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THE INFLUENCE OF THE SUBSTRATE HEAT TREATMENT ON THE MAGNETIC PROPERTIES OF THIN ELECTRODEPOSITED PERMALLOY FILMS

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This paper is a study of the influence of the heat tratment of the substrate on the coercive force of thin electrodeposited permalloy films. The study of the surface of both substrate and film as well as measurements of the coercive force show that the size of the substrate grain has no influence on the coercive force of the sample, provided that no epitaxial growth is present. The roughness of the surface of the substrate, increasing with the increase of the grain size, has a remarkable influence on the value of the coercive force.

I. INTRODUCTION

From among many factors which may influence to a great extent the magnetic properties of thin films, an important role belongs to the structure and surface properties of the substrate on which the thin film is deposited. The evaluation of the influence of the various methods of the substrate treatment and of the influence of the mechanisms of interaction between substrate and film may be found in many papers. Our work deals with the study of the influence of the substrate heat treatment — especially with respect to the changes of substrate graininess due to this treatment — on the coercive force of thin electrodeposited permalloy films.

When the epitaxial growth of the film onto the substrate takes place, then the structure and the properties of the film may be remarkably influenced by the structure of the substrate. It was found already by Reimer [1], that the graininess and the coercive force of thin nickel films deposited onto the copper substrates can be influenced by changing the graininess of the substrate during its preparation. This influence could be explained by the oriented

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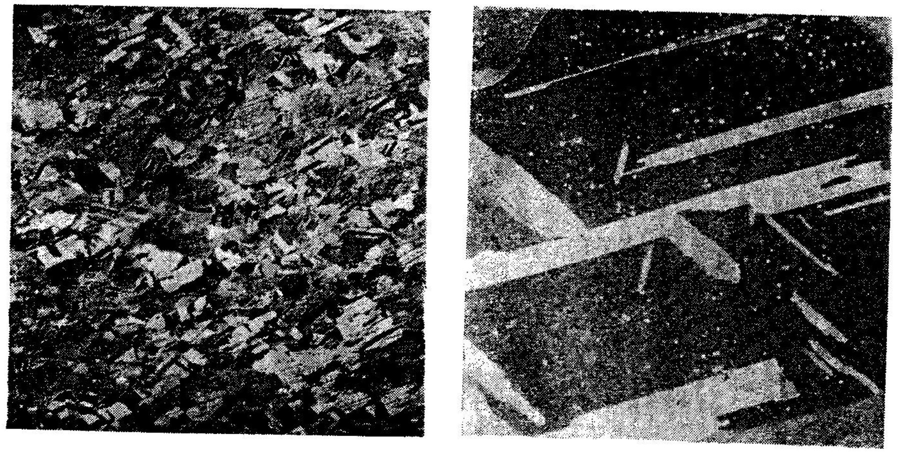

Fig. 1a, 1b. The influence of the annealing temperature on the size of the copper substrate grains. a) Annealing temperature 600 °C. Magnification 60×. b) Annealing temperature 1000 °C. Magnification 60×.

growth of the film crystallites onto the substrate, taking into account that the value of the lattice constant of the copper substrate is close to that of nickel.

II. EXPERIMENTAL RESULTS AND THEIR EVALUATION

The permalloy films of various thickness and composed of 80 % Ni and 20 % Fe were electrodeposited onto the polycrystalline copper substrate, prepared from the rolled sheet and treated in various ways. The films ranged in thickness from 0.06 μm to 0.6 μm, but most measurements were performed on films 2000 Å thick. Various sizes of copper substrate grains — ranging from 50 μm to 1 mm — were obtained by vacuum annealing of the substrate in the temperature range between 400 °C and 1000 °C. All substrates were metallographically polished before annealing under the same conditions. The structural changes in the substrate, caused by the heat treatment, were observed by means of the scanning electron microscope JSM-U3. It is evident from Figs. 1a, 1b that with the change of the annealing temperature an apparent change of the grain size takes place.

The annealing was followed by the chamical polishing of samples with various graininess, performed again under equal conditions. Onto the thus prepared substrates the permalloy films of various tkickness were electrodeposited. The structure of films was observed by means of the electron microscope JSM-U3.

