объединенный
институт
ядерных
исследований
дубна

E3-91-330

L.P.Chernenko, D.A.Korneev, A.V.Petrenko,
N.I.Balalykin, A.V.Skripnik

MEASUREMENT OF MAGNETIC FIELD PENETRATION DEPTH IN NIOBIUM POLYCRYSTALLINE FILMS BY POLARIZED NEUTRON REFLECTION METHOD

Submitted to the Proceedings of the
IInd International Conference on Surface X-ray
and Neutron Scattering, Bad Honnef, Germany,
June 25-28, 1991

1991

As shown in the literature [1], the specular polarized neutron reflection may be used as a direct method of measuring the absolute value of the magnetic field penetration depth of a superconductor (s.p.d.). However, the s.p.d. as determined by measuring the direct current in Josephson junctions in a weak magnetic field [2] has given a value in niobium films (91 nm, T=4.6K) which is well over than that obtained by polarized neutron reflection [1] (43 nm, T=4.6K). The present experiment was started to throw light on causes of this difference.

We carried out experiments on two niobium films of various thickness and roughness prepared with the same sputtering technique . The experiments have been conducted on the spectrometer of polarized neutrons (SPN) in a reflectometry mode [3] at the IBR-2 reactor. Two measurements have been carried out sequentially. At room temperature the specular reflection spectra were measured to obtain neutron-optical parameters (thickness, roughness) of films. Then we carried out the measurements once more at T=4.9 K in the field of 500 Oe. Before the measurements were performed , the reflectometer was turned to the grazing angle θ=4.0 mrad with $\Delta\theta/\theta$=0.025. For data handling we used the new method of calculation of the reflection factor described in [4]. The method consists of replacing the continuous one-dimensional neutron-optical potential of the film with the discrete series of Fermi quasi--potentials to model the reflection of plane waves from inhomogeneous media. Unlike the traditional approach [1] , we took roughness into by introducing in the calculation of the reflectivity increasing amplitudes of Fermi potentials. These were distributed according to the Gaussian error curvewith dispersion equal to the roughness parameter (σ) square. Actually the results of the two techniques are in excellent agreement for pure nuclear potentials. The two methods to evaluate roughness become different only when both nuclear and magnetic potentials are present [4].

In view of the geometric arrangement of the sputtering apparatus, the "thin" film of 28mmx50mm (sputtered on a silicon plate) had a graded thickness with an average value of 255(+/-15) nm, σ=0.5 nm. The "thick" film - 700 nm in thickness - was obtained by slanted sputtering on the ceramic substrate (95% Al_2O_3), σ=8 nm. The critical temperature for both films was 8.95K. Since a decrease of the critical temperature of niobium films is expected at a film thickness lower than 200 nm the samples seemed satisfactory. This was confirmed by the analysis of the composition of initial material for niobium sputtering, and the films themselves, using the neutron activation analysis. The analysis does not reveal noticeable amounts of impurities in the films.

To analyse the experimental data we used the diamagnetic profile of a superconducting film according to London's local electrodynamics of superconductors. An extra ingredient of the model was the assumption of the existence of some "dead" layer in niobium close to a substrate, which at T=4.9 K does not pass to a superconducting state.

The figure shows the relation of reflection factors of neutrons with opposite polarization (flipping ratio) depending on a normal component of a neutron wave length. If the model does not consider the "dead" layer on the boundary with a sublayer, the experimental spectra are described by theoretical curves (see fig.) at the value of s.p.d. equal to 145(+/-15) nm for a "thin" film, and 90 (+/-10) nm for a "thick" one, respectively. The value of a s.p.d. equal to 43 nm [1] describes our data adequately only for a "thin" film in a model with a "dead" layer 100 nm in thickness.

