The study of magnetic resistance on thin single-crystal nickel films

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Abstract. In this work the anisotropy of the transverse magnetoresistance of single-crystal nickel films was studied. The measurements were carried out on samples whose surface plane coincided with the [001] plane. Studies of magnetoresistance in a single-crystal nickel film showed the influence of tensile stresses acting on it from the side of magnesium oxide. The modification of the anisotropy of the magnetoconductivity of the film on the substrate as compared with the free sample is apparently associated with a change in the shape of the Fermi surface of the carriers.

1. Introduction

The theory and experimental studies of the so-called transition metals, whose electron shells have unfinished d- or f-layers, occupy a prominent place in the modern doctrine of magnetism. These features of the electronic structure make transition metals, their alloys and compounds an interesting object of study in the theoretical and experimental directions, and attract the attention of practitioners. The current state of the quantum-mechanical theory of transition metals needs to determine the distribution of charge and spin densities, the shapes of Fermi surfaces with a complex dispersion law for conduction electrons, electron densities near the Fermi surface, etc. There is still no rigorous quantitative theory of the exchange bond in transition metal crystals; the nature of the bonding forces itself has not been sufficiently clarified. The solution of the urgent problems of transition metals based on the convergence of the zone and s-d (f) -exchange interpretations of the atomic magnetic order in them is of paramount importance in the applied aspect, since these substances play a leading role in technology.

A separate place in the physics of films is occupied by films of magnetically ordered substances (Ni, Fe, Co, and magnetic alloys). This is due to the fact that they allow solving a number of fundamental problems for “two-dimensional magnetism”, as well as the fact that they have a number of specific magnetic properties: a specific domain structure and associated magnetic anisotropy, “magnetization ripples”, etc. [1,2] Recently, the phenomenon of giant magnetoresistance (HMS) has been added to
them, which has attracted especially great attention to magnetic films and is now the subject of comprehensive research.

Of particular importance is the study of the properties of magnetic films in connection with their widespread use in modern microelectronics [3,4,5].

The choice of Ni films as objects of study was due to a number of reasons. Firstly, Ni is an excellent candidate for studying magnetic properties depending on thickness, because has the lowest Curie point \( TC = 631 \) K in the series of ferromagnetic metals (Fe, Co); over the entire range of thicknesses and temperatures, Ni, unlike Fe and Co, has no polymorphic transitions, while maintaining the fcc lattice responsible for ferromagnetism. With an increase in the film thickness, nickel demonstrates both the dependence of the TS on the thickness and the transition from two-dimensional Ising magnets to three-dimensional Heisenberg magnets \([6,7]\). Secondly, Ni films both in the bulk state and in the film \([8]\) are the simplest, as it were “model”, to study their properties, in addition, to date, the electrical and especially galvanomagnetic properties of the films have been little studied.

The influence of the substrate and the dependence on the angle \( \phi \) between the axis \([100]\) of single-crystal thin nickel films on the change in the electrical resistance of films under the influence of a magnetic field or magnetization (magnetoresistance) have not been studied.

The goal of this work is to study the magnetoresistance and angular dependence, as well as the influence of the substrate and the dependence on the angle \( \phi \) between the \([100]\) axis on thin single-crystal films \(500–600\) thick at \(295\) K in magnetic fields up to \(20\) kOe.

2. **Methods of measuring magnetoresistance**

The magnetoresistance was measured by an unbalanced Thomson double bridge with an accuracy of about \(10^{-6}\) Ohms. The magnetoresistance was measured in the longitudinal and transverse directions of the external magnetic field, as well as depending on the angle \( \phi \) (between the \([100]\) axis and the direction of the external field). In all measurements, the current passing through the samples remained constant \(5 \times 10^{-4}\) A. When measuring the longitudinal and transverse magnetoresistance, the external magnetic field varied from 0 to 20000 E. The effect was measured in our experiments with an accuracy of an average of \(2-4\)\%.

When measuring the magnetoresistance depending on the angle \( \phi \), the value of the saturation field was \(5800\). The directions of measurements of \( r \), electric current \( i \), and external magnetic field \( H \) with respect to the \([100]\) axis had the following orientations: for the transverse effect, when \([100]\) \( \parallel i \parallel r \perp H \); for longitudinal \([100]\) \( i \parallel r \parallel H \).

The magnetoresistance was measured as a function of the angle \( \phi \) at \([100]\) \( i \parallel r \perp H=\phi \).

The experimental part was performed on thin single-crystal films obtained in vacuum \((10–4 \text{ mm Hg})\) at a substrate temperature of \(450\) K for LiF and at a substrate temperature of \(520\) K for MgO. The film thickness was \(5\) \(\mu\)m, the film was obtained by chemical transport reactions. Supposed change of \( \Delta\rho/\rho \) with a change in the shape of the film, it is associated with the Hall potential difference \([9]\). The electron diffraction pattern was used to check the plane \([001]\) of thin nickel films.

