Impact of Ni doping on critical parameters of PdTe superconductor

Reena Goyal1,2, Rajveer Jha1, Brajesh Tiwari3, Ambesh Dixit4 and V P S Awana1

1 CSIR-National Physical Laboratory, Dr K S Krishnan Marg, New Delhi-110012, India
2 Academy of Scientific and Innovation Research, NPL, New Delhi-110012, India
3 Sardar Vallabhbhai National Institute of Technology, Surat-395007, Gujarat, India
4 Department of Physics, Indian Institute of Technology, Jodhpur, Rajasthan, India

E-mail: awana@mail.nplindia.org

Received 26 August 2015, revised 7 May 2016
Accepted for publication 10 May 2016
Published 31 May 2016

Abstract

We report the effect of Ni doping on superconductivity of PdTe. The superconducting parameters like critical temperature ($T_c$), upper critical field ($H_{c2}$) and normalized specific-heat jump ($\Delta C/\gamma T_c$) are reported for Ni doped Pd$_{1-x}$Ni$_x$Te. Samples of series Pd$_{1-x}$Ni$_x$Te with nominal compositions $x=0, 0.01, 0.05, 0.07, 0.1, 0.15, 0.2, 0.3$ and $1.0$ are synthesized via the vacuum shield solid state reaction route. All the studied samples of Pd$_{1-x}$Ni$_x$Te series are crystallized in a hexagonal crystal structure as refined by the Rietveld method to space group $P6_3/mmc$. Both the electrical resistivity and magnetic measurements revealed that $T_c$ decreases with increasing Ni concentration in Pd$_{1-x}$Ni$_x$Te. Magnetotransport measurements suggest that flux is better pinned for 20% Ni doped PdTe as compared to other compositions of Pd$_{1-x}$Ni$_x$Te. The effect and contribution of Ni 3d electron to electronic structure and density of states near the Fermi level in Pd$_{1-x}$Ni$_x$Te are also studied using first-principle calculations within the spin polarized local density approximation. The overlap of bands at the Fermi level for NiTe is larger as compared to PdTe. Also the density of states just below the Fermi level (in conduction band) drops much lower for PdTe than as for NiTe. In summary, Ni doping in Pd$_{1-x}$Ni$_x$Te superconductor suppresses superconductivity moderately and also Ni is of non-magnetic character in these compounds.

Keywords: superconductivity, magnetotransport, heat capacity, PdTe BCS superconductor, Ni doping

(Some figures may appear in colour only in the online journal)

Introduction

The discovery of new superconductors always attracts enormous interest from both experimental and theoretical condensed matter physicists. For the meantime, the already discovered superconductors keep on motivating us to understand their underlying physics. The role of magnetic impurities in known superconductors has been of great interest for a long time [1–4]. For example, the magnetic Mn impurities in Ba$_{0.5}$K$_{0.5}$Fe$_2$As$_2$ and Ba(Fe$_{1-x}$Co$_x$)$_2$As$_2$ systems showed strong suppression of $T_c$ [5–7], while $T_c$ is nearly unchanged in Mn doped FeSe$_{0.5}$Te$_{0.5}$ superconductors [8]. The non-magnetic Zn doped BaFe$_{1.89-2x}$Zn$_x$Co$_{0.11}$As$_2$ compounds showed that $T_c$ decreases rapidly with increasing Zn doping level [9], but the superconducting state is quite robust for Fe$_{1-x}$Zn$_x$Se$_{0.5}$Te$_{0.5}$ compound [10]. In the case of high $T_c$ cuprates, a significant decrease in $T_c$ was observed with Cu site Zn doping [11–13]. Studying the effect of both magnetic and non-magnetic impurities on known superconductors has been of prime interest for several years [1–13].