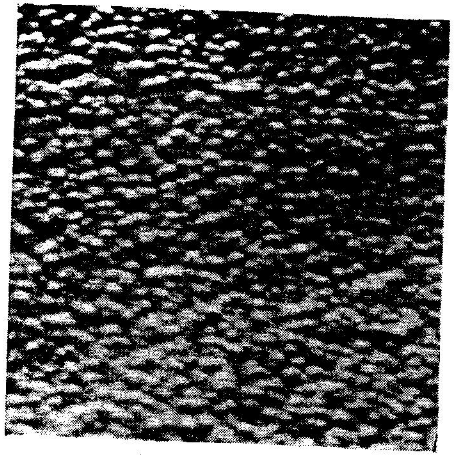

Fig. 2. The surface structure of the thin permalloy film electrodeposited onto the copper substrate. Magnification 20000×.

One of the typical structures is shown in Fig. 2. It is characteristic that the size of the granules seen on the film surface is the same for all samples, irrespective of the substrate grain size. Coarser grains of the film can be seen only sporadically — in places where the film fills in the local misroscopic defects on the surface of the copper substrates.

The dependence of the coercive force upon the particular temperature of annealing was investigated on the thus prepared samples. Measurements were carried out on films of various thickness (in the range from 600 to 6000 Å) and they showed unambigously that the coercive force of the sample was independent of the substrate grain size (Fig. 3a).

Let us evaluate this result with respect to the method of substrate preparation. With the increasing annealing temperature — which is accompanied with the growth of the substrate grains — an evaporation of some relatively weak bonded copper atoms gradually takes place. To such an evaporation are subjected above all the atoms along the grain boundaries, but also some atoms on the grain surface. A so-called vacuum etching of the substrate takes place, which is clearly seen in Fig. 4, showing the substrate annealed at 900 °C. The orientation of the etching patterns differs in various grains, but is the same within one grain. Such and similar etching patterns began to appear from the annealing temperature of about 800 °C upwards. A relatively small change of the annealing temperature above this temperature not only caused the grain size to change, but influenced also the surface relief of the substrate. In our experiments the relatively uniform quality of the surface of the substrate was obtained by polishing it chemically before the film was deposited. During the electrodeposition of the film there were the same conditions — consistent with the mechanism of crystallization [2] — for the formation of

crystal nuclei over the whole surface of the substrate from the energetical point of view. The film becomes essentially uniformly fine-grained, whereby also the observed constancy of the coercive force may be explained.

