Effect Of Magnetic Field on The Resistance of Magnetic Materials

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Abstract. The effect of magnetic field on the resistance of magnetic materials is a topic of great interest in physics and engineering. Magnetic materials are those that exhibit magnetism. The resistance of a material is a measure of how much it opposes the flow of electric current. The resistance of a material can be influenced by various factors include external magnetic fields. The article will explore how magnetic fields affect the resistance of different types of magnetic materials, also what are the applications and explanation of this phenomenon. One of the methods to study the effect of magnetic field on the resistance of magnetic materials is to use Young's modulus measurement device. This device is also known as a tensile tester or a universal testing machine. In this essay, it will include the review the theory of the effect of magnetic field on the resistance of magnetic materials using Young's modulus measurement device. Article will also contain the advantages and limitations of this method. At the end of the essay, it will have the discussion of the future of magnetic material resistance measurement technology and more application.

Keywords: Magnetic field; Magnetic materials; Giant magnetoresistance, Young's model.

1. Introduction

Materials that can be magnetized by an external magnetic field or that already possess permanent magnetization are known as magnetic materials [1]. The level of electric current obstruction caused by magnetic materials is known as their resistance. Several variables, including temperature, contaminants, and magnetic fields, have an impact on the resistance of magnetic materials. The magnetoresistance effect is the name for how a magnetic field affects a magnetic material's resistance. It has various uses in science and industry, including magnetic sensors, data storage, and spintronics. The author shall examine many sorts of magnetoresistance effects, the underlying physical principles, and a few applications in contemporary gadgets in this essay [2].

The magnetoresistance effect is a phenomenon that was discovered as early as 1857 but did not attract much attention until the end of the 20th century. In 1988, Baibich et al. discovered the giant magnetoresistance (GMR) effect in a magnet, a nonmagnetic metallic multilayer film, whereby the electrical resistance changes drastically when the applied magnetic field is parallel or antiparallel to the direction of the magnetization of the individual ferromagnetic layers in the multilayer film [3]. This discovery laid the foundation for the development of spintronics and won the 2007 Nobel Prize in Physics [4].

In this paper, the author will introduce the GMR effect and Young's modulus measurement device in detail in Section 2, as well as the advantages and disadvantages of Young's modulus measurement device, and Section 3 is about the application of the GMR effect.

2. Measurement of GMR Effect

2.1. The GMR Effect

According to recent research, a magnetic field can impact a material's resistance in two different ways: directly via its influence on an electric current or indirectly through magnetization. The Lorentz force, or the force a magnetic field applies to a moving charge, is what causes the magnetic field's direct impact on electric current [5]. The charge carriers may veer from their initial course due to the Lorentz effect, changing the material's resistance. A Corbino disc, which comprises of a conducting

annulus and flawlessly conducting rims, may be used to study this phenomenon. A radial current flow between the rims in the absence of a magnetic field. Due to the Lorentz force, when a magnetic field perpendicular to the annulus' plane is applied, a circular component of current also flows. Magnetoresistance is the term for the increase in resistance brought on by the magnetic field between the inner and outer rims [6].

The indirect action of magnetic field on the resistance of a material is through magnetization, which is the alignment of magnetic moments of atoms or molecules in a material. The magnetization can affect the scattering rate and mobility of charge carriers, which are related to the resistance of the material. Depending on the type and orientation of magnetization, different effects can be observed, such as anisotropic magnetoresistance, GMR, tunnel magnetoresistance, colossal magnetoresistance, and extraordinary magnetoresistance. These effects have different mechanisms and applications, such as in sensors, memory devices, spintronics, and superconductivity [7].

A multilayer system with alternating ferromagnetic and non-magnetic layers experiences a significant shift in resistance known as GMR when an external magnetic field is applied. The resistance is determined by the relative magnetization orientation of nearby ferromagnetic layers. Resistance is low with parallel magnetization and large with antiparallel magnetization. Albert Fert and Peter Grünberg independently discovered this phenomenon in 1988, earning them the 2007 Nobel Prize in Physics for their work. The GMR is stated as follows [8]

$$\delta_H = \frac{R(H) - R(0)}{R(0)} \tag{1}$$

The ratio of positive stress to positive strain per unit area is known as the Young's modulus, a physical parameter that characterizes a material's elastic capabilities. The little length change that happens when a material is exposed to a force may be used to compute Young's modulus, which is one method of measuring it. Light bars and photoelectric sensors are examples of equipment used in conventional measuring techniques that are used to detect changes in length. However, these techniques are extremely dependent on ambient conditions and need careful adjustment and calibration.

2.2. Young's Modulus Measurement Device

A Young's modulus measurement device based on the GMR effect has been proposed in order to improve the accuracy and convenience of the measurement. The GMR effect is a phenomenon observed in the structure of a thin film layer between magnetic and non-magnetic materials, which manifests itself in the fact that the resistance value of the structural substance is related to the magnetization direction of the thin film layer of the magnetic material (see Fig. 1). When the magnetization direction of the two magnetic material film layers is opposite, the resistance value is larger; when the magnetization direction of the two magnetic material film layers is the same, the resistance value is smaller.

