

Supplementary Information for
**Nonreciprocal charge transport in topological insulator candidate
 $\text{Bi}_2\text{Te}_3/\text{PdTe}_2$ heterostructure**

Makoto Masuko¹, Minoru Kawamura^{2,*}, Ryutaro Yoshimi², Motoaki Hirayama^{1,2},
Yuya Ikeda¹, Ryota Watanabe¹, James Jun He², Denis Maryenko², Atsushi Tsukazaki³,
Kei S. Takahashi², Masashi Kawasaki^{1,2}, Naoto Nagaosa^{1,2}, and Yoshinori Tokura^{1,2,4}

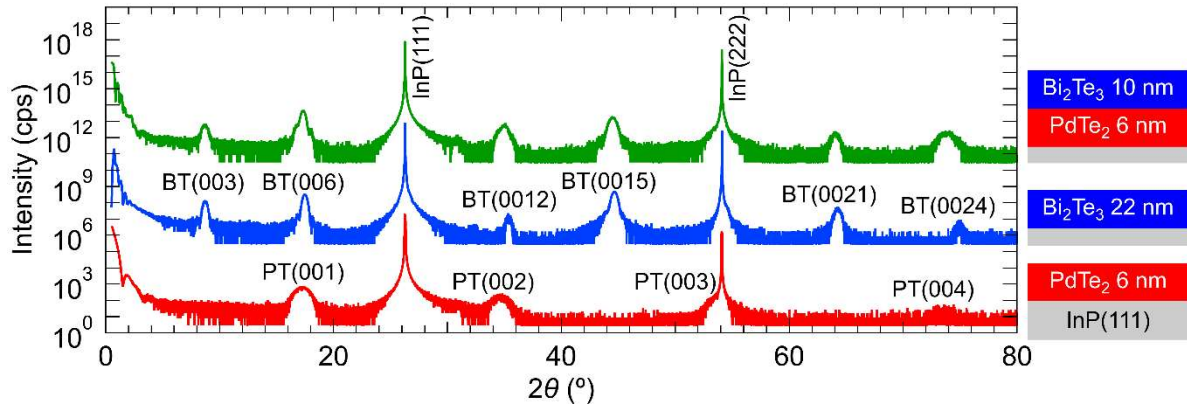
¹Department of Applied Physics and Quantum Phase Electronics Center (QPEC),
University of Tokyo, Tokyo 113-8656, Japan.

²RIKEN Center for Emergent Matter Science (CEMS), Wako 351-0198, Japan.

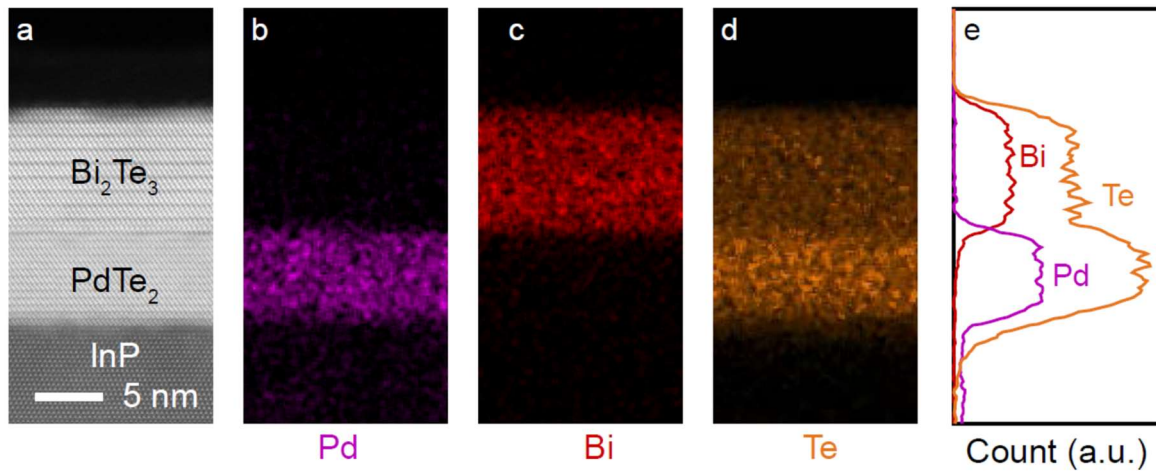
³Institute for Materials Research, Tohoku University., Sendai 980-8577, Japan

⁴Tokyo College, University of Tokyo, Tokyo 113-8656, Japan.

