THE ELECTRICAL PROPERTIES OF THIN NICKEL FILMS AT LOW TEMPERATURES

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The electrical properties of thin nickel films of very high purity, obtained by thermal evaporation in a vacuum inside a vessel kept in a helium bath during the deposition, have been investigated. Films with thicknesses from 30 A and upwards had a residual resistivity and Hall e.m.f. of the order of magnitude close to that of bulk nickel specimens.

A considerable number of papers have been devoted to the study of ferromagnetic films. However, the features of the magnetic properties of films obtained in a vacuum of the order of 10^{-5}—10^{-6} mm Hg, found by several authors[1,2] are, as shown by the later investigations of Neugebauer,[3] related to a considerable extent to the effect of contamination by the residual gas on deposition and to the oxidation of the film on bringing it into the atmosphere. In particular, it was shown in Neugebauer's work that the saturation magnetization of thin nickel films, deposited in a vacuum of 10^{-9} mm Hg is independent of thickness down to a thickness of about 30 A.

The present investigation was carried out with the aim of finding out to what extent the electrical and galvanomagnetic properties of films with thicknesses down to 30 A, deposited in a vessel immersed in a liquid helium bath, differ from the corresponding properties of bulk specimens.

The films were obtained by thermal evaporation of nickel. Figure 1 shows the general appearance of the evaporation apparatus. A tungsten wire serves as evaporator. After the preparation of the evaporator (cleaning, degassing and preconditioning in a vacuum of 10^{-7} mm Hg) the substrate was sealed into the vessel and a second degassing of the whole apparatus was carried out in the same vacuum. A beaker, optically polished to 0.1 interference fringe, was used as substrate. Four platinum leads were sealed into the ends of the beaker. Current and Hall contacts were deposited onto the substrate by cathode sputtering. During deposition of a film the apparatus was in a helium bath. The residual gasses, other than helium, were thus frozen out. The pressure in the apparatus before evaporation started, calculated from the amount of helium in the atmosphere, was of the order of 10^{-13} mm Hg. The amount of metal deposited was controlled by measuring the electrical resistance during the process of deposition.

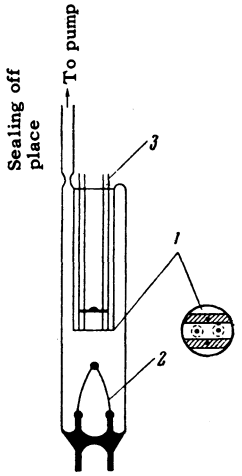

FIG. 1. Apparatus for deposition of the films: 1 – substrate with deposited platinum contacts, 2 – evaporator, 3 – platinum electrodes.

The temperature dependence of the electrical resistance was studied for films of thickness from 1300 down to 30 A at temperatures from 2 to 300°K. In the temperature range 4.2 to 40°K the temperature was measured with a constantan resistance thermometer, and above 40°K by a copper-constantan thermocouple. The thickness of the films was determined by an interferrometric method, using a universal monochromator of the UM-2 type*.

Figure 2 shows curves indicating the change of electrical resistance of the films studied, on heating newly condensed films from 4.2 to 300°K and on cooling to the original temperature (4.2°K) after holding at 300°K. Further heating produces no further changes in the form of curves 3 and 4. Calculation showed that the specific electrical resistivity for films of all the thicknesses mentioned above is close to the specific resistivity of bulk nickel. Destruction of the vacuum (taking the films into the air after keeping them for three months in the vessel) led to a rapid and sharp increase in

*The authors are grateful to Yu. Durasova for measuring the film thickness.

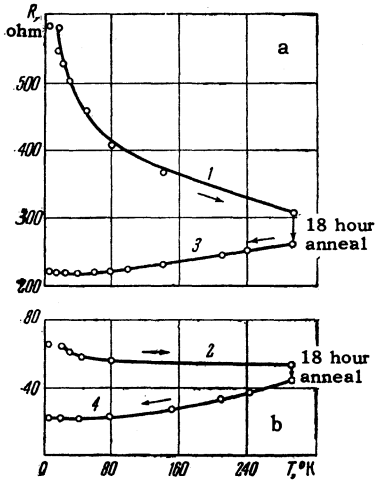

FIG. 2. a – the change of electrical resistivity of a freshly deposited film on heating from 4.2°K to room temperature: b – the change of electrical resistivity of a film on cooling it from room temperature to 4.2°K after holding at room temperature for 18 hours: curve 1 – for d = 50 A, curve 2 – for d = 135 A, curve 3 – for d = 50 A, curve 4 – for d = 135 A.

