DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB101J-Electromagnetic Theory, Quantum Mechanics, Waves and Optics

Module 2 Lecture-13

Tunnel Magnetoresistance and Colossal Magnetoresistance

Tunnel Magnetoresistance (TMR)

Tunnel magnetoresistance is a quantum mechanical effect which occurs when two ferromagnets are separated by a few atomic layers of insulator. The conductance of such a tunneling junction can vary dramatically depending on whether the ferromagnets are aligned in parrallel or antiparallel. The effect is termed "tunnel magnetoresistance" (TMR) and the relative change in the resistance of the junction, is called ‘optimistic’ magnetoresistance ratio.

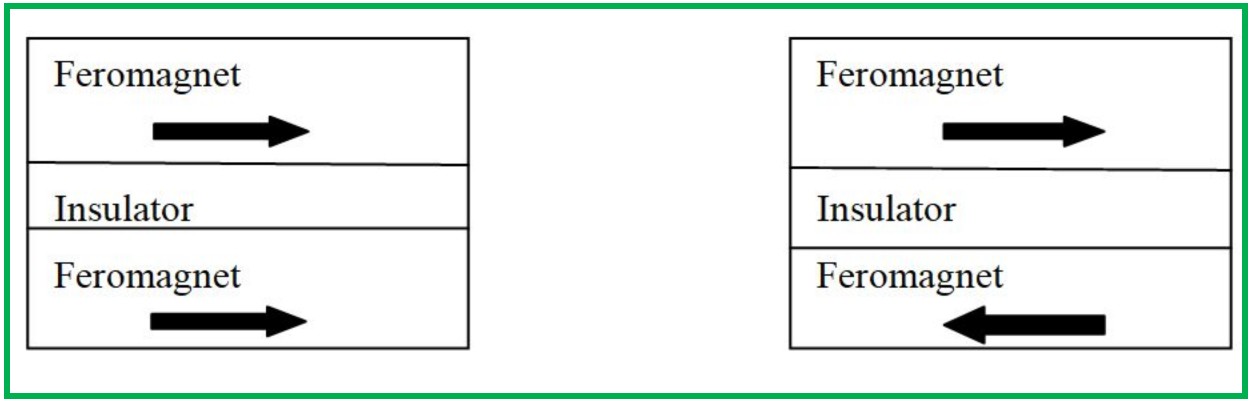

Fig. Schematic representation of layered structure for Tunnel Magneto resistance (a) Parallel state (b) Antiparallel State

Tunnel Magnetoresistance (TMR)

TMR is a consequence of spin-dependent tunneling. TMR can be understood in terms of Julliere's model, which is based on two assumptions. First, it is assumed that spin of electrons is conserved in the tunneling process.

It follows that tunneling of up- and down-spin electrons are two independent processes, so the conductance occurs in the two independent spin channels.

According to this assumption, electrons originating from one spin state of the first ferromagnetic film are accepted by unfilled states of the same spin of the second film. If the two ferromagnetic films are magnetized parallel, the minority spins tunnel to the minority states and the majority spins tunnel to the majority states.

Tunnel Magnetoresistance (TMR)

In this parallel state the possibility of electron tunneling between the two ferromagnetic electrodes through the insulator layer becomes larger, resulting in larger tunneling current.

However, the two films are magnetized antiparallel the identity of the majority- and minority-spin electrons is reversed, so the majority spins of the first film tunnel to the minority states in the second film and vice versa.

In this antiparallel state the electron with opposite spin orientation with respect to the magnetization of the ferromagnetic electrode cannot be tunneled successfully. Then the tunneling electron current become smaller compared to the case for the same directions of the magnetizations.

Tunnel Magnetoresistance (TMR)

Second, it is assumed that the conductance for a particular spin orientation is proportional to the product of the effective density of states of the two ferromagnetic electrodes.

The schematic representation of TMR with parallel state of ferromagnetic films and antiparallel state of ferromagnetic films are shown in Fig.

By sputter depositing ferromagnetic film on top of antiferromagnetic layer, the orientation of the magnetization of thin films can be "pinned" by the exchange coupling between the moment of the anitiferromagnetic layer and the thin ferromagentic layer.

Tunnel Magnetoresistance (TMR)

The thickness of the ferromagentic layer must be thinner than the exchange length of the material. The magnetization of the other ferromagnetic layer can be easily changed by applying external field if the film is made of soft magnetic thin film. By this configuration, the magnetic resistance changes sensitively depending on the external magnetic field, thus can be used as high sensitive magnetoresistive devices such as magnetic random memory (MRAM).