Recently, PdTe superconductors have received attention [14, 15]. These works prompted us to study the effect of magnetic nickel on bulk polycrystalline PdTe superconductor. The effects of magnetic impurities and the possibility of magnetic ordering in Bardeen–Cooper–Schrieffer (BSC) type conventional PdTe superconductors could provide better
understanding of superconductivity. Generally, it has been believed that the conduction electrons cannot be ordered both magnetically and superconductively due to strong spin scattering [16, 17]. On the other hand, Cooper pairs are formed in cuprates and iron based compounds possibly through spin fluctuations, and superconductivity occurs after suppressing the magnetic ordering by chemical doping or the application of hydrostatic pressure [18–20]. Electron–phonon coupling as proposed in BCS theory fails to explain the superconductivity in cuprate and iron based materials [21]. The superconductivity in high $T_c$ cuprates is induced from electronic charge carriers doping in antiferromagnetic Mott insulating phase [21–23]. There is a hypothetical possibility of the magnetic excitations replacing phonons in exotic high $T_c$ superconductors [23]. On the other hand, there are some examples of the coexistence of superconductivity with either ferromagnetic or antiferromagnetic ordering in UGe2, URhGe, UCoGe, MgCu2Ni, RuS2GdCu2O8, etc [24–28]. As far as the coexistence of superconductivity and magnetism is concerned, there is no concrete explanation to understand the interaction between superconducting and magnetic order parameters. In some experimental reports, it has been suggested that $T_c$ decreases linearly with increasing magnetic impurity concentration in superconducting systems [6–9]. The decrease in $T_c$ of bulk lanthanum by rare-earth impurities depends on the spin of the impurity atoms rather than on their magnetic moment, which has been reported by Matthias in a detailed study [29–33].

Keeping in view the importance of the impact of magnetic ion doping in various superconductors, we report here on the synthesis and characterization of Pd$_{1-x}$Ni$_x$Te (0 $\leq x \leq 1$) series. For pristine PdTe, our results are a sort of confirmation of the only other report [14] available in the literature on superconductivity at 4.5 K in PdTe, besides our previous work [15]. The difference, which we feel is important, is that the earlier report is on tiny (15 μm) single crystals [14], the present one is on the other hand on polycrystalline bulk samples. Also, magnetooheat capacity was added [15], which is useful in not only probing the bulk superconductivity but the order parameter as well.

X-ray diffraction (XRD) measurements revealed that Pd is substituted by Ni in the parent hexagonal phase (space group P6$_3$/mmc) of PdTe. The superconducting transition temperature $T_c$ of Pd$_{1-x}$Ni$_x$Te is studied by resistivity measurements using a Quantum Design Physical Property Measurement System (QD-PPMS) down to 2 K under different magnetic fields. Heat capacity measurements for Pd$_{0.99}$Ni$_{0.01}$Te are also presented and analyzed. Ni doping in Pd$_{1-x}$Ni$_x$Te decreases superconductivity moderately, and the reason behind this is that Ni is of non-magnetic nature in PdTe. Ni(3d) and Te(sp) orbital possible strong hybridization might be the reason behind the non-magnetic nature of Ni in Pd$_{1-x}$Ni$_x$Te. Detailed first-principles density functional calculations revealed that Ni affects the Te-p orbitals, resulting in suppression of superconducting transition temperature. Interestingly, to the best of our knowledge, this is the first study on Ni substitution at the Pd site in a PdTe superconductor.

**Experimental and computational details**

Bulk polycrystalline samples of series Pd$_{1-x}$Ni$_x$Te (0 $\leq x \leq 1$) were synthesized by the solid state route via vacuum encapsulations. The required elements Pd (3 N), Te (4 N) and Ni (4 N) were ground in a stoichiometric ratio in an argon filled glove box. The powders were pelletized by applying uniaxial stress of 100 kg cm$^{-2}$ and vacuum sealed (<10$^{-3}$ Torr) in quartz tubes. The sealed encapsulated quartz tubes were kept in a box furnace and then heated to 750 °C (rate 2 °C min$^{-1}$) for 24 h and cooled down to room temperature naturally. The obtained samples were dense and shiny black. For the structural analysis, x-ray diffraction (XRD) was done at room temperature using CuK$_{α}$ radiation of wavelength 1.5418 Å. Magneto-resistance measurements were performed by the four-probe technique in an applied field in a QD-PPMS-14 Tesla—down to 2 K. Specific heat measurements were also carried out at the same facility. Magnetic measurements were performed in an MPMS system. DC magnetization with temperature variation was carried out in both zero field and field cooled modes.