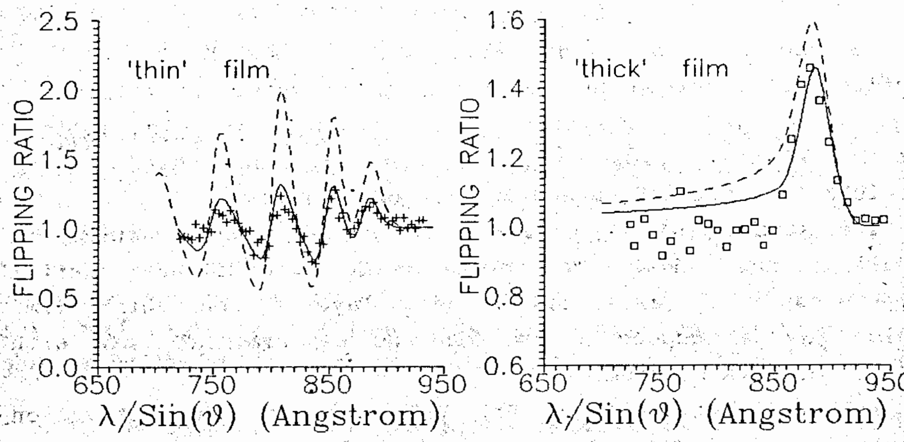

Figure. Experimental values of the flipping ratio: crosses are for the film 255 nm in thickness; squares are for the film 700 nm in thickness. Lines correspond to theoretical calculations considering the corrections for polarization and resolution of the reflectometer. Dashed lines are for the s.p.d. of 50 nm.

The analysis of systematic factors leading to a possible shift of s.p.d. has shown that the obtained values at T=4.9 K of 145 nm and 90 nm are the low values of s.p.d. for the thin films investigated. We believe that the hypothesis of a "dead" layer 100 nm in thickness, bringing the value of s.p.d. to that of 43 nm (T=4.9 K) is not well based for two reasons. Firstly, the analysis of the depth composition of a film by backward scattering of accelerated ions of helium with an energy from 3.0 Mev to 3.2 Mev has shown that there is neither oxygen nor other impurities across the whole width of the thin film. Secondly, the films 100 nm in thickness at T=4.9 K are superconducting.

Conclusions

We conclude that our measurement of s.p.d. by neutron reflectometry method on the niobium polycrystalline films gave the s.p.d. that is different from the s.p.d. in bulk niobium. At T=4.9K the s.p.d. for the "thin" film and that for the "thick" film are 145 nm and 90 nm, respectively.

The studies of the film contents by neutron activation analysis and backward scattering of He ions did not confirm hypothesis of the existence of "dead" layer in the "thin" film, which was introduced to explain the experimental data with s.p.d. of bulk niobium.

Authors wish to thank Dr. V.Nazarov for the activation analysis of samples. Thanks are due to Dr. A.Kobzev and Dr. D.Shirokov for backward scattering spectrometery.

[1] G.P.Felcher, R.T.Kampwirth, K.E.Gray and R.Felici, Phys.Rev.Lett.,52,1539(1984).

[2] M.Russa, J.Low Temp. Phys.,50,301(1983).

[3] V.V.Pasyuk, D.A.Korneev, A.V.Petrenko and E.B.Dokukin, "Neutron reflectivity studies on superconducting, magnetic and absorbing thin films on the polarized neutron spectrometer at the pulsed reactor IBR-2", preprint JINR E3-91-276.

[4] D.A.Korneev and L.P.Chernenko, JINR Rapid Communication 4[30]-88 and Poverhnost'. Fizika, himija, mehanika. 9,61(1990) (in russian)

Received by Publishing Department
on July 22, 1991.

Черненко Л.П. и др. E3-91-330
Измерение глубины проникновения магнитного поля
в ниобиевые поликристаллические пленки методом
отражения поляризованных нейтронов

Приводятся величины глубин проникновения магнитного поля в сверхпроводник (г.п.), измеренные для "тонкой" (255 нм) и "толстой" (700 нм) ниобиевых пленок. Полученные в наших экспериментах при T = 4.9 K величины г.п. равны 145(+/–15) нм для "тонкой" пленки и 90(+/–10) нм для "толстой" пленки. Это существенно отличается от полученного для массивного ниобия (43 нм при T = 4.6 K, см. G.P.Felcher et al., Phys.Rev.Lett., 52, 1539 (1984)). Эксперименты выполнены на спектрометре поляризованных нейтронов СПН на реакторе ИБР-2 в Дубне.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1991

Chernenko L.P. et al. E3-91-330
Measurement of Magnetic Field Penetration Depth
in Niobium Polycrystalline Films by Polarized Neutron Reflection Method

The values of the superconducting penetration depth (s.p.d.) measured on "thin" (255 nm) and "thick" (700 nm) niobium films are presented. The obtained values of s.p.d. in our experiments at T = 4.9 K are 145(+/–15) nm for a "thin" film, and 90(+/–10) nm for a "thick" film. It is essentially different from that one for bulk niobium (43 nm at T = 4.6 K after G.P.Felcher et al., Phys.Rev.Lett., 52, 1539 (1984)). The experiment has been carried out on the polarized neutron spectrometer SPN at the IBR-2 reactor in Dubna.

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1991