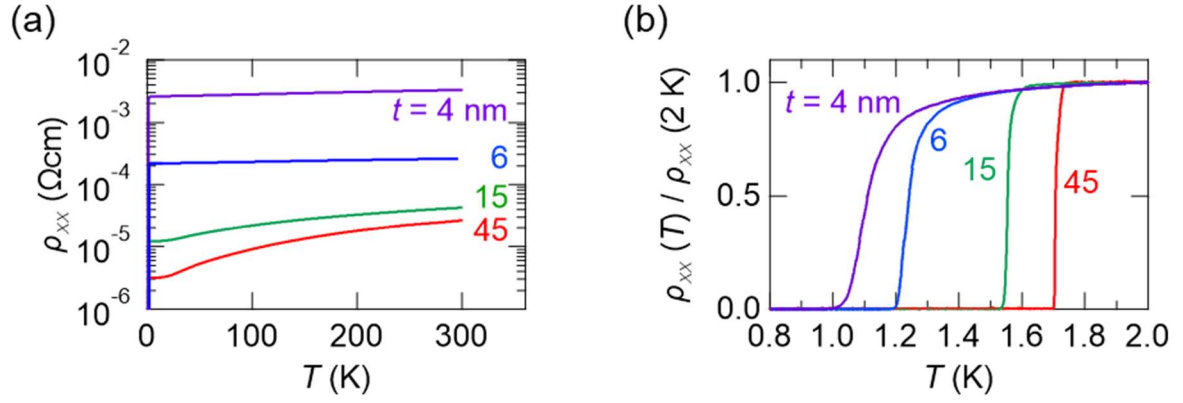
*Corresponding author: minoru@riken.jp



Supplementary Figure 1 | Structural characterization of thin films by X-ray diffraction (XRD). XRD patterns in 2θ - ω scans for the thin films of PdTe₂ (6 nm), Bi₂Te₃ (22 nm), and Bi₂Te₃ (10 nm)/PdTe₂ (6 nm). The c -axis lattice constant of the PdTe₂ estimated from the (001) peak is 5.13 Å, which is comparable with the value of the bulk crystal.

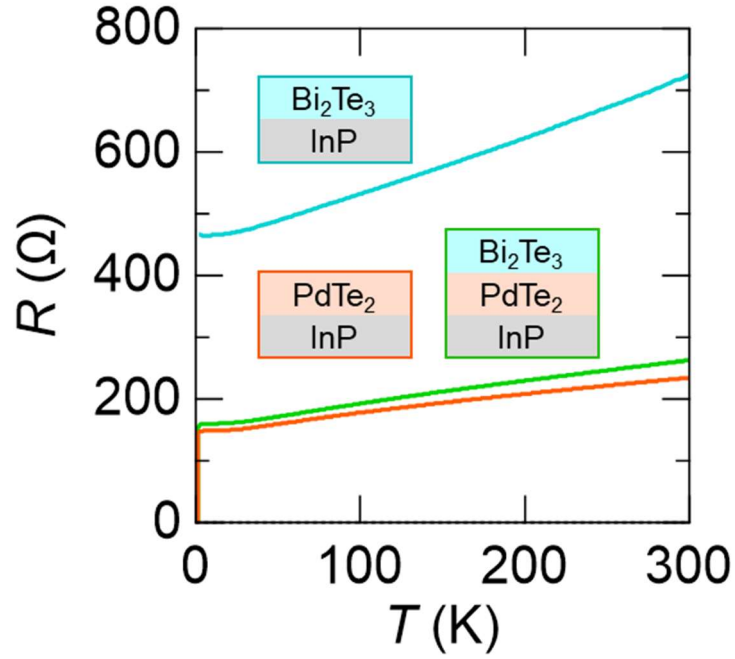


Supplementary Figure 2 | Transmission electron microscopy (TEM) and energy dispersive X-ray (EDX) spectroscopy measurement on Bi₂Te₃/PdTe₂ heterostructure. **a**, TEM image of the Bi₂Te₃/PdTe₂ heterostructure. **b-d**, Elemental distribution map of the EDX spectroscopy corresponding to the area in **a**. **e**, Averaged line profile of Pd, Bi, and Te.



Supplementary Figure 3 | Thickness dependence of superconductivity in PdTe₂ thin films.

