On the Possibility of Training Demonstration of the Giant Magnetoresistance Effect in Higher School

V. B. Loboda, M. Ya. Dovzhyk, V. O. Kravchenko, S. M. Khursenko and Yu. O. Shkurdoda

Abstract The method and technique of training demonstration of the giant magnetoresistance effect on the example of film samples (single layer Co film and three-layer film Co/Cu/Co) in CIP-geometry with the help of simple experimental equipment are presented.

Keywords Nanosize multilayer films · Anisotropic magnetoresistance · Giant magnetoresistance

1 Introduction

In the middle of the twentieth century, a new scientific and technical direction began to form in the most developed countries of the world. By the 1970s it became known as the thin films physics (FTP). The complete notion of the physics and technology of thin films of this time is given in the encyclopedic edition [1, 2]. At the end of the twentieth century, the FTP became a strong scientific basis for both applied technical directions that provide the further development of traditional microelectronics (nanoelectronics) and new material science directions in solid state physics called nanotechnology (ion-plasma technologies for creating and modifying surfaces, etc. [3–10]. And then a rather strange situation arose, when despite the determining influence of the FTP on the development of the majority of modern science-intensive technologies, in the FTP itself did not found the attainment that pretended for universal scientific recognition. And only in 2007, A. Fert and P. Grünberg for the discovery of the giant magnetoresistance effect in the FTP was awarded the Nobel Prize in Physics [11–13].

V. B. Loboda · M. Ya. Dovzhyk · V. O. Kravchenko · S. M. Khursenko
Sumy National Agrarian University, Sumy, Ukraine

Yu. O. Shkurdoda (✉)
Sumy State University, Sumy, Ukraine
e-mail: yu.shkurdoda@gmail.com

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The giant magnetoresistance effect (GMR) is the galvanomagnetic quantum mechanical effect observed in specially created multilayer film objects, which consist of a system of magnetic and non-magnetic conducting alternating layers. The thickness of such layers is usually about units and tens of nanometers. The effect is manifested in the fact that the electrical resistance of such objects when they are introduced into a magnetic field (magnetoresistance MR) significantly changes. The relative change in the electric resistance value $\delta = \Delta R/R_0$, where $\Delta R = R - R_0$ (R is the electrical resistance of the conductor in the magnetic field, R_0 is the electrical resistance of the conductor in the absence of a magnetic field) is one units, tens and even hundreds of percent depending on the material of the layers, number of layers and temperature. Since this is several orders of magnitude larger than the magnetoresistance of massive natural conductors, hence the name is giant magnetoresistance.

Over the past 20 years, research topics in the field of GMR have not lost their relevance and continue to be of interest to researchers [14–24]. Some practical aspects of using the GMR effect are presented in [25–28].

2 Experimental Details

In the simplest case, the GMR effect is realized in CIP geometry in three-layer film objects (FO) of type FM/NM/FM, where FM is a layer of ferromagnetic metal (Co), NM is a layer of non-magnetic metal (Cu) [14, 16]. Depending on the thickness of the layers and the heat treatment, the magnitude of the effect is $\delta = 1$–4%. Such three-layer Co/Cu/Co films with GMR are offered by us for demonstration and study of the GMR effect in higher education institutions in the field of physics, electronics or magneto-electronics. We received a certificate from the Ministry of Education and Science of Ukraine on the recognition of compliance with pedagogical requirements No 06/029 dated June 24, 2014, for a product "Film objects for demonstration and study of the giant magnetoresistance effect".

FO is obtained by methods of layer vacuum spraying of metals (Cr, Cu, Co) on glass substrates. The FO consists of (Fig. 1) from the film resistor (3) (active part of the FO) and contact pads (2) for fixing the measuring conductors. Film resistors in the substrate plane have dimensions of 2 × 10 mm and are obtained by vacuum spraying Co, Cu. The substrates are polished glass plates (1) 25 × 25 mm in size. On each plate two identical film resistors (working and backup) are sprayed.

The contact pads are made using the vacuum layer spraying Cr and Cu. The layer of chrome thickness up to 50 nm is applied to the glass first and provides adhesion to the surface of the glass of the next copper contact layer thickness up to 150 nm. The contact pads after spraying are incubated in a vacuum to a temperature of 400 °C to provide their mechanical strength. The conductors for connecting the instrument to measure the electrical resistivity of the film resistor can be connected to such contact pads or soldering or purely mechanically using spring clamps.

During the demonstration and study of the GMR phenomenon, the change in the electrical resistance R of the film resistor in an external magnetic field by induction

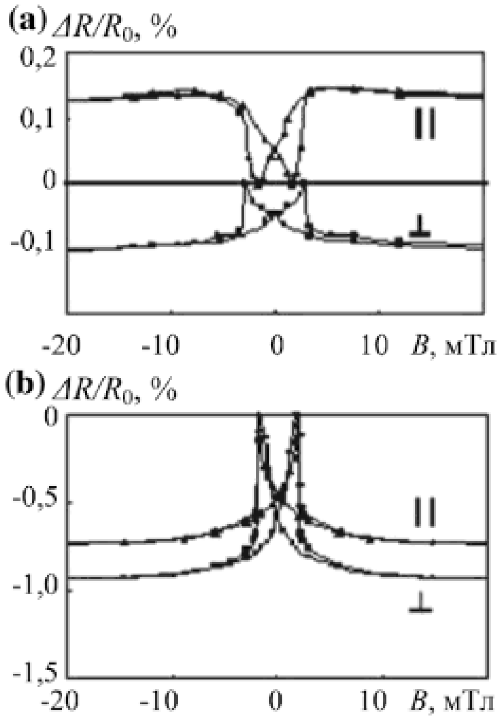

Fig. 4 The dependence of the magnetic resistance of film resistors on the induction of an external magnetic field: **a** resistor is single layer Co film (typical AMR); **b** resistor is three-layer film Co/Cu/Co (typical GMR)

