Effect of pressure on the superconducting transition in the Dirac semimetal PdTe₂

A. Ohmura1*, H. Leng2, L. N. Anh3, F. Ishikawa1, T. Naka4, Y. K. Huang2, A. de Visser2

1Faculty of Science, Niigata University, 8050 Ikarashi 2-no-cho, Nishi-ku, Niigata 950-2181, Japan
2Van der Waals-Zeeman Institute, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands
3International Training Institute for Materials Science, Hanoi University of Sci. and Technol., 1 Dai Co Viet Road, Ha Noi, Vietnam
4National Institute for Materials Science, Sengen 1-2-1, Tsukuba, Ibaraki 305-0047, Japan.

Keywords: Type-II Dirac semimetal, superconductivity, transport measurement

*e-mail: ohmura@phys.sc.niigata-u.ac.jp

The transition metal dichalcogenide PdTe₂ attracts much attention because of its classification as a type-II Dirac semimetal with a topologically non-trivial surface state. Moreover, it is a superconductor at low temperatures. A recent study of superconductivity at ambient pressure revealed that PdTe₂ is a bulk type-I superconductor with \( T_c = 1.64 \) K [1]. The critical field \( H_c(T) \) follows the standard quadratic temperature variation with \( \mu_B H_c(0) = 13.6 \) mT. Intriguingly, surface superconductivity is identified with \( T_c = 1.33 \) K, which is lower than \( T_c \) of the bulk. It persists up to \( \mu_B H_c(0) = 34.9 \) mT, but does not follow the standard Saint-James – de Gennes behavior. With regards to the effect of pressure on PdTe₂, a theoretical study by Xiao et al. reported the depression of superconductivity up to 10 GPa, as well as a transition from the type-II Dirac semimetal to type-I in the pressure range 4.7 - 6.1 GPa [2]. In this experimental study, we report the effect of high pressure up to ~2.5 GPa on superconductivity in PdTe₂ [3].

Electrical resistivity, \( \rho(T, H) \), and ac-susceptibility, \( \chi_{ac}(T, H) \), under high pressure were measured utilizing a clamp-type piston-cylinder cell. Two single crystals for \( \rho \) and \( \chi_{ac} \) were loaded into a Teflon capsule together with an ac-coil set and a pressure-transmitting medium (Daphne7373) for hydrostatic compression. The generated pressure in the capsule was estimated from the calibration data for this cell, which was obtained in a separate experiment. Data were taken in applied dc-magnetic fields, \( \mu_B H_m \), up to 180 mT for \( \rho \) and 30 mT for \( \chi_{ac} \). The experiments were performed in two runs on the same sample pieces up to pressures of 1.24 and 2.49 GPa, respectively.

The superconducting transition temperature as a function of pressure is shown in Figure 1. \( T^0_c \) is obtained from \( \rho(T) \) and \( T^0_c \) from \( \chi_{ac}(T) \), respectively. \( T^R_c \) and \( T^S_c \) originate from bulk superconductivity and show a good agreement between them, especially up to 1.24 GPa. The transition temperature reaches a maximum value of 1.91 K around 0.91 GPa and then decreases to 1.27 K at 2.49 GPa as pressure increases. Similar to \( H_c(T) \) at ambient pressure, \( H_c(T, H) \) under pressure defined by \( T^R_c \) follows the quadratic temperature variation for type-I superconductivity as well. Furthermore, the \( H_c(T, H) \)-curves at all pressures collapse on a single universal curve. This strongly supports that type-I superconductivity is robust under pressure. Interestingly, in \( \chi_{ac}(T) \) at pressures of 1.41 to 2.49 GPa, a second transition appears at \( T^S_c \) above \( T^R_c \). The inset of Figure 1 shows the 2.49 GPa curve as an example. The second transition is attributed to the surface superconductivity mentioned above. \( T^S_c \) below 1.41 GPa is obtained from the field-temperature phase diagrams by extrapolating \( T^S_c(H) \) to zero field [3]. The pressure variation of \( T^S_c \) with a maximum near 0.9 GPa is comparable to the one for the bulk \( T_c \). \( T^S_c \) survives at the highest pressure we measured and is higher than \( T^S_c \) above 1.41 GPa, indicating that the surface superconductivity is also robust under pressure. Unlike the \( H_c(T) \)-curves, the reduced plot of the \( H_c^0(T) \)-curves to \( T^S_c \) shows pressure variation. The behavior of \( T^S_c \) and the \( H_c^0(T) \)-curves under pressure implies that the surface superconductivity of PdTe₂ may possibly have a non-trivial nature. In addition to the pressure variation of \( T_c \), we will report in this contribution the field-temperature phase diagrams of PdTe₂ under high pressure.

Acknowledgments: This work was part of the research program on Topological Insulators funded by FOM (Dutch Foundation for Fundamental Research on Matter). H.L. acknowledges the Chinese Scholarship Council for Grant No. 201604910855. It was further supported by the Japan Society for the Promotion of Science Program for Fostering Globally Talented Researchers, Grant Number R2903.

Figure 1. Pressure variations of the superconducting transition temperature at \( \mu_B H_m = 0 \). \( T^0_c \) (closed circles) is determined from resistance, and \( T^0_c \) (open diamonds) from ac-susceptibility. \( T^S_c \) denotes surface superconductivity (closed and grayish squares). Grayish squares are the extrapolated values of \( T^S_c \) at \( \mu_B H_m = 0 \). The dashed lines are guides for the eye. The inset shows how \( T^S_c \) and \( T^R_c \) are extracted from the ac-susceptibility at \( P_{\text{max}} = 2.49 \) GPa.