Colossal magnetoresistance (CMR)

- It is a property of some materials, mostly manganese-based perovskite oxides, that enables them to dramatically change their electrical resistance in the presence of a magnetic field.
- The magnetoresistance of conventional materials enables changes in resistance of up to 5%, but materials featuring CMR may demonstrate resistance changes by orders of magnitude.
- Colossal Magnetoresistance has been predominantly discovered in manganese-based perovskite oxides.
- This arises because of strong mutual coupling of spin, charge and lattice degrees of freedom.

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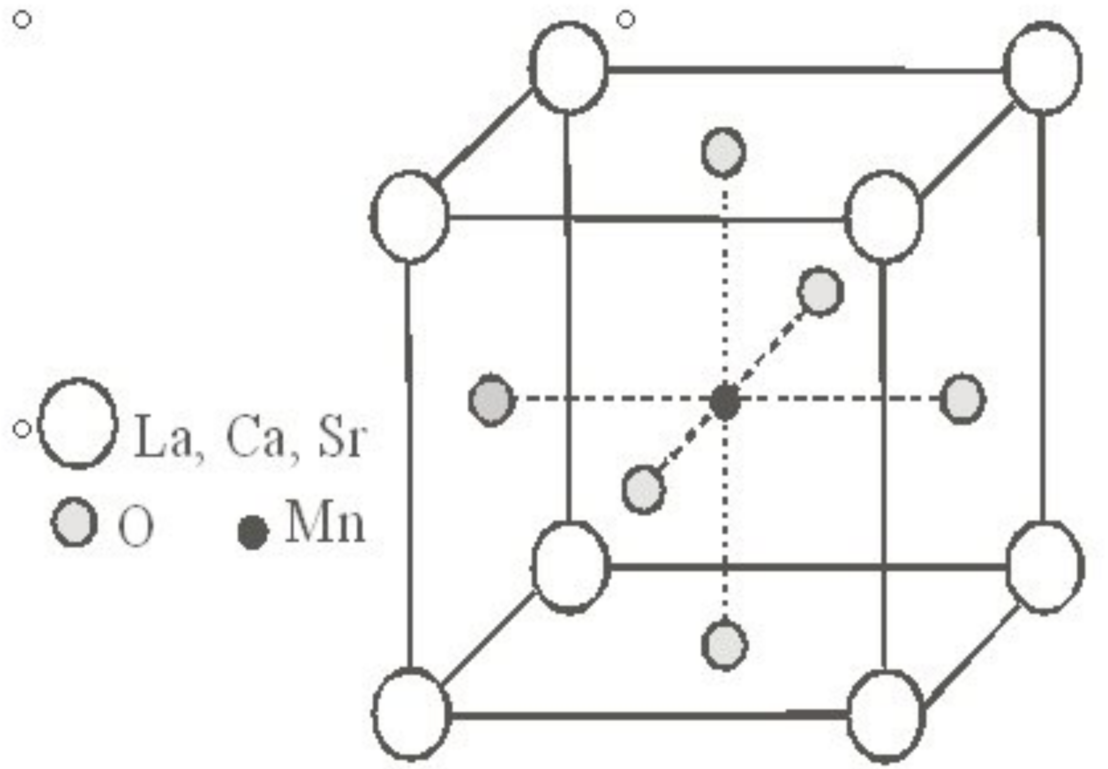
Colossal magnetoresistance (CMR)

- Hence not only high temperature superconductivity, but also new magnetoelectronic properties are increasingly discovered in materials with perovskite structures.
- The perovskite like material $LaMnO_3$ has manganese in the Mn^{3+} valence state. If the La^{3+} is partially replaced with ions having a valence of 2+, such as Ca, Ba, Sr, Pd or Cd, some Mn^{3+} ions transform to Mn^{4+} to preserve the elcetrical neutality.
- The result is a mixed valence system has been shown to exhibit very large magnetoresistive effects.

Colossal magnetoresistance (CMR)



ystal structure of $LaMnO_3$ which displays colossal magnetoresistance when the La doped with Ca or Sr.

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Colossal magnetoresistance (CMR)

Applications of CMR and GMR materials

- The understanding and application of CMR offers tremendous opportunties for the development of new technologies such as read/write heads for high-capacity magnetic storage, sensing elements in magnetometers and spintronics.

- The largest technological application of GMR is in the data storage industry.
- On-chip GMR sensors are available commercially from Non-Volatile Electronics.
- Other applications are as diverse as solid-state compasses, automotive sensors, non-volatile magnetic memory and the detection of landmines.

Colossal magnetoresistance (CMR)

- Read sensors that employ the GMR effect available for detecting the fields from tiny regions of magnetization.

- It is expected that the GMR effect will allow disk drive manufacturers to continue increasing density at least until disk capacity reaches 10 Gb per square inch.

Thank you