4. Get the dependence of the value of the electrical resistance of the film resistor on the magnitude of the induction of the magnetic field $R_{PP} = R_{PP}(\overrightarrow{B})$. To do this, turn on the power supply of the magnetic system and, step by step, increasing the current (increasing the magnetic field induction) with a small increment, record the ohmmeter at each step.
5. Lock the ohmmeter indications after reaching the magnetic field induction value B = 100 mT and start with a small incremental step to reduce the current (to reduce the magnetic field induction) through the coils of the magnetic system to zero, again capturing at each step the ohmmeter indications.
6. Turn off the power supply of the magnetic system. Change the direction of induction of the magnetic field in the magnetic system to the opposite (change the polarity of the power supply) and again repeat the measurement of the electrical resistance of the sample in accordance with paragraphs 4 and 5 (Get the dependence $R_{PP} = R_{PP}(-\overrightarrow{B})$).
7. According to the results of the measurements, construct a complete loop of the magnetoresistive effect for the longitudinal magnetoresistance R_{PP}, that is to construct the two branches of the dependence $R_{PP} = R_{PP}(\overrightarrow{B})$ as for the current flowing through the film resistor in the direction of the vector $\vec{B}$ ($R_{PP} = R_{PP}(\overrightarrow{B})$) and for the current flowing through the film resistor in the direction opposite the vector $\vec{B}$ ($R_{PP} = R_{PP}(-\overrightarrow{B})$).

3.2 Transverse Magnitude (Dependence $R_{\perp} = R_{\perp}$ (B))

To measure the transverse magnitude resistance $R_{\perp}$, place the FO so that the direction of induction of the magnetic field of the magnetic system is perpendicular to the direction of flow of the electric current through the film resistor (Fig. 4b). Repeat the measurement for this position of the film object in accordance with p. 1–6 and, based on the results of measurements, construct a complete loop of the magnetoresistive effect for the transverse magnetoresistance $R_{\perp}$ (construct a complete graph of the dependence $R_{\perp} = R_{\perp}(\overrightarrow{B})$ similar to item 7).

Measurement carry out of the magnetic resistor for both PO with a single layer film resistor from Co and PO with a three-layer film resistor from Co/Cu/Co.

4 Results and Discussion

The obtained results of measurements of the MR must be expressed in percent using the formulas:

Longitudinal MR:

$$\delta_{\parallel} = \frac{\Delta R_{\parallel}}{R_0} = \frac{R_{\parallel} - R_0}{R_0}, \tag{1}$$

where R_{PP} is the electrical resistance of the resistor for longitudinal geometry of measurements (Fig. 3a); R_0 is the electrical resistance of the film resistor in the absence of a magnetic field;

Transverse MO:

$$\delta_{\perp} = \frac{\Delta R_{\perp}}{R_0} = \frac{R_{\perp} - R_0}{R_0}, \tag{2}$$

where $R_{\perp}$ is the electrical resistance of the film resistor for transverse measurement geometry (Fig. 3b).

According to the results of the measurements, construct a complete magnetic resistor loop (p. 7) (dependency graphs $\Delta R_{\parallel}/R_0 = \Delta R_{\parallel}/R_0(\vec{B})$ and $\Delta R_{\perp}/R_0 = \Delta R_{\perp}/R_0(\vec{B})$ for resistors from single layer Co film and three layer film Co/Cu/Co).

In Fig. 4 illustrates typical full-magneto-resistive loops for such films.

For film single-layer resistors from Co (Fig. 4a), there is a positive longitudinal PP (electrical resistance is increasing) and a negative transverse $\perp$ (electrical resistance decreases) magnetoresistance, which is a demonstration of AMR inherent in homogeneous ferromagnetic metals, both in massive and film conditions.

For a three-layer film resistor Co/Cu/Co (Fig. 4b), only a significant decrease in the electrical resistance (the ratio $\partial = ДR/R_0$ is less than zero) is observed regardless of the direction of the applied magnetic field, current and sample orientation (absence of anisotropy of the magnetoresistance). This is a characteristic feature of the GMR and allows a simultaneous change in the orientation of the magnetic moments of the film resistor elements (layers separated by a thin nonmagnetic layer Cu).

Compare the obtained dependencies in the case of AMR and GMR. Set the differences and determine the maximum GMR percentage.

5 Conclusions

The set of film objects of CIP-geometry created by us enables us to demonstrate and study in the courses of general physics, electronics, or magnetoelectronics, using the available simple equipment, as an ordinary anisotropic magnetoresistance (single layer film sample Co, Fig. 4a) and GMR (three-layer film sample Co/Cu/Co, Fig. 4b), which allows students to get acquainted with the physical effect of GMR.

Each sample (film object) has its own passport, which specifies its characteristics (composition electrical resistance, GMR amplitude, saturation field, coercive force, etc.) and a detailed instruction for demonstrating and studying the GMR effect.

In conclusion, the following should be noted. The GMR effect is experimentally discovered at the end of the twentieth century and the authors of the discovery in 2007 were awarded the highest scientific award—the Nobel Prize in Physics—is a fundamentally new physical phenomenon for artificially created macrosystems which structural elements have nanoscales and spin conduction electrons in which plays a main role.

Its practical use is one of the components of nanotechnology and spintronics, and the proposed set of film objects and the above-described method of their research, in our opinion, allow them to acquaint with them students of physical and technical specialties of universities.

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