considering the so-called multiferroic tunnel junction (MFTJ) with the structure: ferromagnetic (FM)/ferroelectric (FE)/ferromagnetic (FM), i.e. using electrodes from MTJ and barriers from FTJ. However, this approach brings with it challenges, because ferroelectric is not the optimal tunnel barrier for MTJ and ferromagnets are not optimal electrodes for FTJ. So far, no room-temperature-working junction with four resistance states (dependent of polarization and magnetization direction) have been achieved. Achieving this would allow for potential applications.

The development of electronics requires the use of 3D memory cells - one layer of memory cells on the other. This allows you to achieve larger number of logic states per surface area. The author's concept is to create a device with two barriers (Double tunnel junction DTJ), which would be a serial connection of MTJ and FTJ junctions with one common electrode (Fig. 1 c). The resistance of this junction would be a sum of FTJ and MTJ resistances. The DTJ junction gives the possibility of better properties than MFTJ, and until now there have been no tests for this type of junction. There are only studies of the double MTJ junction. But DTJ has the advantage over double MTJ that the ferroelectric is switched by voltage, which will reduce energy consumption. In addition, various DTJ switching mechanisms (ferromagnetic and ferroelectric) will allow easier control. There is also the potential to increase numbers of logic levels to 8 when all electrodes are ferromagnetic. The author also wants to test new possibilities offered by two isolating layers. One of them is to place between two barriers a material, that can change its resistance under the influence of an electrical charge. This would allow control of the thickness of the barrier (and large resistance change) using voltage. This project will allow to exploit the interesting concept of a double tunnel junction, which may contribute to its commercial use.

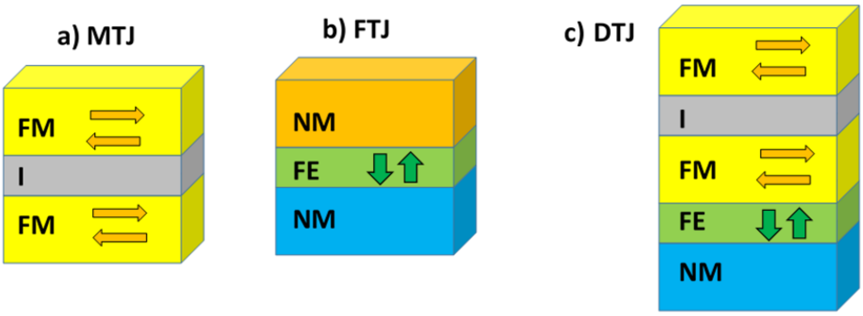

Fig. 1. *Different types of tunnel junctions. Where FM means ferromagnet, I - isolator, NM - electrode of FTJ, FE - ferroelectric:* ***a)*** *Magnetic tunnel junction MTJ,* ***b)*** *Ferroelectric tunnel junction FTJ,* ***c)*** *DTJ junction.*