The lead wires were fastened with a special solder consisting of pure elements \((57\% \text{ Ga} + 23\% \text{ In} + 20\% \text{ Sn wt. Parts})\), having a low melting temperature and ensuring contact reliability \([10]\).

3. **Results and discussion**

The obtained results of the longitudinal transverse magnetoresistance, as well as the dependence of the magnetoresistance on the angle \( \phi \) for single-crystal thin films of different thicknesses are shown in figures 1,2,3. Figure 1 shows the dependency graphs of \( \Delta\rho/\rho \) from \( H \) films obtained during the same process cycle on LiF and MgO substrates. The direction of the current in the measurements was parallel \([100]\), the direction \( H \) is perpendicular, the streamline or in the plane of the film \( \Delta\rho/\rho \), either along its normal \( \Delta\rho/\rho \).

The films on the LiF and MgO substrates experience thermoelastic stresses of different signs, which obviously correlate with the different dependences of their transverse magnetoresistance on the field \( N \).
The film on LiF of $(\Delta \rho / \rho) \perp$ in the field of 5 kOe reaches a value of 0.2% and reaches saturation. For a Ni / MgO film in a field of 20 kOe of $(\Delta \rho / \rho) \parallel$ reaches a value of 17%, but $(\Delta \rho / \rho) \perp$ - values of 10%.

![Figure 1](image1.png)

**Figure 1.** Field dependency graphs of $(\Delta \rho / \rho) \perp$ and $(\Delta \rho / \rho) \parallel$ nickel films on the LiF (a) and MgO (b) substrates. Film thickness 500 Å.

It is assumed that tensile density stresses transfer the Ni / MgO film to the “strong” (according to Campbell, see figure 2.) ferromagnet characterized by a high magnitude of magnetoresistance (up to 25% at low temperatures). A known method for converting nickel to the state of a “strong” ferromagnet is the introduction of impurities (Fe, Co, Cu, etc.) into it. The fact that large values of $(\Delta \rho / \rho)$ Ni / MgO films are caused by mechanical stresses is evidenced by the fact that during repeated heating – cooling cycles these values decrease [11].

![Figure 2](image2.png)

**Figure 2.** Schemes of the density of states d of the nickel zone (a), “strong” (b) and “weak” (v) ferromagnets.

When measuring the magnetoresistance depending on the angle $\varphi$, a shift towards the negative effect is observed with a decrease in the film thickness (figure 3).

Thus, the influence of tensile stresses acting on it from the side of magnesium oxide on the transverse magnetoresistance of a monocrystalline nickel film is demonstrated. The modification of the anisotropy of the magnetoresistance of the film on the substrate as compared with the free sample is apparently associated with a change in the shape of the Fermi surface of the carriers.
Figure 3. The dependence of the magnetoresistance of \((\Delta \rho/\rho)\) on the angle \(\phi = [010] \parallel H \wedge i\) in the field \(H = 5800\) Oe.

4. Conclusion
The magnetoresistance in both the longitudinal and transverse magnetic fields for all the studied film thicknesses has a different curve: in the first case with a positive, in the second with a negative value of the effect.

The magnitude of the magnetoresistance at a magnetic saturation field of 5800 Oe, depending on the angle \(\phi\) between the [100] axis and the direction of the magnetic field \(H\), shifts to the negative effect with decreasing film thickness and reaches zero at \(\phi\) equal to 145\(^\circ\) and 135\(^\circ\) for 600 films Å.

On films with a thickness of 500 Å, the magnitude of the magnetoresistance in the entire range of the angle change has a negative sign of the magnitude of the effect.

References
[1] Poulopoulos P and Baberschke K 1999 J. Phys. Condens. Matter. 11 9495-515
[2] Frolov G I 2001 J. Technical Physics 12 50-7
[3] Huang F, Kief M T and Mankey G J 1994 J. Phys. Rev. 6 3962-71
[4] Snigirev O V, Tishin A M and Gudoshnikov S A 1998 J. Sol. Stat. Phys. 9 1681-5
[5] Loboda V B, Pirogov S M and Protsenko C I 2001 Bulletin of SSU, Series Physics, Mathematics, Mechanics. 3-4 74-83
[6] Loboda V B, Pirogov S M and Shkurkoda Yu O 2002 Bulletin of SSU, Series Physics, Mathematics, Mechanics. 13 150-8
[7] Viret M, Vignoles D and Cole D 1996 J. Phys. Rev. 53 8464-8
[8] Kim P D, Khalyapin D L and Turpanov I A 2000 J. Solid State Physics. 9 1641-3
[9] Kan S V, Kiselev N I and Mankov Yu 1 1987 J. Physics of Met. and Metall. 3 615-9
[10] Urinov Kh O, Zhumanov Kh A, Khidirov A M, Mirzokulov Kh B and Urinov Zh O. 2019 Scientific Bulletin of Samarkand State University 3 41-6
[11] Urinov Kh O, Salakhtdinov A N and Mirzokulov Kh B 2018 New in magnetism and magnetic materials XXIII International Conference (Moscow) pp 593-5