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Superconductivity in Nb_2InC

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ABSTRACT

In this work the Nb_2InC phase is investigated by X-ray diffraction, heat capacity, magnetic and resistivity measurements. Polycrystalline samples with Nb_2InC nominal compositions were prepared by solid state reaction. X-ray powder patterns suggest that all peaks can be indexed with the hexagonal phase of Cr_2AlC prototype. The electrical resistance as a function of temperature for Nb_2InC shows superconducting behavior below 7.5 K. The $M(H)$ data show typical type-II superconductivity with $H_{C1} \sim 90$ Oe at 1.8 K. The specific heat data are consistent with bulk superconductivity. The Sommerfeld constant is estimated as $\gamma \sim 12.6$ mJ mol^{-1} K^{-1}.

1. Introduction

The so-called $M_{n+1}AX_n$ phases (MAX), where M is a transition metal, A an A-group element and X is C or N, were synthesized via conventional solid state reaction by Nowotny and co-workers in the 1960s [1]. The crystal structure of these compounds is reported to be hexagonal with space group $P6_3/mmc$ and can be described as layers of M_2X intercalated with A-group elements [2]. The weakness of the bonding through the A-layer coupled with relatively strong transition-metal carbide layers underline potential application due to their mechanical, electrical and thermal properties [1–8]. In addition, these compounds have surprisingly high electrical and thermal conductivities. Thus, some of these phases have been the focus of recent work. Only three articles have dealt with superconductivity in these materials [9–11]. Recently our group has contributed to discovery of superconductivity in these materials [12,13]. The Nb_2InC phase was first synthesized by Jeitschko et al. [14] but few results have been reported about this compound. This work reports the first observation of superconductivity in the Nb_2InC with $T_C = 7.5$ K.

2. Experimental procedure

The samples were prepared using mixtures of graphite, Nb and In powders of high purity in the stoichiometric combination Nb_2InC. The powders were compacted in square form of 10×10 mm^2 and 2 mm in thickness, sealed in a quartz ampoule, and placed in a tube furnace at 1000 °C for 48 h. After this treatment, the samples were ground and homogenized in an agate mortar, pressed again with same dimensions as before, and sintered at 1000 °C further for 120 h. After this sintering procedure, all samples were characterized by X-ray diffraction in a XRD-6000 Shimadzu, using Ni filter and Cu K_α radiation. The electrical transport properties were carried out by the conventional four probe method as a function of the temperature between 2.0 K and 220 K, in an Oxford Instruments MagLab EXA-9T. Magnetization measurements were performed in a 7 T VSM-SQUID magnetometer from Quantum Design. Specific heat data were collected in a Quantum Design PPMS-12 instrument using the thermal relaxation method at zero magnetic field.

3. Discussion

The crystal structure of Nb_2InC heat-treated at 1000 °C for 120 h was determined by X-ray powder diffraction displayed in Fig. 1. The peaks position are well indexed in the hexagonal unit cell with Cr_2AlC prototype. There are some peaks which can be indexed as metallic indium. The calculated lattice parameters are $a = 3.172$ Å and $c = 14.37$ Å, these results are consistent with the data reported by Jeitschko et al. [14]. In order to study the transport properties of the Nb_2InC samples the electrical resistivity as a function of temperature was measured. The $\rho(T)$ curve is shown in Fig. 2 where

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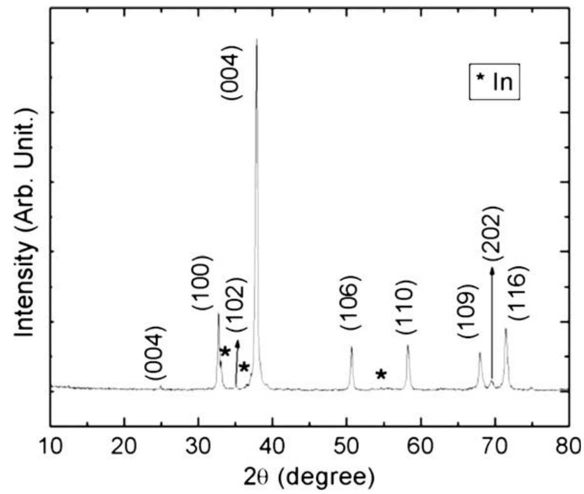

Fig. 1. Diffractogram of the Nb_2InC sample heat treat at 1000 °C. Peaks were indexed by using a hexagonal symmetry Cr_2AlC prototype. Traces of In metallic were found.

