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SUPERCONDUCTING AND TRANSPORT PROPERTIES OF NbTi LAYERED METALS†

J.Q. Zheng and J.B. Ketterson

Department of Physics and Astronomy and Materials Research Center
Northwestern University, Evanston, Illinois 60201

Charles M. Falco and Ivan K. Schuller

Argonne National Laboratory, Argonne, Illinois 60439

We report data on the superconducting transition temperature and room temperature resistivity of layered NbTi for thicknesses in the range 7 - 70 Å.

I. Introduction

Layered metals have recently attracted considerable attention due to the possibility of fabricating new materials with unusual, tunable physical properties (e.g. mechanical[1], magnetic[2], or superconducting[3]). We report measurements on the superconducting transition temperature and electrical resistivity for the NbTi system.

Equal layer thickness (7-70Å) Nb/Ti specimens (∿2μ total thicnkess) were prepared on 90° sapphire substrates using a sputtering technique described earlier.[4] The composition wavelengths (i.e. 2 x layer thickness) are obtained from the positions of the x-ray satellites (up to third order) associated with the Bragg peaks using a standard θ-2θ diffractometer scan about the substrate plane normal.[5] Nb (bcc) and Ti (hcp) deposit in a (110) and (0001) texture respectively. The interplane spacing of Nb (110) is 2.334Å; for Ti the (0001) hcp spacing is 2.342Å and the metastable (110) bcc spacing is 2.355Å. Thus a θ-2θ diffractometer scan about the normal to the substrate provides insufficient information to uniquely characterize the structure in the Ti rich regions of a given layer. To obtain further information, transmission Laue photographs were taken on a sample which was stripped off the sapphire substrate; it showed the presence of several rings. The observation of rings rather than spots implies the presence of a texture rather than epitaxy with the grain size of the crystallites small on the scale the x-ray beam diameter (∿.020"). Three of these rings correspond to the (211), (310) and (011) (and equivalent) planes of the bcc structure with a (110) plane normal. A fourth ring could not be indexed with a plane of the bcc or hcp structures assuming (110) or (0001) plane normals respectively (the diffractometer scan showing the presence of no other textures). This ring does index with a (111) plane of the fcc structure assuming a (111) plane normal. A diffractometer scan with the film rotated to place the other (111) plane normal to the θ-2θ scan axis yielded a plane spacing consistent with a fcc structure having the same interatomic distance (2.342Å) as the Ti hcp structure. Since it is well known[6] that many of the bcc transition metals adopt fcc structures in thin films we presumably have some fcc Ti. A diffractometer scan with the film rotated such that the (011) plane of the hcp structure was normal to the scan axis showed the presence of a small amount of hcp Ti. In summary the structural study indicates that most of the Ti is in the bcc phase.

Transition Temperature Measurements

Superconducting transition temperature measurements were performed on all samples using an ac mutual inductance bridge with the oscillating field applied parallel to the film. In addition the transition was studied resistively in four samples. Fig. 1 shows the observed transition temperatures for the samples having

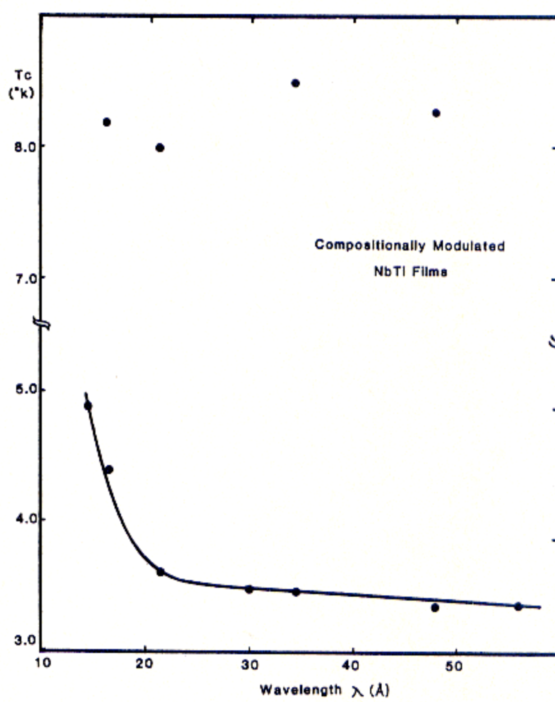

FIGURE 1 The dependence of the observed superconducting transition on composition wavelength; the dominant transition occurs at the lower temperature.

