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Superconductivity in Nb$_2$InC

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**Abstract**

In this work the Nb$_2$InC phase is investigated by X-ray diffraction, heat capacity, magnetic and resistivity measurements. Polycrystalline samples with Nb$_2$InC 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$_2$AlC prototype. The electrical resistance as a function of temperature for Nb$_2$InC shows superconducting behavior below 7.5 K. The $M(H)$ data show typical type-II superconductivity with $H_C1 = 90$ 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$^{-1}$.

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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$_2$X 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$_2$InC 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$_2$InC 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$_2$InC. The powders were compacted in square form of 10 x 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 Kα 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$_2$InC heat-treated at 1000 °C for 120 h was determined by X-ray diffraction, heat capacity, magnetic and resistivity measurements. Polycrystalline samples with Nb$_2$InC 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$_2$AlC prototype. The electrical resistance as a function of temperature for Nb$_2$InC shows superconducting behavior below 7.5 K. The $M(H)$ data show typical type-II superconductivity with $H_C1 = 90$ 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$^{-1}$. The peaks position are well indexed in the hexagonal unit cell with $a = 3.172$ 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$_2$InC samples the electrical resistivity as a function of temperature was measured. The $\rho(T)$ curve is shown in Fig. 2 where
it is possible to observe a transition temperature close to 7.5 K (on-set 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 a clear diamagnetism behavior bellow 7.5 K corroborating with the resistivity measurement.

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$\gamma = 12.6 \text{ mJ mol}^{-1} \text{K}^{-2}$ and $\beta = 0.54 \text{ mJ mol}^{-1} \text{K}^{-4}$. These values are higher than in the isostructural materials Nb$_2$SnC ($\gamma = 3.15 \text{ mJ mol}^{-1} \text{K}^{-2}$), Ti$_2$AlN$_3$ ($\gamma = 8.12 \text{ mJ mol}^{-1} \text{K}^{-2}$), and Ti$_3$SiC$_2$ ($\gamma = 5.21 \text{ mJ mol}^{-1} \text{K}^{-2}$) [15–17]. The Debye model connects the $\beta$ coefficient and Debye temperature ($\Theta_D$) through [18]

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

where $R = 8.314 \text{ J mol}^{-1} \text{K}^{-1}$, $\beta_m = 4\beta$, and $n = 4$ for Nb$_2$InC. With this data it is possible to estimate $\Theta_D \sim 154 \text{ K}$. With this value the electron–phonon coupling constant ($\lambda_{ep}$) can be estimated from McMillian’s relation [19]

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

where $\mu^*$ is a Coulomb repulsion constant. A typical value for $\mu^*$ 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$_2$InC 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 Nb2InC compound. This work reveals that the Nb2InC 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 ($C_p$) measurements reveal bulk superconductivity. Furthermore, the $\gamma$ 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 Cr2AlC prototype.

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References