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P. 82–84, the main thought of each paragraph

Magnetoresistance is the change of conductivity in the presence of an external magnetic field. In ferromagnetic materials, it is anisotropic and is only a few percent in magnitude.

Even though it was only a few percent, the technology was being used for readout heads for magnetic disks. However, there was not seen any performance improvement.

The discovery of GMR was a great surprise. It appears in systems composed of stacked layers of ferromagnetic and non-ferromagnetic metals with each layer only a few atoms thick.

The origin of magnetoresistance in GMR systems is completely different. Grünberg had also realized the significance of his discovery and patented it.

The GMR effect originates from the difference in energy levels of spin-up and spin-down electrons in an external magnetic field. When electrons propagate between layers, they acquire different electric resistance depending on the magnetic field.

In the presence of an external magnetic field, polarizations of ferromagnetic layers align in the same direction, and the resistance is expressed through spin-up and spin-down resistances.

The conductivity of spin-up and spin-down electrons depends on their densities at the Fermi energy, which can be quite different. 100% spin polarization was predicted and then observed for CrO_2.

To create layered systems, one can also grow alternating layers of a metal and an insulator, but the insulator has to be only a few nanometers thick so that electrons can tunnel it.

GMR is a good example how a fundamental discovery can change technology. It started the field of megnetoelectronics, using the electron charge and spin at the same time, and now drives the development of nanotechnology.

Ex. 2, p. 85

a) About 150 years ago W. Thomson (Lord Kelvin) measured the behavior of the resistance of iron and nickel in the presence of an external magnetic field. He found that the resistance increases along the field lines and decreases across them. He discovered magneroresistance.

b) Anisotropic magnetoresistance is the dependence of electric resistance in a specific direction on the angle between it and the external magnetic field lines. Giant magnetoresistance is the effect similar to magnetoresistance, but originates differently. It comes from the electron spin and the difference in Fermi energies of spin-up and spin-down electrons.

c) Peter Grünberg with his colleagues used a trilayer system Fe/Cr/Fe, and Albert Fert used multilayer systems of the form $(Fe/Cr)_n$, where n could be up to 60. They achieved very large dependency of electric resistance on the external magnetic field, very large magnetoresistance.

d) The GMR device is a stack of alternating layers of a ferromagnetic and a non-conducting materials, each about a few atoms thick. When an external magnetic field is applied, the Fermi levels of spin-up and spin-down electrons are distorted, and electron densities change. This leads to differences in electric resistance.

e) Half-metals are materials that behave like metals (i.e. conduct electricity) in one direction and like insulators in another.

f) The tunneling magnetoresistance is the effect of passing thin insulator layers by electrons when they traverse from one metal to another. This effect leads to megnetoresistance.

g) The discovery of GMR led to the emergence of magnetoelectronics, where both the electric charge and the spin of electrons are used.

h) The GMR effect made it possible to miniaturize hard drives, read data more effectively, and create much more precise measuring devices.

Ex. 3, p. 85

a) Ферт и Грюнберг не только существенно улучшили магнеторезисторы, но и увидели эти наблюдения как новое явление, в котором происхождение магнетосопротивления было совершенно другим.

b) Поскольку магнетосопротивление связано с электрической проводимостью, очевидно, что именно поведение электронов на поверхности Ферми (определяемой энергией Ферми) наиболее интересно.

c) Здесь изолирующий материал должен быть всего несколько атомных слоев в толщину, чтобы электроны имели значительную вероятность квантовомеханически протуннелировать через изолирующий барьер.

P. 86, translation

The contribution of Albert Fert and Peter Grünberg

Albert Fert with his colleagues studies a system of a few tens of alternating layers of iron and chromium. To get the expected effect, scientists conducted the experiment in almost complete vacuum and at low temperature. Peter Grünberg's group dealt with a simpler system consisting of only two or three iron layers separated by chromium layers.

Fert found that the electric resistance of films decreases by 50%, when the relative magnetization of ferromagnetic layers changes from antiparallel to parallel, while an external magnetic field is applied at low temperature. Grünberg's figures are smaller —

only 1.5% — but at room temperature (this figure rose to 10% at 5 K). The physical nature of the phenomenon seen by the two groups independently turn out to be the same. The scientists concluded they observed a completely new phenomenon. Albert Fert was one of those who suggested a theoretical explanation of Giant Magnetoresistance, and in his first publication, 1988, noted that the discovery can be important for application. Peter Grünberg also noted the practical potential of the phenomenon and together with publishing his research in 1989 also patented his work in Germany, Europe, and USA.

But for wide use of the new technology, it was required to develop an industrial way to achieve such thin layers. The method used by Grünberg and Fert was pretty complex and expensive. It best suited for laboratory investigations, but not large scale industrial manufacturing. The works of an Englishman Stuart Parkin helped to embody the fundamental developments. He showed that the magnetron sputtering technique can be used to create thin-layered magnetic sandwiches, even at room temperature. The manufacturing of GMR reading heads started in 1997 and let us increase the capacity of hard drives manifold.