We also performed density functional calculations to see the role of Ni doping on electronic structure of PdTe. These calculations were carried out within the generalized gradient approximation (GGA) of Perdew, Burke and Ernzerhof, as given in the Vienna Ab-initio Simulation Package (VASP), to compute the ground state electronic band structure and density of states [34].

**Results and discussion**

In figure 1, the observed and Rietveld fitted room temperature XRD patterns of the Pd$_{1-x}$Ni$_x$Te samples are shown. All the samples are well fitted with the space group P6$_3$/mmc, suggesting complete solubility of Ni in PdTe. It can be observed from figure 1 that the (100) crystallographic plane around $2θ = 24.82^\circ$ is being suppressed with increasing concentration of Ni. On the other hand the (002) plane at $2θ = 33.07^\circ$ appears only above $x = 0.1$. The lattice parameters for PdTe are; $a = b = 4.153(2)$ Å and $c = 5.673(5)$ Å and for NiTe $a = b = 3.941(2)$ Å and $c = 5.363(2)$ Å as obtained by fitting to the P6$_3$/mmc space group. As seen from the upper panel of figure 2, the Rietveld refined lattice parameters $a = b$ and $c$ and unit cell volume $(V)$ are consistently decreasing with increasing Ni-doping fraction in Pd$_{1-x}$Ni$_x$Te series. Almost linear shrinkage of the unit cell volume of Pd$_{1-x}$Ni$_x$Te with $x$ indicates complete substitution of Pd by Ni in PdTe, suggesting the increase of chemical pressure. The lower panel of figure 2 shows that the lattice parameters $a$ and $c$ decrease simultaneously. Although, we could not carry out elemental analysis, the linear decrease in lattice parameters indicates successful substitution of smaller ion Ni at the Pd site in Pd$_{1-x}$Ni$_x$Te. For brevity, we took the nominal $x$ value as Ni content in the studied Pd$_{1-x}$Ni$_x$Te. Chemical pressure may play an important role in the superconductivity of parent PdTe compound. For Pd doped FeTe compound, it has been reported that negative chemical pressure as well as doping
induced structural phase transition occurs from tetragonal to hexagonal phase [35].

Figure 3 represents the ac susceptibility for all the superconducting samples of series $Pd_{1-x}Ni_xTe$ ($0 \leq x \leq 1$) compounds. The bottom (blue) lines correspond to the difference between the experimental and calculated data.

Figure 1. Experimental (red open circles) and Rietveld refined (black solid line) room temperature XRD patterns of $Pd_{1-x}Ni_xTe$ ($0 \leq x \leq 0.2$) compounds. The bottom (blue) lines correspond to the difference between the experimental and calculated data.

Figure 2. Nominal $x$ dependence Rietveld fitted cell parameters $a(\text{Å})$, $c(\text{Å})$ and $V(\text{Å}^3)$ for $Pd_{1-x}Ni_xTe$ samples.

Figure 3. Temperature dependence of ac susceptibility for superconducting $Pd_{1-x}Ni_xTe$ ($x = 0, 0.01, 0.05, 0.07, 0.1, 0.15, 0.2$ and $0.3$) compounds.

monotonically to lower temperatures from $4.5$ K ($x = 0.0$) to $2.5$ K ($x = 0.20$). The Ni substitutions above $20\%$ in PdTe did not show superconductivity in the studied temperature range down to $2$ K.

