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Applied Physics

Lecture-2

Topic: Magnetic Recording,Magnetoresistance and Giant magnetoresistance-Part 2

The Effect of Magnetic Fields on Resistance

Resistance is caused by collisions between charge carriers (like electrons) and other carriers or atoms. An electron moving through a perfect crystal of metal at a temperature of absolute zero will experience no collisions, so the crystal would have zero resistance. Imperfections, however, do exist, and temperatures above absolute zero cause the atoms to vibrate out of their lattice locations. These vibrations and imperfections cause collisions, increasing the resistance of the crystal.

Applying a magnetic field can also increase the resistance of a material, since the magnetic force on the moving charges will tend to increase the number of collisions between charges. This dependence of resistance on magnetic field is called **magnetoresistance**. Magnetoresistance is proportional to the strength of the magnetic field, with a larger field producing a higher resistance. This property is used in computers to read magnetic data. A potential difference is applied to a wire that is placed close to the magnetic material on disk or tape. As the magnetic fields representing data on the material pass by the wire, the resistance of the wire changes with the magnetic field of the data. This change in resistance changes the current through the wire. Monitoring this current provides a reading of the magnetic field on the tape or disk.

Reading magnetic data is better with magnetoresistance than through induction. How?

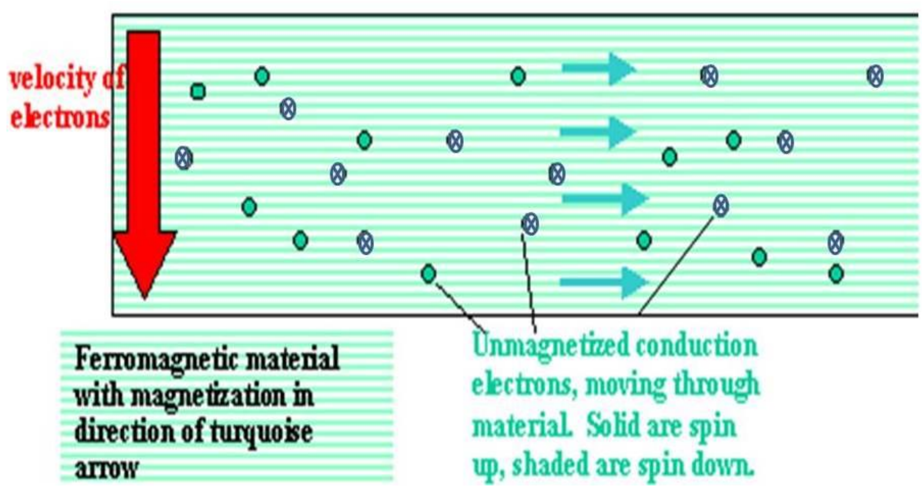
- Magnetoresistance can provide more accuracy than induction.
- In addition, magnetoresistance depends on the field, not the change of field, so its use is less dependent on precise speed of magnetic material.
- Finally, the circuitry needed to measure magnetoresistance (1 loop of wire with a potential difference applied, connected to an ammeter) is much simpler than the circuitry needed for induction (multiple loops of wire, arranged to maximize induced current, hooked up to an ammeter). The size of the effect is typically measured by dividing the change in resistance (or change in current) by the magnetic field of the storage medium. Inductive heads can give about a 1% effect, while magnetoresistance heads give about a 4% effect.

IBM started using magnetoresistance in its read heads in 1992. By 1994, all read heads produced by IBM were using magnetoresistance. Coils of wire are still used to write magnetic data, since a change in resistance does not cause a magnetic field. But only one coil is needed to write data, so the combination of inductive writing with magnetoresistive reading is still a simpler arrangement than the prior inductive read/write combination.

Giant Magnetoresistance

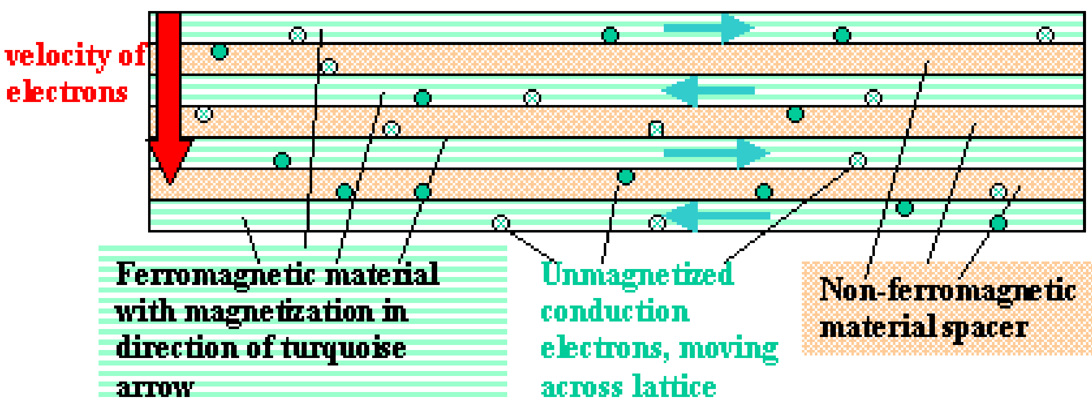
As we have learned that electrons have intrinsic magnetic fields, described by the property of spin. We can only measure magnetic field along one axis at a time (thank the uncertainty principle again). If a material is not magnetized, half of the electrons will have spin with a positive component along the chosen axis, and half will have a negative component. Those with a positive component are called "spin-up"; those with a negative component are called "spin-down."