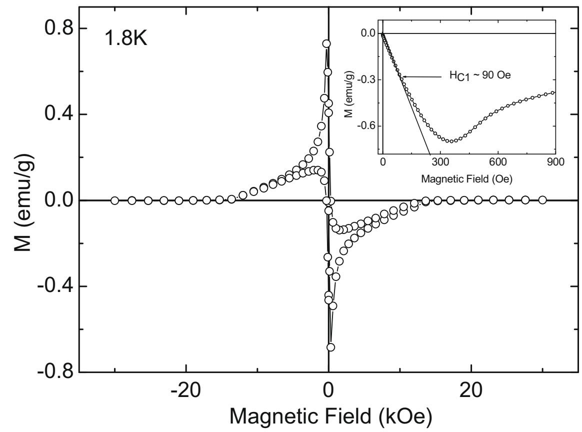

Fig. 3. Magnetization as a function of applied magnetic field measure at 1.8 K shows a typical type-II superconductivity. H_{C1} is estimated through linear regime at 1.8 K has 350 Oe. The linear regime leads to an estimated superconducting volume fraction of approximately 23% which suggests bulk superconductivity.

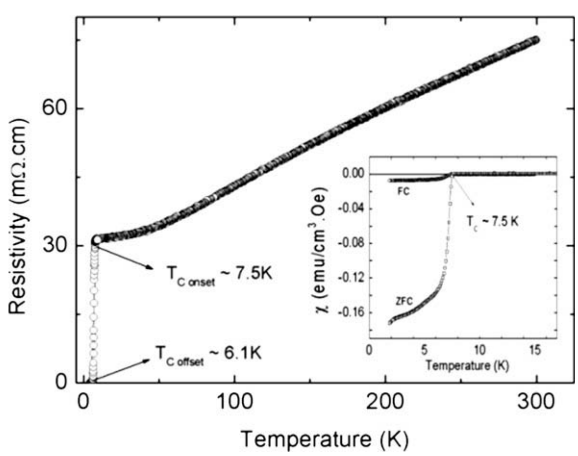

Fig. 2. The electrical resistance as a function of temperature from 4.2 K to 300 K for the Nb_2InC sample. It is a clear superconductor behavior below to 7.5 K. In the inset susceptibility measurements in the zero-field cooling (ZFC) and field cooling (FC) mode are shown. The figure shows a clear diamagnetism behavior bellow 7.5 K corroborating with the resistivity measurement.

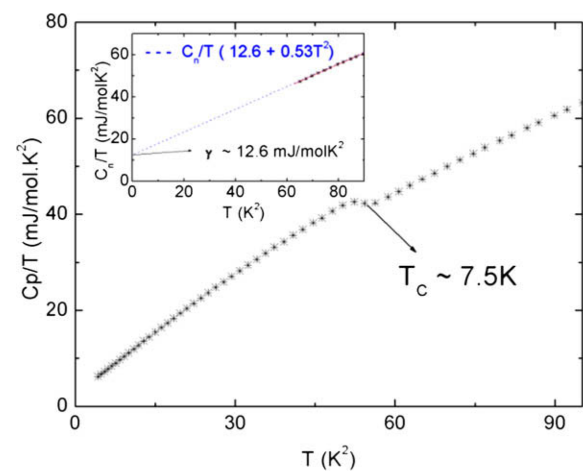

Fig. 4. Cp/T versus T^2 for zero applied magnetic fields is displayed. A peak at 7.5 K can be seen which is in agreement with T_C observed in transport properties and susceptibility measurements. The extrapolation of the linear behavior from 7.5 K down to zero temperature yields an electronic specific heat coefficient $\gamma = 12.6$ mJ mol^{-1} K^{-2}.

