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THE APPEARANCE OF UNIAXIAL ANISOTROPY

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Abstract

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PHYSICS

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THE APPEARANCE OF UNIAXIAL ANISOTROPY IN STRONGLY DEFORMED NICKEL AFTER THERMOMAGNETIC TREATMENT

(Presented by Academician S. V. Vonsovskii, October 21, 1966)

1. It is known that thin metallic films possess a number of physical properties different from those of bulk materials. One of the most important such properties of ferromagnetic films is uniaxial magnetic anisotropy, obtained when they are deposited (or annealed) in a magnetic field ([1]); moreover, in contrast to bulk ferromagnets, this anisotropy can also be obtained in one-component films of iron, nickel, or cobalt (whereas in bulk ferromagnets annealing in a magnetic field—thermomagnetic treatment—is effective only in alloys) ([2]). Such a difference between one-component films and bulk ferromagnetic metals with respect to annealing in a magnetic field is apparently connected with a difference in their crystalline structure. The structure of films differs from that of bulk metals primarily in a very fine crystalline grain, as well as in a high density of dislocations and a high content of vacancies ([3]). A fine grain, comparable in magnitude with intergrain boundaries, can lead to magnetic uniaxiality owing to shape anisotropy ([4]). Dislocations and vacancies can also lead to the appearance of uniaxial anisotropy, for example by the Néel mechanism ([5]).

It follows from the foregoing that if it were possible to bring the structure of a bulk ferromagnetic metal closer to the structure of a film, then the possibility might arise of creating magnetic uniaxiality in it by annealing in a magnetic field. In the present work an attempt was made to bring the structure of pure nickel closer to the structure of a film by means of strong plastic deformation and to obtain in it uniaxial magnetic anisotropy by annealing in a magnetic field. It is known that under strong plastic deformation the grains of a metal are broken up into blocks several hundred angstroms in size ([6]), i.e., down to the grain size characteristic of films. The dislocation density in this case can be brought up to 10^{11} per 1 cm^2 (see, for example, ([6])). The same dislocation density has also been observed in films ([7]). The number of vacancies under plastic deformation also increases, although it cannot reach as large a value as in films. It could

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Fig. 1

Figure 1: Fig. 1

quite well be expected that in such a strongly deformed material annealing in a magnetic field would prove effective.

2. The study was carried out on nickel foil 15μ thick, prepared by rolling, with 99% reduction, an ingot obtained from electrolytic nickel that had first been remelted in vacuum. The principal method for determining the anisotropy induced in nickel during annealing in a field was measurement of the curves of mechanical rotating torque. The specimens were disks 5 mm in diameter. In order to reduce the influence of the rolling anisotropy of the specimen and thereby facilitate the detection of the resulting small uniaxial anisotropy, the disks were arranged-

were stacked arbitrarily in a pile of 20–30 specimens and glued together with silicate glue. Most of the treatments in the magnetic field and the measurements were carried out on such stacks of specimens. A few experiments were also carried out on individual disks.

The experiment was carried out as follows. The specimen was mounted in a torque magnetometer, and then the initial curve of torques was recorded. After this the specimen was annealed in the apparatus under the required conditions in a magnetic field of 6000 Oe, and the torque curve was recorded again at room temperature. The difference between the curve obtained as a result of annealing and the initial rotation curves characterizes the effect produced by annealing in the magnetic field. This procedure, in which remounting of the specimen is not required, considerably increases the accuracy of the measurements and makes it possible to detect a rather weak effect produced by the field.

Fig. 1

3. The principal results of the study are given in Fig. 1. Curve **A** represents the difference between the torque curve obtained after one hour of annealing of the specimen at 100° in a field of 6000 Oe, oriented in an arbitrary direction in the plane of the disks (this direction is taken below as the origin for measuring angles and is denoted by $\theta = 0°$), and the initial curve. From curve **A** it is seen that the difference is a curve close to a sinusoid with a period of 180°. This means that, as a result of thermomagnetic treatment at 100° for 1 hour, an additional uniaxial anisotropy appeared in the specimen. As is seen from curve **A**, the axis of easy magnetization is close to the direction of the field during annealing (this direction is indicated by an arrow on all the curves). The value of the uniaxial-anisotropy constant is $1.5 \cdot 10^3$ erg $\cdot$ cm^{-3}. After this, repeated annealing was carried out at 100° for one hour; the magnetic field in this case was applied at an angle $\theta = 90°$, i.e., perpendicular to the direction of the field during the first annealing. The difference of the torque curves obtained in this case

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is represented by curve **B**. It is seen that uniaxial anisotropy was induced in the specimen with an easy-magnetization axis located at an angle θ close to 90°. Curves **V** and **G** represent the result of subsequent one-hour annealings at 100°; the magnetic field was applied, respectively, at angles 0 and 90°. It is seen that the direction of easy magnetization follows the direction of the field during annealing.

Similar experiments were also carried out on single disks. They qualitatively confirm the results obtained on the stack of disks. Quantitative conclusions from experiments on individual disks are difficult to make because of the low sensitivity of the anisometer used and the large rolling anisotropy of the disks. On individual disks, using a vibrating magnetometer, the angular dependence of the residual magnetization and hysteresis loops were measured in the initial state and after annealing in a magnetic field that led to the appearance of uniaxial anisotropy. No noticeable difference in the angular dependence or in the hysteresis loops recorded before and after thermomagnetic treatment was found. Such a result was to be expected, since the influence of a small uniaxial anisotropy on the magnetic properties is masked by the strong influence of the natural anisotropy of nickel and by large, chaotically distributed internal stresses.

Annealing in a magnetic field was also carried out on specimens at higher temperatures—200, 250, and 300°. At a temperature of 200° a weak uniaxiality first appears, but it is then masked by a stronger anisotropy of a nonuniaxial type. At temperatures of 250–300°, the change that occurs in the torque curves immediately has a more complex, nonuniaxial character. Apparently, at temperatures of 200° and above, a partial change occurs in the existing rolling texture, which masks the appearance of uniaxial anisotropy.

For the question under investigation it was essential to carry out analogous thermomagnetic treatments of recrystallized specimens, possessing large grains and a significantly smaller number of dislocations and point defects. In such specimens uniaxial anisotropy should not appear. The thermomagnetic treatment we carried out on such specimens (preliminarily annealed for 3 hours at 650°) at 100, 200, and 300° showed that in them uniaxial anisotropy either does not appear, or appears so weakly that it cannot be distinguished against the background of measurement errors.

4. Thus, in the present work it has been established that in strongly deformed nickel (compression of the order of 99%), annealing in a magnetic field of 6000 Oe at 100° leads to the appearance of an additional uniaxial anisotropy of the order of 10^3 erg $\cdot$ cm^{-3}. The direction of the easy magnetization axis in the specimen follows the direction of the field during annealing. In recrystallized specimens such anisotropy is either absent or very small. At present it is not possible to give an unambiguous explanation of the mechanism of this effect. However, it is clear that it is closely connected with the reduction of the crystalline grain during plastic deformation, and also with the appearance of a large number of disloca-

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tions and point defects. Apparently, an analogous mechanism is also at work in the case of thin films: annealing in a magnetic field is effective only in fine-grained films, whereas in coarse-crystalline films this effect disappears.

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Note: Figure translations are in progress. See original paper for figures.

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