Figure 4 shows the magnetization isotherms at $2$ K to estimate the lower critical field ($H_{c1}$) values of superconducting $Pd_{1-x}Ni_xTe$ samples. With increasing magnetic field from zero, the magnetization increases linearly up to...
Hc₁, signifying diamagnetic character. For PdTe the value of magnetization starts increasing above the magnetic field $H_{c1}$, reaches zero i.e. at the upper critical field $H_{c2}$, and becomes positive above an applied field of 1 kOe. The estimated $H_{c1}$ values are 200 Oe, 160 Oe, 51 Oe, 41 Oe, and 32 Oe for Pd$_{1-x}$Ni$_x$Te; $x$ = 0, 0.01, 0.05, 0.07 and 0.1, respectively. Clearly, $H_{c1}$ of Pd$_{1-x}$Ni$_x$Te series decreases with increasing Ni content.

The temperature dependence of electrical resistivity for PdTe the value of magnetization starts increasing above the magnetic field $H_{c1}$, reaches zero i.e. at the upper critical field $H_{c2}$, and becomes positive above an applied field of 1 kOe. The estimated $H_{c1}$ values are 200 Oe, 160 Oe, 51 Oe, 41 Oe, and 32 Oe for Pd$_{1-x}$Ni$_x$Te; $x$ = 0, 0.01, 0.05, 0.07 and 0.1, respectively. Clearly, $H_{c1}$ of Pd$_{1-x}$Ni$_x$Te series decreases with increasing Ni content.

The temperature dependence of electrical resistivity for Pd$_{1-x}$Ni$_x$Te (0 ≤ $x$ ≤ 1.0) series in the temperature range 300–2 K is shown in figure 5(a). It is important to check the variation of normal state resistivity with Ni doping, as the same hosts the superconductivity at low temperatures. Apparently, normal state electrical resistivity of all the samples increases with temperature, albeit with metallic behaviour. Figure 5(b) shows $\rho-T$ plots of Ni doped PdTe superconducting compounds in the temperature range 6–2 K. The onset resistivity increases while superconducting transition temperature ($T_c$) decreases with increasing Ni substitution at the Pd site. This trend is shown in figure 6 in terms of $H_{c1}$.
Figure 8. (a)–(g) Temperature dependence of electrical resistivity under various magnetic fields of superconducting Pd$_{1-x}$Ni$_x$Te ($x = 0, 0.01, 0.05, 0.07, 0.1, 0.15$ and $0.2$) compounds. (h) Upper critical field ($H_{c2}$) as a function of temperature. The solid lines are linearly extrapolations of experimental data.
Figures 8(a)–(g) demonstrate the temperature dependence of electrical resistivity under various magnetic fields in the temperature range 2–6 K for superconducting Pd_{1-x}Ni_xTe (x = 0 to 0.2) samples. $T^\text{onset}$ and $T^\rho(0)$ decrease with increasing magnetic field and this superconducting behaviour has been observed for all the samples. Figure 8(h) shows the upper critical field $H_c$ corresponding to the temperatures where the resistivity drops to 90% of the normal state resistivity. $H_{c2}(0)$ is estimated by using the conventional one-band Werthamer–Helfand–Hohenberg (WHH) equation, i.e.,

$$H_{c2}(0) = -0.693T_c(dH_{c2}/dT)_{T=T_c}.$$ 

The solid lines are the ones being extrapolated to $T = 0$ K, for 90% $\rho_0$ criteria of the $\rho(T)$H curve for Pd_{1-x}Ni_xTe samples. The estimated $H_{c2}(0)$ values are 2.6 kOe, 2.3 kOe, 2.4 kOe, 2.6 kOe, 2.61 kOe, 2.66 kOe and 3 kOe for Pd_{1-x}Ni_xTe (x = 0, 0.01, 0.05, 0.07, 0.1, 0.15 and 0.2) samples. The $H_{c2}(0)$ value for 20% Ni doped PdTe is significantly higher than the pristine sample, while its $T_c(3 K)$ is lower than the $T_c(4.5 K)$ of the pristine PdTe sample. The upper critical field values $H_{c2}(0)$ estimated for all the samples are well within Pauli paramagnetic limit, which is defined as $\mu_B H_p = 1.84T_c$ [36].

