

Superconductivity in $\text{Y}_2\text{PdGe}_{3-x}\text{Si}_x$: interplay between Debye temperature and coupling constant

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Abstract

We have studied $\text{Y}_2\text{PdGe}_{3-x}\text{Si}_x$ superconductor using magnetization and specific heat measurements. The compounds are very sensitive to changes in the honeycomb layers by Si substitution. The critical temperature shows a maximum of $T_c = 3.55\text{K}$ near $x=0.3$ and decreases with further increase in Si concentration. The changes in the Debye frequency and electron-phonon coupling have combined effect to control the critical temperature.

Key words: germanide superconductors; critical temperature ; magnetisation; specific heat;

1. Introduction

The discovery of MgB_2 has created tremendous impact on the investigation of the systems having AlB_2 -like structures [1]. The origin of the higher critical temperature in a noncuprate high- T_c superconductor is not properly explained so far. Boron atoms forming honeycomb lattice play an important role in the origin of the superconductivity of the hexagonal compound. Any superconductor isostructural to MgB_2 may be important to explain the role of the graphaite-like honeycomb layers responsible for the origin of superconductivity. Y_2PdGe_3 is a superconductor with AlB_2 structure having Pd and Ge in the honeycomb site of the crystal with equal probability [2]. If any of these elements are replaced partially by some other lighter elements, then the condition of the pairing will be affected which in turn affects various superconducting properties. We have substituted Si for Ge to investigate the impact of the lighter element in the the honeycomb layers. $\text{Y}_2\text{PdGe}_{3-x}\text{Si}_x$ with different x has been studied by the magnetization and specific heat measurements. Variation of T_c with Si substitution is discussed based on the McMillan formula [3].

2. Experimental

The synthesis of the various $\text{Y}_2\text{PdGe}_{3-x}\text{Si}_x$ compounds is done by arc-melting method in Ar environment followed by annealing in evacuated quartz tubes at 850°C for one week. All the samples with $x=0$ to 3 are characterised by X-ray diffraction and found to be almost single-phase. Magnetization of the samples are measured as a function of temperature using SQUID magnetometer at a magnetic field of 2 Oe. The specific heat is measured by PPMS using heat relaxation method.

3. Results and discussions

The lattice constants extracted from the X-ray diffraction data are plotted in the inset of Fig. 1. Beyond $x=2.5$ (not shown) the changes in lattice parameters with x becomes weaker. The variation of T_c with x determined by the onset of diamagnetism is shown in Fig. 1 which reveals that T_c increases with x at lower concentration and then decreases with the further increase in x . T_c in $\text{Y}_2\text{PdGe}_{3-x}\text{Si}_x$ is lower than 1.8K above $x=1.5$. Therefore, T_c is not a monotonic function of lattice constants as in $\text{AGa}_x\text{Si}_{2-x}$ ($\text{A}=\text{Ca}$,

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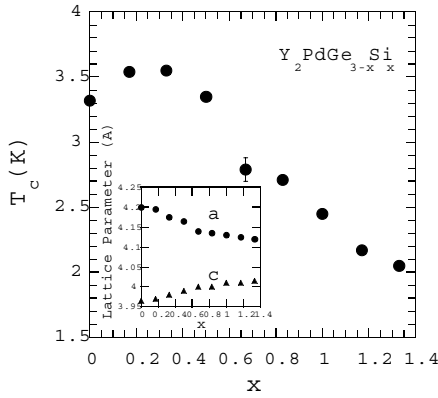


Fig. 1. Variation of critical temperature with x . Inset shows the changes of lattice parameters with x .

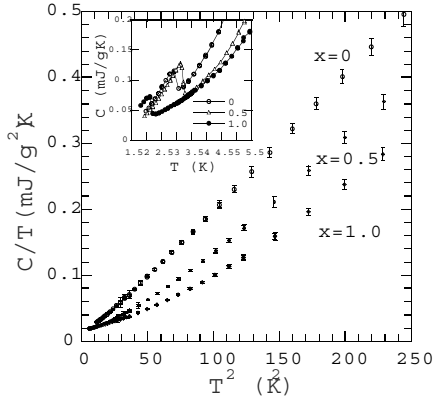


Fig. 2. C/T versus T^2 of $Y_2PdGe_{3-x}Si_x$ with $x=0, 0.5$, and 1.0 . Inset shows the transition region of C as a function of temperature.

Sr, Ba) [4] and shows a maximum near $x = 0.3$. In order to shed light in this characteristics of T_c we have investigated the specific heat (C) of several samples. Specific heat of three compounds with $x=0, 0.5$, and 1.0 as a function of temperature is shown in the inset of Fig. 2. The critical temperatures are 3.1 K, 3.3 K, and 2.24 K for $x=0, 0.5$, and 1.0 , respectively, which is consistent with Fig. 1. The Debye temperature (Θ_D) of the samples are extracted from the variation of C/T with T^2 for three samples as shown in Fig. 2. We have found that Θ_D are 127K, 151K and 177K for $x=0, 0.5$ and 1.0 , respectively within the temperature range below 10 K. The Sommerfeld constants are 1.35 mJ/Y mole K^2 , 1.58 mJ/Y mole K^2 and 2.91 mJ/Y mole K^2 for $x=0, 0.5$ and 1.0 , respectively. The variation of T_c with Si concentration is related to the change in the Debye temperature and electron-phonon coupling constant λ . According to the McMillan equation, λ is extracted as follows.

$$\lambda = \frac{1.04 + \mu^* \ln(\Theta_D/1.45T_c)}{(1 - 0.62\mu^*) \ln(\Theta_D/1.45T_c) - 1.04} \quad (1)$$

Using the above expression and the Coulomb coupling constant, $\mu^* = 0.10$ we have extracted the electron-phonon coupling constant $\lambda=0.66, 0.63$ and 0.53 for the samples with $x=0, 0.5$ and 1.0 , respectively. Therefore, the critical temperature is controlled by Θ_D in the lower concentration whereas the electron-phonon coupling strength decreases with the higher Si concentration. In Y_2PdGe_3 , the band structure calculation shows that Y 4d electrons are the origin of pairing [5]. Therefore, the bond related to Y site, equivalent to Mg site in MgB_2 , is responsible unlike in MgB_2 . However, the present study clearly reveals that the replacement of Ge by Si strongly affects the superconducting properties.

4. Conclusions

The critical temperature of $Y_2PdGe_{3-x}Si_x$ has a bell-shaped dependence on the silicon concentration. The lattice parameter a decreases and c increases with x . The Debye temperature and the electron-phonon coupling constant increases and decreases respectively with Si concentration. In $Y_2PdGe_{3-x}Si_x$ superconductor the variation in the critical temperature is a combined effect of the change in the Debye temperature and the electron-phonon coupling due to the changes in graphite-like honeycomb layers.

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