

SUPERCONDUCTING TRANSITION TEMPERATURE AND STRUCTURE OF MOLYBDENUM FILMS DOPED WITH CARBON

V.M. Golyanov, A.P. Demidov, M.N. Mikheeva, and A.A. Teplov

Submitted 1 February 1972

ZhETF Pis. Red. 15, No. 7, 365 - 367 (5 April 1972)

Condensation of Mo on a substrate cooled with liquid helium revealed [1] a considerable rise in the superconducting transition temperature ($T_c = 4 - 6.7^\circ\text{K}$ as against 0.92°K for bulky Mo). A rise of T_c to 6.5°K was also observed in films prepared by simultaneous sputtering of Mo and SiO_2 , and the plot of T_c against the SiO_2 concentration had a minimum. A similar effect produced by Y (in place of SiO_2) was noted in [2], where it was proposed in [2] that the cause of the change of T_c is the observed decrease of the grain dimension with increasing impurity content.

We investigated the properties of films of molybdenum doped with carbon. The samples were prepared by cathode sputtering in Kr at $\sim 10^{-5}$ Torr [3 - 5]. The partial pressure of all the residual gases except hydrogen did not exceed 10^{-10} Torr, and the partial pressure of hydrogen was $\sim 2 \times 10^{-9}$ Torr.

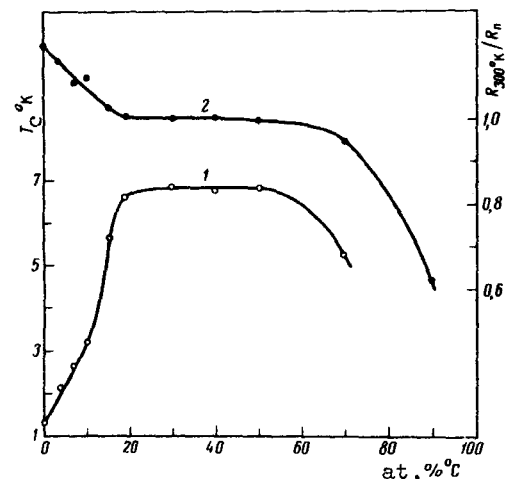
The films were deposited on glass substrates with platinum leads. The substrates were at liquid nitrogen temperature.

The samples were prepared by layer-by-layer sputtering of alternating monatomic layers of molybdenum and the fractions of monatomic carbon layers required to obtain the required concentration. The sputtering rates were ~ 7 Å/min and ~ 2 Å/min for molybdenum and carbon, respectively.

We measured the sample resistance as a function of the temperature. T_c was defined as the temperature at which $R = R_n/2$, where R_n is the sample resistance in the normal state. The transition width was usually $0.2 - 0.3^\circ\text{K}$. The plot of the sample critical temperature against the carbon concentration had a gently sloping maximum. The figure shows such a curve for a film ~ 60 Å thick. The maximum of T_c lies in the concentration range $20 - 50$ at.% C, at which value the critical temperature reaches $6.9 \pm 0.1^\circ\text{K}$.

A similar plot of T_c against the carbon concentration was observed for samples prepared by sputtering mosaic cathodes. The Mo and C were then scattered simultaneously, and the compositions of the samples were determined by the geometry of the cathodes.

The results depend little on the film thickness at thicknesses above 50 Å. The thickness dependence of the critical



Critical temperature (curve 1) and resistance ratio $R(300^\circ\text{K})/R_n$ (curve 2) of Mo-C samples vs. the carbon concentration.

temperature was investigated in detail at a concentration 16 at.% C. In this case, to prevent oxidation, the film was coated with a carbon layer 20 Å thick. At film thicknesses 50 - 120 Å the critical temperature depends little on thickness. The rapid decrease of T_c , which is apparently connected with thermodynamic fluctuations which appear on going to the two-dimensional case, begins at thicknesses lower than 30 Å. All the data that follow are for films 60 Å thick.

The sample resistance increases with increasing carbon concentration. The resistance ratio $R(300^\circ\text{K})/R_n$ (where $R(300^\circ\text{K})$ is the resistance at room temperature and R_n the resistance immediately after going over the normal state) decreases with increasing carbon concentration, from 1.2 for pure molybdenum to 0.95 for 70 at.% C. The sample containing 90 at.% C did not become superconducting down to 1.5°K and had $R(300^\circ\text{K})/R(1.5^\circ\text{K}) = 0.6$. It should be noted that samples with $R(300^\circ\text{K})/R_n > 1$ correspond to the points lying to the left of the maximum of the T_c (at.% C) curve, whereas the points to the right of the maximum correspond to samples with $R(300^\circ\text{K})/R_n < 1$.

Electron-microscope and electron-diffraction investigations of the samples in transmission have shown that the pure Mo crystallizes under experimental conditions in the form of a polycrystalline material having a grain of ~ 70 Å and gives a sharply defined diffraction pattern corresponding to diffraction by bulky Mo. When Mo is doped with carbon, a gradual broadening of the diffraction maxima is observed with increasing carbon content, as well as an increase in the lattice parameter, thus indicating that internal stresses are produced in the material. The electron-diffraction patterns revealed no additional diffraction maxima, thus demonstrating the absence of carbides. Doped Mo samples containing up to ~ 20 at.% C have the same grain as pure Mo. When the carbon content rises above ~ 30 at.% the grain decreases to ~ 10 Å. Both electron-microscope and electron-diffraction investigations have shown that the structure of samples prepared by alternately sputtering layers of Mo and C is the same as that of samples prepared by simultaneous condensation of Mo and C.