To see the effect of magnetic doping on the electronic heat capacity of one of the superconducting compound Pd_{0.99}Ni_{0.01}Te, the low temperature specific heat has been recorded under different magnetic fields as shown in figure 9(a). As mentioned in the experimental section the specific heat ($C_p$) measurements are carried out on a QD-PPMS with an instrument accuracy of 10 nJ K$^{-1}$ at 2 K. Critical examination of heat capacity measurements made on a QD-PPMS reported an accuracy of the same within 1%–5%. A detailed inter-comparison and data analysis is given in [37].

In the absence of any applied field, the anomaly in specific heat ($C_p$) is observed at the temperature 4.5 K, which decreases to low temperature with magnetic field. The superconductivity anomaly is suppressed and not seen down to 2 K at an applied magnetic field of 1.5 kOe. The specific heat is fitted to the expression $C_p(T) = \gamma T + \beta T^2 + \delta T^3$, where $\gamma$ is Sommerfeld coefficient, $\beta$ and $\delta$ are the phononic heat coefficients. The inset of figure 9(a) represents $C_p/T$ as a function of $T^2$ which is used to find the electronic and phononic contribution to the specific heat. The obtained coefficients are $\gamma = 7.42$ mJ mol$^{-1}$ K$^{-2}$, $\beta = 0.8$ mJ mol$^{-1}$ K$^{-4}$ and $\delta = 0.0019$ mJ mol$^{-1}$ K$^{-6}$. The Debye temperature $\theta_D$ is 229.9 K, which is calculated by using the relation $\theta_D = (234 c R/\beta)^{1/3}$, where $R$ is the Rydberg constant (8.314 Jmol$^{-1}$ K$^{-1}$) and $z$ is the number of atoms in the Ni doped PdTe unit cell. The Kadowaki–Woods ratio $A/\gamma^2$ is $8.7 \times 10^{-5}$ $\mu$cm mol$^{-1}$ K$^{-1}$ J$^{-2}$, where A is evaluated by fitting the temperature dependent resistivity from the previous section. Interestingly, the value of the Kadowaki–Woods ratio for the Pd_{0.99}Ni_{0.01}Te sample is in good agreement with transition metal systems [38]. The value of $\delta$ is so small that the data could be fitted well even without the $T^3$ term. The fitting of $C_p(T)$ without the $T^3$ term gave $\gamma = 6.666$ mJ mol$^{-1}$ K$^{-2}$ and $\beta = 0.884$ mJ mol$^{-1}$ K$^{-4}$. This resulted in $\theta_D$ as 223 K and a Kadowaki–Woods ratio $A/\gamma^2$ of $10.5 \times 10^{-5}$ $\mu$cm mol$^{-1}$ K$^{-1}$ J$^{-2}$. In any case, both with and without the $T^3$ term, the fitting resulted in close $\theta_D$ and

**Figure 9.** (a) Temperature dependence of heat capacity ($C_p$) under various magnetic fields of superconducting Pd_{0.99}Ni_{0.01}Te compounds. The inset shows $C_p/T$ versus $T^2$ at different fields and the solid red line is the fit to the relation $C_p(T) = \gamma T + \beta T^2 + \delta T^3$ (b) Electronic specific heat $C_e/T$ as a function of temperature under different magnetic field.