having wavelengths between 14 and 140Å. The dominant transition is that occuring at the lower temperature. However a weaker transition (at least four times smaller) was observed at a higher temperature of about 8.3°K in some samples. The fact that this transition does not correlate with the wavelength, and is relatively weak, suggests that it may be due to a small amount of phase separated Nb. The lowering of the dominant transition temperature relative to Nb can be understood as proximity effect averaging between Nb and Ti. The transition temperature of pure as deposited Nb in our sputtering unit is 8.9-9.2°K (vs. 9.2 K in bulk); similar films of Ti were not superconducting down to 1.9°K. A transition temperature of ∿3.5 K in the modulated structures for wavelengths larger than 20Å implies that either

1) The majority of the Ti is not in the bcc structure, because if this phase were dominant one would expect at large wavelengths a temperature intermediate between 9.2 K, the T_c of bcc Nb, and 4.0K (bcc Ti), or
2) T_c of bcc Ti and Nb are supressed relative to the bulk values. Evidence for this possibility comes from a proximity effect study of the NbCu LUCS system.[3]

At very low λ(∿20Å) we find an increase in T_c, possibly due to intermixing at the interfaces of the two materials.

Resistivity Measurements

The wavelength dependence of the resistivity was studied in detail at room temperature; this data is shown in Fig. 2 where we plot the resistivity as a function of the reciprocal of the wavelength. Depending on the wavelength, the data corresponds to three separate regimes. For very long wavelengths the effective resistivity arises from bulk slabs of Nb and Ti in parallel. The poing at $\frac{1}{\lambda} = 0$ is the computed value for the parallel resistivity determined from measurements on as deposited Nb and Ti films in our sputtering system. As λ^{-1} increases a transition to a region where the mean free path is dominated by λ is found. Based on experience in other systems, considerable scattering is expected at the Nb/Ti interface, especially if the stacking sequence is other than bcc/bcc. This leads[7] to a linear dependence of ρ as a function of λ of the form $\rho = \rho_0 + A/\lambda$. The value of the intercept $\rho_0 = 80\mu\Omega$ cm is identical to that for a uniform alloy of Nb Ti; if the stacking sequence is fcc/bcc this agreement would be fortuitous. For wavelengths shorter than 30Å the resistivity saturates at a value of about 115μΩ cm. Maximum 3D resistivities of this order have been observed in other systems[8] in accordance with ideas advanced by Ioffe and Regel.[9]

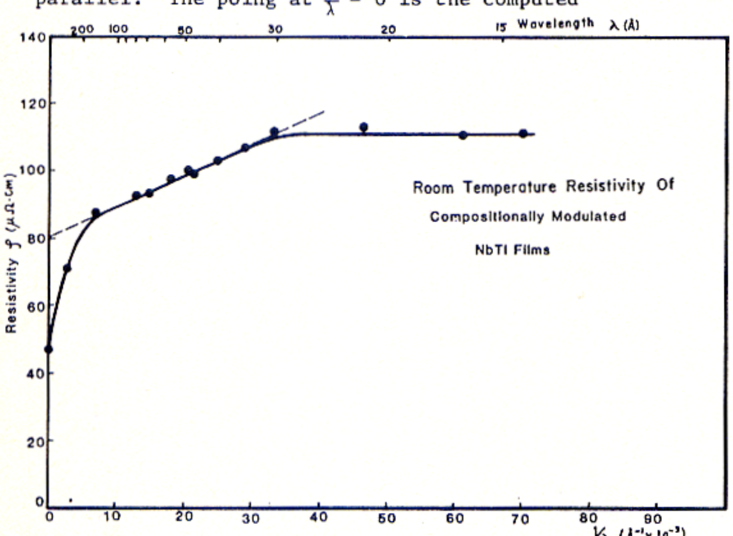

FIGURE 2 The dependence of the room temperature resistivity on composition wavelength.

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