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Superconducting characteristics in purified tantalum-foils

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ABSTRACT

We have conducted extensive investigations on the electrical transport and magnetization on a purified tantalum foil with extremely sharp resistive transition (transition width $\Delta T_c < 0.02$ K) at 0 T and residual resistivity ratio $\rho_{290K}/\rho_{5K} = 16.75$. Many effects, such as anisotropic field–induced resistive broadening and second peak of the magnetization-hysteresis loop, are observed in the sample. The maximum upper critical field determined by criteria of $R/R_n = 0.9$ is about 1.08 T rather weak compared to that in cuprate and/or iron-based superconductors. Although the value of upper critical field $H_{c2}(0)$ and the field dependence of effective pinning energy U show that the flux pinning potential is weaker, the critical current density $J_c(2\text{ K}, 0\text{ T}) = 1.145 \times 10^5$ A/cm^2 and the effect of second peak indicate that there should be higher collective vortex pinning potential in the tantalum foil. The carriers are dominated by holes with the density $n = 6.6 \times 10^{22}$/cm^3.

1. Introduction

Investigation of high temperature superconductivity has achieved tremendous progress since the discovery of cuprate superconductors in 1986. Besides the determination of the phase diagram and pairing symmetry of high-Tc superconductors, a large number of novel physical phenomena, including the pseudogap effect, charge-spin separation, linear resistivity and strong superconducting phase fluctuation, have been discovered. Meanwhile, many new concepts and phenomena of vortex physics, such as collective vortex creep, vortex glass, vortex melting, the second-peak effect of magnetization, etc., have been proposed or discovered [1]. However, up to now, the mechanism of high-temperature superconductivity remains a mystery. Although developing new measurement technology with new quantum many-body theory and computational method is very important to understand a number of anomalous quantum phenomena observed in cuprate superconductors, we think that to re-measure the superconducting materials with simple structure is also a way to solve these problems in the existing framework of quantum many-body theory. Therefore, we would like to investigate the superconducting characteristics of high purity tantalum-foil.

Tantalum exists in two crystalline phases, α-Ta and β-Ta. The α-Ta has body-centered cubic (BBC) structure (space group Im3m, lattice constant a = 0.33058 nm). The β-Ta is tetragonal (space group P42/mnm, a = 1.0194 nm, c = 0.5313 nm). Bulk tantalum is almost entirely alpha phase [2], and the beta phase usually exists as thin films [3]. The superconducting transition of tantalum metal was firstly reported by Meissner in 1930 [4]. The quoted values for tantalum single crystal were the critical temperature $T_{c0} = 4.50$ K, the critical field $H_c(0) = 83.5$ mT, the electronic specific heat coefficient $\gamma = 6.22$ mJmole^{-1}K^{-2}, the Ginzburg–Landau parameter $K_0 = 0.314$, the coherence length $\xi(0) = 95$ nm, and the penetration depth $\lambda(0) = 31$ nm [5]. The Fermi surface of this 5d element is similar to its 4d counterpart, Nb, and the phonon spectra of Ta and Nb are similar. This makes at least approximately transferable to Ta a rather extensive body of calculation relating to electron-phonon coupling and other superconducting properties. However, the critical field was enhanced up to several Tesla in thin films [6]. Goodman [7] approximately gave the value of Ginzburg–Landau parameter K in the impure material by

$$K = K_0 + 7.53\rho_0\gamma^{1/2}, \qquad (1)$$

where ρ_0 is the residual resistivity in μΩcm and γ the electronic specific heat constant in erg/cm^3 deg^2. The residual resistivity may be approximated as 13.6R^{-1} μΩcm where R^{-1} is the resistance ratio (resistance at room temperature to resistance just above the transition temperature). K is expected to increase as the temperature is decreased.