it is possible to observe a transition temperature close to 7.5 K (onset temperature). Furthermore a careful inspection of the data in Fig. 2 indicates a linear behavior to $R(T)$ above superconducting transition. The normal state has metallic behavior from 4.2 K to 300 K. Susceptibility measurement corroborates the superconductivity (inset Fig. 2). This figure shows the superconducting transition close to 7.5 K in both zero-field cooling (ZFC) and field cooling (FC) magnetic susceptibility measurements. $M(H)$ data also show clearly that Nb_2InC is a type-II superconductor (Fig. 3). H_{C1} at 1.8 K was 90 Oe estimated from the linear regime in the $M(H)$ curve, which implies a Ginzburg–Landau superconducting penetration depth λ_{GL} of approximately 0.271 μm. From the linear regime in the $M(H)$ curve we estimated the superconducting volume which it is approximately 33%. The specific heat (Cp) is shown in Fig. 4. As expected, the specific heat data in zero field show an anomaly at $T_C = 7.5$ K which is close to the T_C determined by resistivity and susceptibility measurements. The normal-state specific heat measured at $\mu_0H = 0$ T is fitted to $Cp = \gamma T + \beta T^3$, where the first, and second terms represent the electronic and the lattice contributions, respectively. The linear fit to these data gives: $\gamma \sim 12.6$ mJ mol^{-1} K^{-2} and $\beta \sim 0.54$ mJ mol^{-1} K^{-4}. These values are higher than in the isostructural materials Nb_2SnC ($\gamma = 3.15$ mJ mol^{-1} K^{-2}), Ti_4AlN_3 ($\gamma = 8.12$ mJ mol^{-1} K^{-2}), and Ti_3SiC_2 ($\gamma = 5.21$ mJ mol^{-1} K^{-2}) [15–17]. The Debye model connects the β coefficient and Debye temperature (Θ_D) through [18]

$$\Theta_D = \left(\frac{12\pi^4}{5\beta_m} nR\right)^{\frac{1}{3}}$$

where $R = 8.314$ J mol^{-1} K^{-1}, $\beta_m = 4\beta$, and $n = 4$ for Nb_2InC. With this data it is possible to estimate $\Theta_D \sim 154$ K. With this value the electron–phonon coupling constant (λ_{ep}) can be estimated from McMillian's relation [19]

$$\lambda_{ep} = \frac{1.04 + \mu^* \ln\left(\frac{\Theta_D}{1.45T_C}\right)}{(1 - 0.62\mu^*)\ln\left(\frac{\Theta_D}{1.45T_C}\right) - 1.04}$$

where $\mu*$ is a Coulomb repulsion constant. A typical value for μ^* is 0.10. Taking $\mu*$ in the range 0.05–0.2, we find $\lambda_{ep} \sim 0.8$–1.2, which implies that Nb_2InC is a moderately strong coupled superconductor.

These results show unambiguously a new superconductor belonging to MAX phase which has not been previously reported.

4. Conclusions

Specific heat, resistivity and magnetic experiments performed on polycrystalline samples have been used to characterize Nb_2InC compound. This work reveals that the Nb_2InC compound superconducts at 7.5 K. The magnetization as a function of temperature corroborates the resistivity measurement showing diamagnetism below 7.5 K. The $M(H)$ data shows typical type-II superconductivity with a lower critical field of approximately 90 Oe at 1.8 K. Specific heat (Cp) measurements reveal bulk superconductivity. Furthermore, the γ value obtained through specific heat measurement agrees with other materials belonging to the MAX materials class. Finally these results show a new interstitial superconductor which crystallizes in the Cr_2AlC prototype.

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