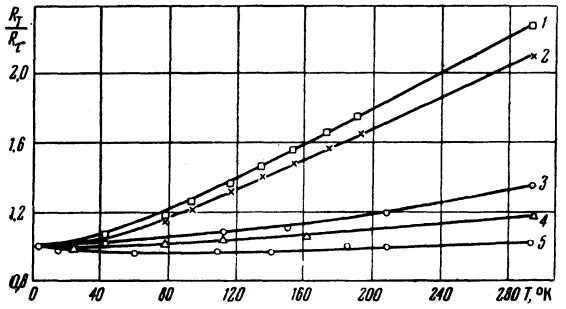

FIG. 3. The dependence of R_T/R_τ on temperature for films of different thickness: curve 1 – d = 1300 A; curve 2 – d = 835 A; curve 3 – d = 135 A; curve 4 – d = 75 A; curve 5 – d = 30 A.

electrical resistance: the resistance of thick films increased 1.5—2 fold, and of thin films several tens of times.

Figure 3 shows curves of the dependence of R_T/R_τ on temperature for heated films of various thicknesses. Here R_T is the resistance of a film at temperature T and R_τ is the resistance at helium temperature. The thinner the film the smaller is the relative change of resistance on increasing the temperature. For films of thickness 1300 A the value of $R_\tau/R_0 = 0.4$, where R_0 is the resistance at room temperature. For a 30 A thick film $R_\tau/R_0 = 0.95$. In addition, the curves show that the boundary of the residual resistance region is shifted to higher temperatures for thin films.

Figure 4 shows curves of the dependence of the specific resistivity on film thickness for temperatures of 300 and 4.2°K. It can be seen that the resistivity at 300°K of films with thicknesses from 1300 to 300 or 400 A is independent of thickness and does not increase significantly with decreasing thickness for thin films of thickness from 300 to 30 A. An increase of resistivity with decreasing thickness is already observed at 4.2°K for films of thickness less than 900 A. The resistivity decreases 2—2.5 fold on going from room temperature to helium temperature for thick films

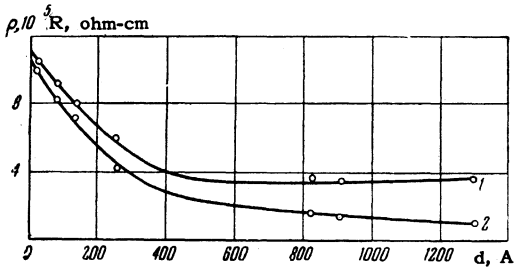

FIG. 4. The dependence of electrical resistivity on film thickness for temperatures: curve 1 – 300°K and curve 2 – 4.2°K.

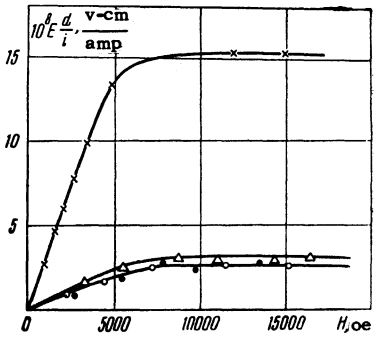

FIG. 5. The dependence of the Hall field for films of different thickness on the strength of the applied magnetic field: x – d = 50 A, Δ – d = 835 A, o – d = 1000 A, • – d = 1300 A.

(d > 1000 A) and decreases by only 4—5% for thin films (d < 100 A).

We also studied the Hall effect in the films we obtained. The dependence of the Hall field on the magnetic field H, perpendicular to the plane of the film, is shown in the curves of Fig. 5. The Hall field was measured at room temperature. It corresponds approximately to the bulk specimen value for thicknesses of 1300 – 835 A, but increases on going to 50-A films, evidently connected with the increase in resistivity of such a film.

Preliminary calculations show that the behavior of the resistivity and its temperature dependence for thin films less than 300—400 A thick, must be related to the fact that the electron mean free path in these films becomes comparable with the film thickness.

In conclusion the authors express their deep thanks to A. I. Shal'nikov for valuable advice and great help in the carrying out of this work.

[1] Colombani, Coureaux, and Huet, Colloque international de Magnetisme, July, 1958, Centre National de la recherche Scientifique, Paris, 1959, p. 239.

[2] N. I. Ginzburg and A. M. Polyakov, ZhTF **28**, 1029 (1958), Soviet Phys. Tech. Phys. **3**, 957 (1958).

[3] C. A. Neugebauer, Structure and Properties of Thin Films, ed. Neugebauer, Newkirk and Vermilyea, New York 1959, p. 358.

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