$T^\text{onset}$ versus Ni content for Pd_{1-x}Ni_xTe superconducting samples. Here one can see that the $T^\text{onset}$ is nearly unchanged for the x = 0.01 sample and the same decreases rapidly for higher Ni content samples. None of the samples showed a superconducting transition down to 2 K for x > 0.3. Figure 7 shows the variation of residual resistivity $\rho_0$ and the residual resistivity ratio (RRR; ratio of resistivity at 300 K to the extrapolated resistivity at zero K) with Ni concentration. The residual resistivity $\rho_0$ has been calculated by fitting the electrical resistivity using equation $\rho = \rho_0 + A T^2$, where A is the slope of the graph, shown in the inset of figure 7. RRR is found to decrease with Ni content, suggested increased scattering of electrons with Ni doping. In our case the residual resistivity increases monotonically up to the doping level of 20%, and later rapidly increases as superconductivity disappears. The suppression of $T_c$ in the Pd_{1-x}Ni_xTe system may result from the change of the charge carrier density along with the impurity scattering. The fitted values of both $\rho_0$ and A for all the studied Pd_{1-x}Ni_xTe samples are given in table 1.

$T^\text{onset}$ versus Ni content for Pd_{1-x}Ni_xTe superconducting samples. Here one can see that the $T^\text{onset}$ is nearly unchanged for the x = 0.01 sample and the same decreases rapidly for higher Ni content samples. None of the samples showed a superconducting transition down to 2 K for x = 0.3. Figure 7 shows the variation of residual resistivity $\rho_0$ and the residual resistivity ratio (RRR; ratio of resistivity at 300 K to the extrapolated resistivity at zero K) with Ni concentration. The residual resistivity $\rho_0$ has been calculated by fitting the electrical resistivity using equation $\rho = \rho_0 + A T^2$, where A is the slope of the graph, shown in the inset of figure 7. RRR is found to decrease with Ni content, suggested increased scattering of electrons with Ni doping. In our case the residual resistivity increases monotonically up to the doping level of 20%, and later rapidly increases as superconductivity disappears. The suppression of $T_c$ in the Pd_{1-x}Ni_xTe system may result from the change of the charge carrier density along with the impurity scattering. The fitted values of both $\rho_0$ and A for all the studied Pd_{1-x}Ni_xTe samples are given in table 1.
Figure 10. Electronic structure along the line of high symmetry points (left panel) and density of states of Pd$_{1-x}$Ni$_x$Te: $x = 0$, 0.25, 0.5, 0.75 and 1.0, respectively (a)–(e).
Kadowaki–Woods ratio values. As far as the goodness of fitting is concerned, it is 0.99986 for the $A\delta^6$ term and 0.9997(6) without. For different magnetic fields, the variation of electronic specific heat $C_v/T$ ($C_v = C_T/\delta T^4$) with temperature is represented in figure 9(b). It is observed that specific heat jump decreases with magnetic field along with superconducting transition temperature. The electronic specific heat is calculated by subtracting the phononic part from the total specific heat. This plot is used to determine the jump in electronic heat capacity at superconducting $T_c$. It can be seen that the magnitude of the jump ($2\Delta C$) at $T = T_c$ is $10.59 \text{ mJ mol}^{-1} \text{K}^{-2}$, and the value of the normalized specific-heat jump, $(\Delta C/\gamma T_c)$ is 1.42, nearly equal to the BCS weak-coupling limit, i.e. 1.43. This value is slightly larger than as for PdTe, being reported (1.33) in our previous work [15]. Interestingly, the jump value even for pristine PdTe is 1.67 in [14] and 1.33 in [15]. As mentioned by us in an earlier report [15], the jump value depends upon the superconducting volume fraction and disorder may also affect the same, hence it is difficult to comment and compare the exact values. The specific-heat jump, $(\Delta C/\gamma T_c)$ for $Pd_{0.99}Ni_{0.01}Te$ along with our earlier report [15] on pristine PdTe, suggests that the superconductivity of these compounds is within the BCS coupling limit.