These facts indicate that in the process of the film formation no oriented

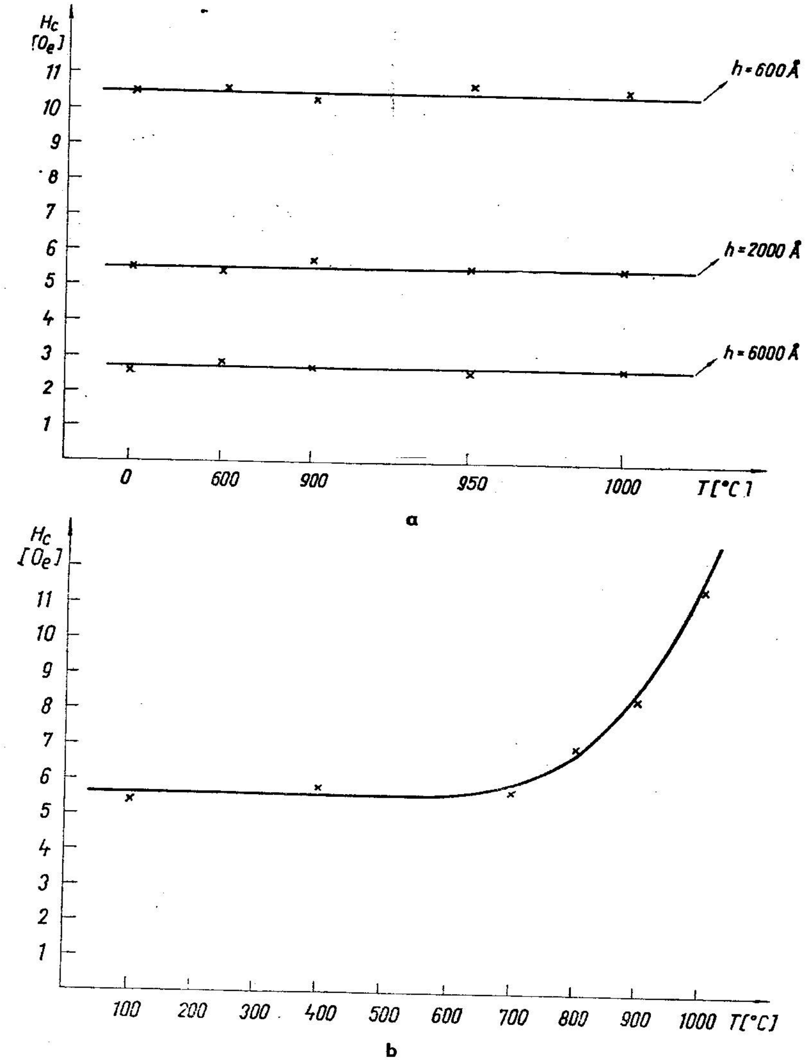

Fig. 3a, 3b. The dependence of the coercive force of the PY 80 film (2000 Å thick) upon the annealing temperature. a) Annealed and chemically polished substrate. b) Annealed, but chemically non-polished substrate.

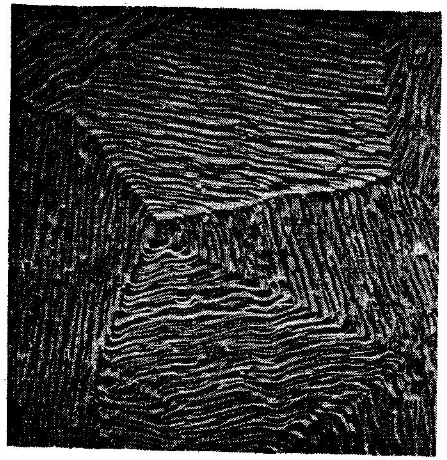

Fig. 4. The surface structure of the copper substrate, annealed at 900 °C. Magnification 100×.

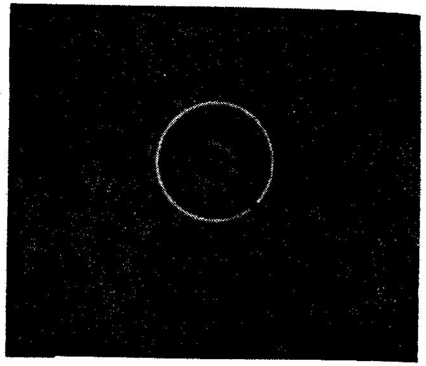

Fig. 5. Diffractogram of the PY 80 film, obtained by means of the transmission electron microscope JEM-7.

growth of its grains onto the substrate takes place, which was confirmed also by the obtained diffractograms. A transmission electron microscope JEM-7 was used for obtaining the diffractograms from various points of the film, separed from the substrate. The separation of the film was accomplished in a 1 : 3.3 solution of hydrogen peroxide in ammonia.

The dimensions of the studied regions of the film, from which the diffraction patterns were obtained, were substantially smaller than those of the substrate grains, onto which the particular film regions grow. Fig. 5 shows one of the obtained diffractograms, on which the continuous and uniformly intensive maxima appear, which confirms the pollycrystalline character of the observed film. A point diffractogram would be expected in the case of the epitaxial growth of the film.

It can be expected — consistently with these results — that the influence of the substrate heat treatment on the coercive force of the film is essentially realized by means of a vacuum etching of the substrate. To verify this, we used the same method of substrate preparation as previously, with the exception of the film having been deposited directly onto the annealed substrate, without having been chemically polished before the electrodeposition. The coercive force does not remain constant in the whole range of the annealing temperatures. Up to the temperatures of 700—800 °C it does not change yet, even when the substrate grains gradually grow. Above this temperature an apparent etching of the surface of the substrate begins to take place, the surface becomes rougher and the coercive force increases Fig. 3b. This result

is in good agreement with the conclusions of a number of papers, dealing with the influence of the substrate roughness on its coercive force [3, 4].

The results of the present work confirm that the heat treatment of the substrate has an influence on the coercive force of electrodeposited thin magnetic films. The roughness of the surface, caused by a vacuum etching of the substrate, is essentially responsible for these changes. The substrate grain size has no influence — provided the epitaxial growth is not present.

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REFERENCES

[1] Reimer L., Z. Naturf., *11a* (1956), 649.
[2] Kocich J., *Povrchové úpravy kovov.* ALFA Bratislava, 1971.
[3] Wiehl H. E., Z. angew. Phys., *18* (1965), 516.
[4] Prosen R. J., Gran B. E., Kivel J., J. Appl. Phys., *34*, (1963), 1147.

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