A comparison of our results with those of [2] shows that in these experiments the form of the impurity added to Mo has little influence on the dependence of T_c on the impurity content. Taking account, in addition, of the data on T_c of films sputtered at liquid-helium temperature [1], we can regard as quite likely the conclusion that the main cause of the rise of T_c in these cases is the distortion of the molybdenum crystal lattice. No correlation was observed in our case between the change of T_c and the grain dimension in the carbon concentration region where the critical temperature increases.

The authors are grateful to N.A. Chernoplekov and B.N. Samoilov for interest in the work and I.A. Kubarev for help in improving the apparatus for sample preparation.

- [1] J.E. Crow, M. Strongin, R.S. Thompson, and O.F. Kammerer, Phys. Lett. 30A, 161 (1969).
- [2] J.J. Hanak, J. Gittleman, J. Pellicane, and S. Bozowsky, Phys. Lett. 30A, 201 (1969).
- [3] V.M. Golyanov, Investigations of Objects that Change During the Course of Preparation and Observation in an Electron Microscope. Proceedings of Symposium, May, 1964 (in Russian), Nauka, 1966, pp. 50 and 81.
- [4] V.M. Golyanov, Author's Certificate (Patent) 179573, Byull. izobret. No. 5, 1966.

[5] V.M. Golyanov, A.P. Demidov, M.N. Mikheeva, and A.A. Teplov, Zh. Eksp. Teor. Fiz. 58, 528 (1970) [Sov. Phys.-JETP 31, 283 (1970)].

THERMOGRAPHIC RECORDING ON A MANGANESE-PERMALLOY FILM WITH EXCHANGE ANISOTROPY

A.A. Glazer, A.P. Potapov, and R.I. Tagirov
 Institute of Metal Physics, USSR Academy of Sciences
 Submitted 9 February 1972
 ZhETF Pis. Red. 15, No. 7, 368 - 370 (5 April 1972)

1. Much attention is being paid of late to research on thermomagnetic information recording. This method consists of heating a local section of a ferromagnet in a magnetic field for a short time. This reverses the magnetization of the heated section, which is subsequently the only depository of the information. The thermomagnetic method of recording and the magnetic materials on which such recording is possible are promising objects for the construction of permanent memories for electronic computers.

Several modifications of thermomagnetic recording are known at present, viz., recording by heating to the Curie point, recording on a material having a sharp temperature drop of the coercivity, recording on gadolinium iron garnet at the condensation point, the thermostriction method, and recording on films with stripe domains [1].

We propose here the use of a new physical phenomenon for thermomagnetic recording, using a two-layer manganese-permalloy film as an example. The phenomenon in question is exchange (or unidirectional) anisotropy due to exchange interaction between the ferro- and antiferromagnetic regions.

2. Manganese-permalloy films with exchange anisotropy [2] are made up of ferromagnetic and antiferromagnetic layers. Owing to the exchange interaction between the layers, such films have a hysteresis loop that is shifted along the field axis. It was shown in [3, 4] that even the minute details of the domain structure can be made permanent by the exchange interaction with the antiferromagnet. This phenomenon can be used for thermomagnetic recording.

Let us examine the recording mechanism by using the scheme of Fig. 1. Figure 1a shows a film with exchange anisotropy in the initial state. The upper layer is ferromagnetic and the lower antiferromagnetic. Thermomagnetic recording is effected by applying to the film a magnetic field that magnetizes in a direction opposite to that of the easy magnetization. A small section of the film is then heated above the Neel point of the antiferromagnetic layer. This state is illustrated in Fig. 1b. The entire ferromagnetic layer is magnetized in the direction of the external field. Within the limits of the heated section (bounded by dashed lines), the magnetization of the ferromagnetic layer is decreased somewhat, but is still high (since the Curie point is higher than the Neel point). In the antiferromagnetic layer, on the other hand, this section has become paramagnetic.

During the time of cooling in the magnetic field, the heated section of the lower layer becomes antiferromagnetic. This transition is influenced by the exchange interaction with the ferromagnetic layer above it. As a result, the spin system of the

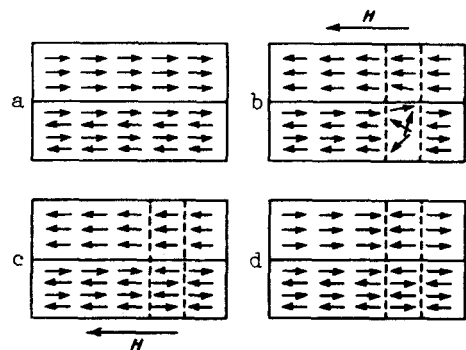


Fig. 1. Diagram explaining the mechanism of thermomagnetic recording on a film with exchange anisotropy.