Figures 10(a)–(e) shows the near Fermi energy electric band structure of $Pd_{1-x}Ni_xTe$; $x = 0.0, 0.25, 0.5, 0.75$ and 1.0, calculated using first principles density functional approximations, as implemented in VASP. A $2 \times 2 \times 2$ PdTe superstructure was used for the calculation of Ni substituted $Pd_{1-x}Ni_xTe$ samples. The structures were relaxed until the force on each atom was less than 0.01 eV Å$^{-1}$ for all these compositions. The starting structures were taken from experimental lattice parameters, being estimated using Rietveld refinement. Apart from the angles $\alpha = 89.3^\circ$ and $\beta = 91.4^\circ$ for doped samples, other lattice parameters are close to experimental values. The details of the calculated parameters are listed in Table 2. Though small, this changes the crystal symmetry, which leads to a large number of energy bands in Ni-substituted samples. These changes in lattice parameters are not discernible from XRD measurements. Except for the overlap of bands at the Fermi level there are no other changes for PdTe and NiTe compounds. The overlap for NiTe is larger as compared to PdTe across the Fermi level. Also worth noticing is that the density of states just below the Fermi level (in the conduction band) drops much lower for PdTe as compared to NiTe, consistent with electronic band overlap, as can be seen in figure 10. This instability at the Fermi level may be responsible for the superconducting gap in PdTe and lowering of the superconducting transition temperature $T_c$ with increasing Ni-doping fraction in PdTe. The residual resistivity is much lower for PdTe than that of NiTe, as can be seen in figure 7. Current carriers of these studied compounds have Fermi liquid like behaviour at low temperatures. This suggests that the nature of bands near the Fermi level is important to explain the residual resistivity in conjunction with impurity scattering. Spin polarized density of states (DOS) per unit cell are shown in the right panel of figure 10 and non-zero DOS at the Fermi level (the Fermi level is set to zero) has been observed for all $Pd_{1-x}Ni_xTe$ solid solutions. In fact, to probe the role of Ni doping in superconducting PdTe and non-superconducting NiTe compounds, further studies on the nature of the Fermi surface and electronic bands are warranted. Our studies are preliminary observations, but are certainly thought provoking and deserve further investigation.

**Conclusion**

In summary, we successfully synthesized Ni doped PdTe compounds. The XRD pattern for the $Pd_{1-x}Ni_xTe$ ($0 \leq x \leq 1.0$) superconductivity ($T_c$) decreases with increasing Ni content and completely disappears above 20% Ni doping. Interestingly, Ni is found to be of non-magnetic nature in $Pd_{1-x}Ni_xTe$, and hence $T_c$ depression is mainly due to disorder alone. The $H_{c2}(0)$ value for 20% Ni doped PdTe is significantly higher than the pristine PdTe sample, suggesting possible pinning. The value of the normalized specific-heat jump $(\Delta C/\gamma T_c)$ of 1.42 is estimated from the analysis of specific heat data of $Pd_{0.99}Ni_{0.01}Te$, suggesting a simple BCS weak-coupling limit. Worth mentioning is the fact that this is first study on Ni doping in a PdTe superconductor, which may yet have loose ends and further investigations may be desired.

**Acknowledgments**

The authors would like to thank the Director of NPL-CSIR India for his encouragement. This work is financially supported by a DAE-SRC outstanding investigator award scheme.
on the search for new superconductors. RG thanks UGC, India, for providing her research fellowship.