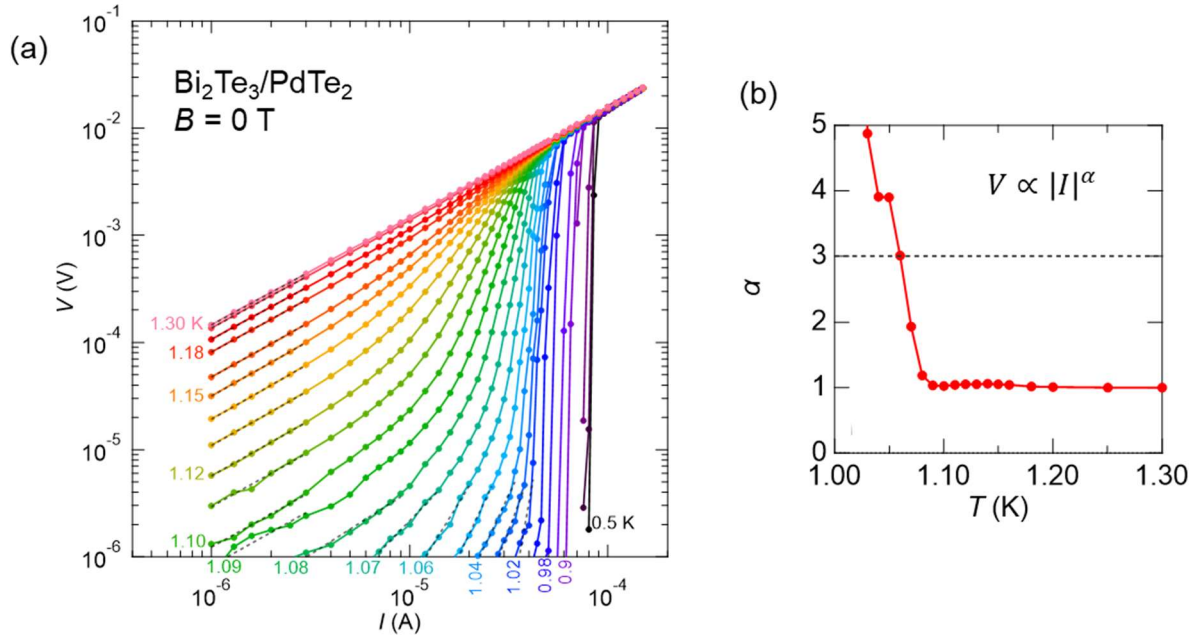
(a) Temperature dependence of resistivity in PdTe₂ thin films on InP(111)A with various thicknesses. (b) Magnified view around superconducting transition. In (b), resistivity is normalized by the value at 2 K for each film.



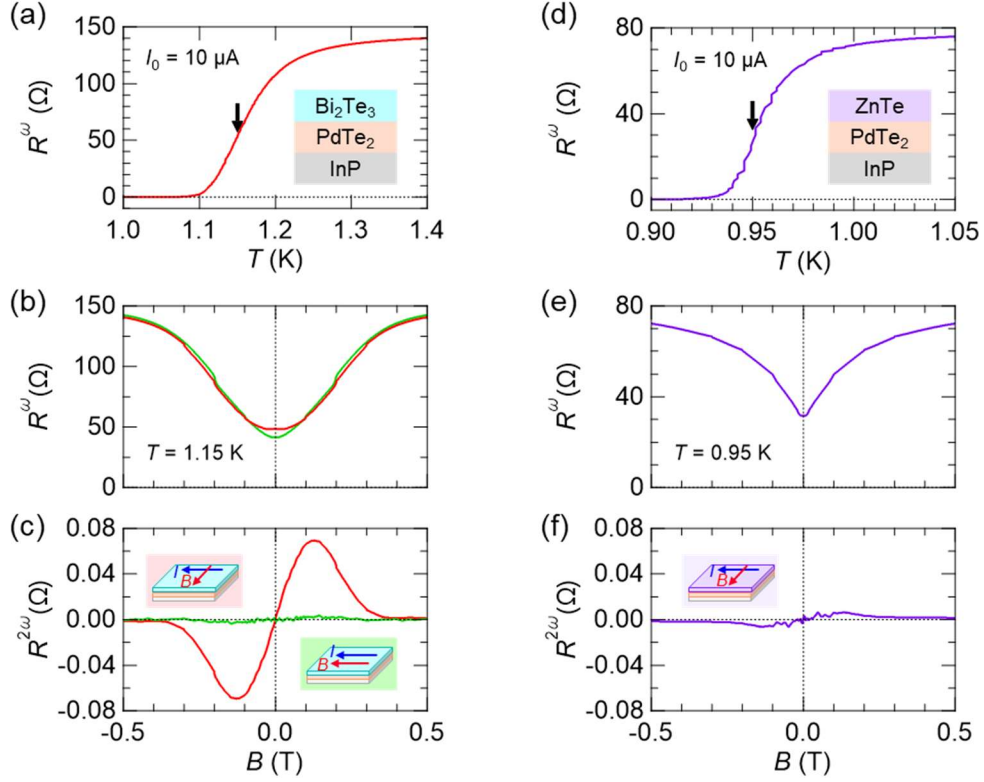
Supplementary Figure 4 | Comparison of sheet resistance of Bi₂Te₃ and PdTe₂ layers.