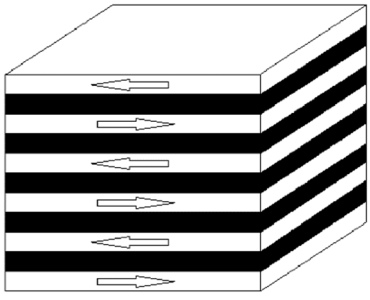


Fig. 1 multilayer thin-film structure

The Young's modulus measurement device based on the GMR effect consists of a GMR sensor, a magnetic steel sheet and a potential difference meter. The GMR sensor consists of a multilayer thin-film structure consisting of two layers of iron and one layer of chromium, and its two ends are

connected to a constant current source and a potentiostat, respectively. The magnetic steel sheet is fixed to the sample under test, and one end of the sheet is tightly fitted to the GMR sensor, while the other end is connected to a spring that can be adjusted in terms of strength. When an external force is applied to the sample under test, a small change in its length occurs, which results in a displacement of the magnetic steel sheet with respect to the GMR sensor. This displacement changes the direction of the relative magnetization between the two, thus changing the resistance of the GMR sensor. By measuring the potentiometer reading at a constant current, the resistance value of the GMR sensor can be obtained and the amount of change in the length of the sample under test can be further calculated.

2.2.1 Advantages

Young's modulus measurement device has the benefit of a measurement technique that is simple and doesn't need fine adjustment or calibration, all that's needed is the measurement of a potentiometer reading at a constant current. Conventional devices, like light bars or photoelectric sensors, need to make sure that the ambient light, temperature, and other variables stay constant in order to avoid affecting the measurement results. On the other hand, the Young's modulus measurement device does not require the use of any optical components; instead, it only needs to be connected to the sample being tested. From there, a straightforward circuit measuring the potentiometer's readings can be used to determine how much the sample under test has changed in length in order to calculate the Young's modulus. This technique increases the accuracy of the measurement data and significantly lowers the likelihood of mistakes and interferences during the measurement procedure [9].

As well as the convenience of the measurement process, there is no need to use optical components such as light sources and light screens, or to consider the effects of ambient light, temperature etc. Conventional devices such as light bars or photoelectric sensors need to measure in dark or semi-dark environments in order to avoid interference with the light signal from outside light. And a constant temperature needs to be maintained to avoid temperature variations that cause changes in material length or changes in optical component performance. All these conditions increase the inconvenience and difficulty of the measurement process. In contrast, the Young's modulus measurement device based on the GMR effect does not need to take these factors into consideration and can be used in any environment to perform the measurement. All that is required is to place the sample to be measured on a stable support, and to apply an external force by means of a spring with an adjustable strength, and the measurement process can be completed. This method greatly improves the convenience and flexibility of the measurement process.

2.2.2 Limitation

Nevertheless, there are several disadvantages to the Young's modulus measurement device. For example, it requires the employment of unique large magnetoresistive sensors and magnetic steel sheets, both of which may be costly and difficult to manufacture and install. Large magnetoresistive sensors are thin-film structures that must be created using high-precision vacuum deposition processes. They are made up of many layers of both magnetic and non-magnetic materials, each just a few nanometers thick.2 Magnetic steel sheets must be made using very precise cutting and machining procedures. The sheets are utilized to adhere to the sample being tested and fit snugly inside the enormous magnetoresistive sensors. The size and form of the steel sheets must match the sample being tested. The expense and complexity of maintaining the measuring instrument increase with these procedures since they need for specialist staff and equipment [10].

It cannot be used to measure non-magnetic materials directly; it is only relevant to magnetic materials or materials coupled to magnetic materials. The resistance value of the GMR sensor can only be altered by varying the length of the sample being tested if the sample is either connected to or made of magnetic material. This is because the GMR effect is based on a change in the relative direction of magnetization between two thin film layers of magnetic material. This method cannot be

used to measure the Young's modulus of non-magnetic materials; instead, the measurement must be made in conjunction with other kinds of sensors, such as strain gauges or manometers.

3. Applications

One of the most important uses is in the readout heads of hard drives, where the GMR effect can be used to make data storing faster and denser. The GMR effect is a thin film layer structure between magnetic and non-magnetic materials in which the value of resistance is linked to the direction of magnetization and can be used to read out data stored by magnetic methods at different sizes of current. Devices like computers, digital cameras, and MP3 players all use this technology now. Another use is in Magnetic Random Memory (MRAM), where each cell can store one bit of information by taking advantage of the fact that the resistance of GMR material changes in different states of magnetization. MRAM is useful because it can hold on to data even when it's not being used. It also uses little power, works quickly, and is very stable. Further, it can be used in weak magnetic field monitors, where the GMR effect makes it possible to pick up on very small changes in the magnetic field. Biosensors, microelectromechanical systems, car navigation, non-contact switches, and rotary encoders are some of the places these devices can be used. Finally, it also has application in magnetic sensors, which use the GMR effect to detect small changes in magnetic fields. These sensors can be used for measuring position, speed, angle, current, and magnetic field strength. They have advantages such as high sensitivity, low power consumption, and fast response time.

The magnetic refrigeration is one of the most abstract applications, which is a cooling technology that uses magnetic fields to change the temperature of a magnetic material. By applying and removing a magnetic field, the material undergoes a reversible phase transition that absorbs or releases heat. This process can achieve lower temperatures and higher efficiency than conventional refrigeration methods.

4. Conclusion

In this essay, the concept and mechanism of GMR effect have been introduced and explained. The GMR effect is a phenomenon that causes a large change in the resistance of a multilayer system composed of alternating ferromagnetic and non-magnetic layers when an external magnetic field is applied. The resistance depends on the relative orientation of magnetization in adjacent ferromagnetic layers. The GMR effect has many applications in various fields, such as data storage, memory devices, magnetic sensors, and magnetic refrigeration. The essay also discussed a novel device for measuring Young’s modulus based on the GMR effect, which has advantages of simplicity, accuracy, and convenience over conventional methods. However, the device also has some limitations, such as the need for special materials and equipment, and the inability to measure non-magnetic materials directly. The GMR effect is a remarkable discovery that has opened new possibilities and challenges for physics and engineering. In the future, more applications will extend the usage of magnetic materials.

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