References

[1] Abrikosov A A and Gor’kov L P 1960 Zh. Eksp. Teor. Fiz. 39 1781
[2] Abrikosov A A and Gor’kov L P 1961 Sov. Phys. JETP 12 1243
[3] Woolf M A and Reif F 1965 Phys. Rev. 137 A557
[4] Maple M B 1976 Appl. Phys. (Berlin) 9 179
[5] Cheng P, Shen B, Hu J P and Wen H H 2010 Phys. Rev. B 81 174529
[6] Cheng P, Shen B, Han F and Wen H H 2013 Europhys. Lett. 104 37007
[7] Li J, Guo Y, Zhang S, Tsujimoto Y, Wang X, Sathish C I, Yu S, Yamaura K and Muromachi E T 2012 Solid State Commun. 152 671
[8] Gunther A, Deisenhofer J, Kant C, Krug von Nidda H A, Li J, Guo Y, Zhang S, Tsujimoto Y, Wang X, Sathish C I, Yu S, Yamaura K and Muromachi E T 2012 Solid State Commun. 152 671
[9] Li J et al 2012 Phys. Rev. B 85 214509
[10] Inabe T, Kawamata T, Noji T, Adachi T and Koike Y 2013 J. Phys. Soc. Japan 82 044712
[11] Alloul H, Bobroff J, Gabay M and Hirschfeld P J 2009 Rev. Mod. Phys. 81 45
[12] Julien M-H, Feher T, Horvatic M, Berthier C, Bakharev O N, Sgransan P, Collin G and Marucco J-F 2000 Phys. Rev. Lett. 84 3422
[13] Xiao G, Cieplak M Z, Gavrin A, Streitz F H, Bakhshai A and Chien C L 1988 Phys. Rev. Lett. 60 1446
[14] Karki A B, Browne D A, Stadler S, Li J and Jin R 2012 J. Phys.: Condens. Matter. 24 055701
[15] Tiwari B, Goyal R, Jha R, Dixit A and Awana V P S 2015 Supercond. Sci. Technol. 28 055008
[16] Ginzburg V L 1957 Sov. Phys. JETP 4 153
[17] Berk N F and Schrieffer J R 1966 Phys. Rev. Lett. 17 433
[18] Mathur N D, Grosche F M, Julian S R, Walker I R, Freye D M, Haselwimmer R K W and Lonzarich G G 1998 Nature 394 39
[19] Hufner S, Hossain M A, Damascelli A and Sawatzky G A 2008 Rep. Prog. Phys. 71 062501
[20] Kamihara Y, Watanabe T, Hirano M and Hosono H 2008 J. Am. Chem. Soc. 130 3296
[21] Lee P A, Nagaosa N and Wen X G 2006 Rev. Mod. Phys. 78 17
[22] Birgeneau R J, Stock C, Tranquada J M and Yamada K 2006 J. Phys. Soc. Japan 75 111003
[23] Kastner M A, Birgeneau R J, Shirane G and Endoh Y 1998 Rev. Mod. Phys. 70 897
[24] Saxena S S et al 2000 Nature 406 587
[25] Huy N, Gasparini A, De Nijs D, Huang Y, Klaasse J, Gortenmulder T, De Visser A, Hamann A, Grlach T and Löhneysen H 2007 Phys. Rev. Lett. 99 67006
[26] Aoki D, Huxley A, Ressouche E, Braithwaite D, Flouquet J, Brison J-P, Lhotel E and Paulsen C 2001 Nature 413 613
[27] He T et al 2001 Nature 411 54
[28] Bernhard C, Tallon J L, Niedermayer C, Blasius T, Golnik A, Bricher E, Kremer R K, Noakes D R, Strochan C E and Ansaldo E J 1999 Phys. Rev. B 59 14099
[29] Matthias B T, Suhl H and Corenzwit E 1958 Phys. Rev. Lett. 1 93
[30] Matthias B T, Suhl H and Corenzwit E 1960 J. Phys. Chem. Solids 13 156
[31] Anderson P W 1959 J. Phys. Chem. Solids 11 26
[32] Balatsky A V, Vekhter I and Zhu J-X 2006 Phys. Rev. B 73 134422
[33] Tsang J K and Ginsberg D M 1980 Phys. Rev. Lett. 45 1973
[34] Perdew J P and Zunger A 1981 Phys. Rev. B 23 1342
[35] Karki A B, Garlea V O, Custelcean R, Stadler S, Plummer E W and Jin R 2013 Proc. Nat. Acad. Sci. USA 110 9283
[36] Clogston A M 1962 Phys. Rev. Lett. 9 6
[37] Lashley J C et al 2003 Cryogenics 43 369
[38] Jacko A C, Fjerestad J O and Powell B J 2009 Nat. Phys. 5 422