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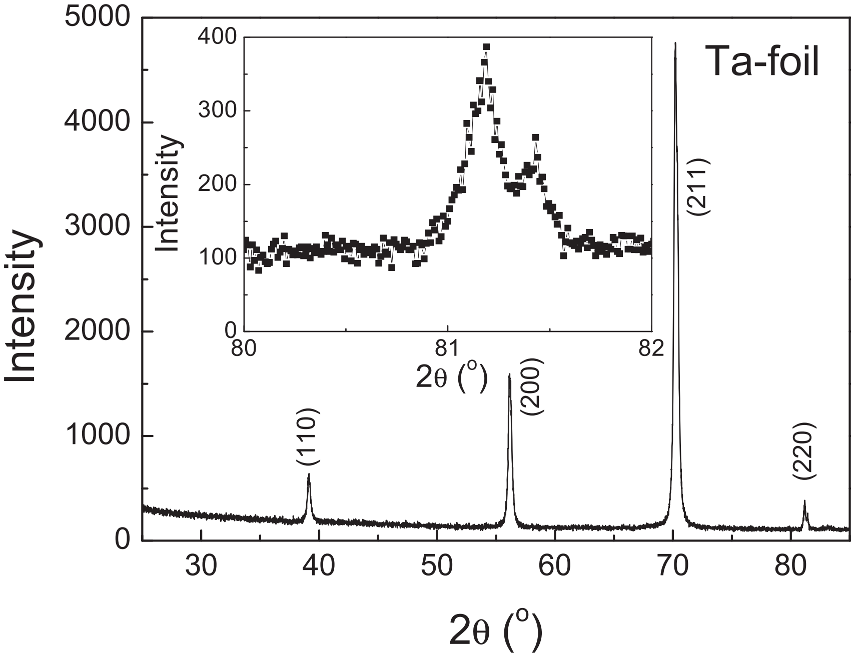

Fig. 1. X-ray diffraction patterns of the purified tantalum foil. Inset: Enlarged peak for (220).

Thus, specimens with R^{-1} less than 25 may be expected to exhibit type II behavior at all temperatures. In this paper, we have measured the properties of electrical transport and magnetization on a purified tantalum foil. The results indicate that the tantalum foil is typical type II superconductor with typical effects observed in cuprate and/or iron-based superconductors.

2. Experimental

Tantalum foil with purity 99.95% obtained from the Haoyi Metal Materials CO., LTD, China. The thickness of tantalum foil is about 0.02 mm. The lattice structure of the sample was characterized by x-ray diffraction (XRD) at room temperature with a Bruck-D8-type

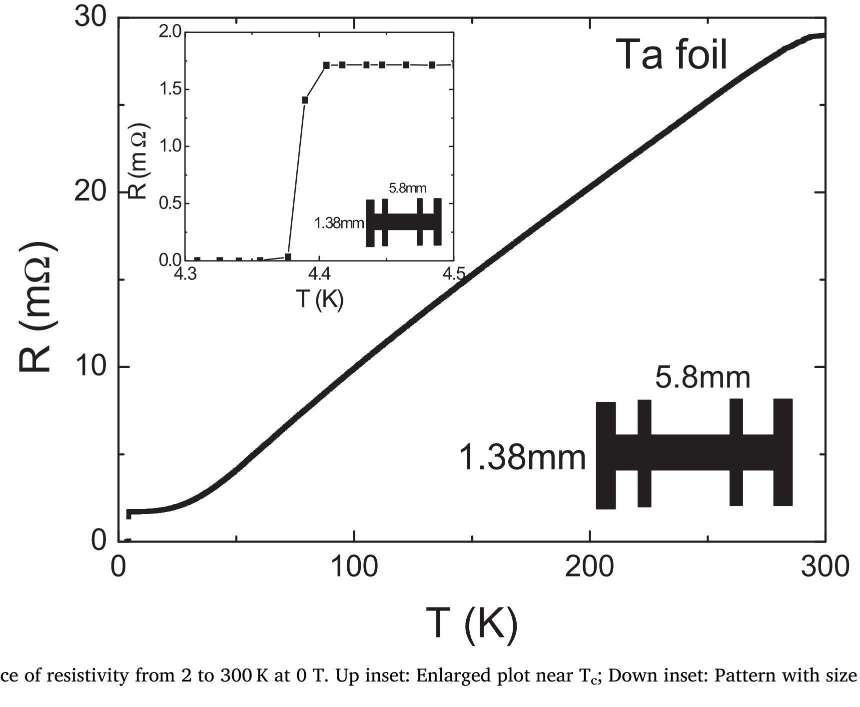

Fig. 2. Temperature dependence of resistivity from 2 to 300 K at 0 T. Up inset: Enlarged plot near T_c; Down inset: Pattern with size of sample used in the transport measurement.

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