If a ferromagnetic material is magnetized along the chosen axis in the positive direction, a spin-up electron will travel through the material more easily than a spin-down electron would. We won't do the quantum mechanical calculation here, but hopefully the conclusion is believable: electrons with spins in the same direction as the magnetic field experience fewer collisions than electrons with spins in the opposite direction of the magnetic field. The origin of this effect involves band structures of ferromagnetic materials, which are more complicated than the band structures already studied in this course.



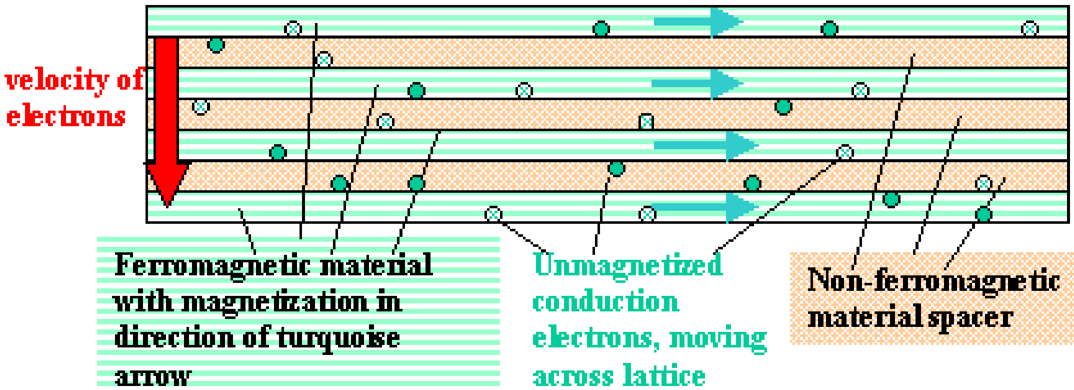
Although (hopefully) believable, this property of electron collisions is not particularly useful in a homogeneous piece of magnetized material. Since conduction electrons move into the material from non-magnetized connecting wires, etc., the conduction electrons are not magnetized. As in our figure below, approximately half of the electrons will be spin-up, and half will be spin-down. So no matter which way the material is magnetized, half of the conduction electrons will experience more collisions than the other half, keeping the resistance of the material constant. In the figure below, the solid spin-up electrons have a horizontal component of spin directed to the right, and the shaded spin-down electrons have a horizontal component of spin directed to the left. The solid spin-up electrons will experience increased mobility, while the shaded spin-down electrons will experience decreased mobility. Since the numbers of each are even, the effects cancel.

If, however, our material is layered, the resistance can change dramatically, leading to the phenomenon of **giant magnetoresistance**. Layers of certain ferromagnetic materials separated by non-ferromagnetic material will naturally have magnetizations which alternate directions (see picture). Such constructions usually consist of many layers and are called **magnetic superlattices**.



As presented, this superlattice does not seem to have any advantages over the previous single domain. Unmagnetized conduction electrons entering this material will all scatter as they move through the layers: electrons with spins toward the right of the page will scatter more in the second and bottom layers, while electrons with spins toward the left of the page will scatter more in the top and third layers. The spin-related effects on resistance cancel for the superlattice, just as they did for the single domain.

When the superlattice is placed in a magnetic field, however, the magnetization of all layers will align with the external field, creating the situation depicted below. Now only conduction electrons with spins toward the left of the page will experience the higher scattering rate. Thus the resistance of the material decreases in a magnetic field.



Giant magnetoresistance did not get its name by being a small effect; dividing the change in resistance (or current) by the applied magnetic field can give ratios of over 100%, which should be compared to the 4% effect of regular magnetoresistance and the 1% effect of inductance. Just like ordinary magnetoresistance, giant magnetoresistance can be used to read magnetic data by monitoring the change in current as magnetic data passes by the superlattice.

Giant magnetoresistance shows great promise for the next generation of magnetic reading devices. IBM produced the first GMR hard drive in 1997, and the use of the new technology is gradually increasing. Current research efforts focus on producing sensitive lattices cheaply. The biggest effects are seen at low temperatures, so efforts are also being made to obtain large giant magnetoresistance effects at room temperatures. Some groups have seen giant magnetoresistance in lattices with only three layers: two ferromagnetic layers separated by one spacer. These devices are called spin valves and are one of the primary candidates for incorporation into computers.