Temperature dependence of sheet resistance in thin films of Bi₂Te₃, PdTe₂, and Bi₂Te₃/PdTe₂.

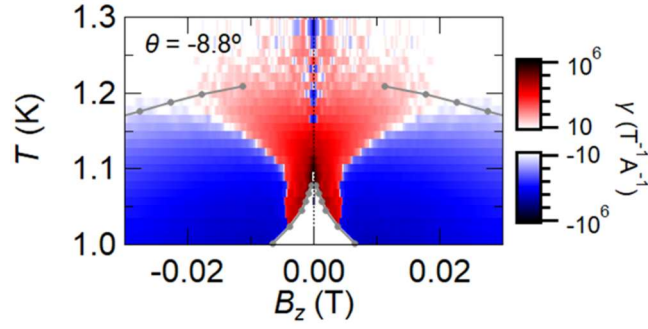
Here, the thicknesses of Bi₂Te₃ and PdTe₂ layers are 10 nm and 6 nm, respectively. In PdTe₂ and Bi₂Te₃/PdTe₂, superconductivity is observed around 1 K.



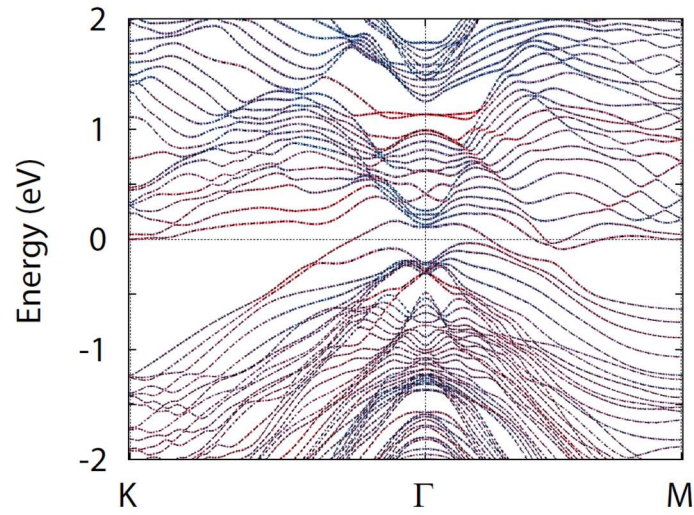
Supplementary Figure 5 | Current-voltage characteristics. (a) Log-log plot of current-voltage characteristics in $\text{Bi}_2\text{Te}_3/\text{PdTe}_2$ measured at various temperatures. (b) Temperature dependence of α value obtained from the fitting by $V \propto |I|^\alpha$ (black dotted lines) in (a). $T_{\text{BKT}} = 1.060$ K is estimated as the temperature at which α crosses 3.



Supplementary Figure 6. | Dependence of nonreciprocal response on the magnetic field direction and on the materials proximitized to PdTe₂. (a, d) Temperature dependence of R^ω in (a) Bi₂Te₃/PdTe₂ and (d) ZnTe (10 nm)/PdTe₂ (6 nm) at $I_0 = 10 \mu\text{A}$. The insets schematically draw the sample structures. (b, c) Magnetic field dependence of R^ω and $R^{2\omega}$ in Bi₂Te₃/PdTe₂ at 1.15 K under in-plane magnetic field perpendicular to I (red) and parallel to I (green). (e, f) Those in ZnTe/PdTe₂ at 0.95 K under in-plane magnetic field perpendicular to I . The insets in (c) and (f) schematically show the configuration of current I and magnetic field B . The arrows in (a) and (d) indicate the temperatures at which R^ω and $R^{2\omega}$ in (b, c) and (e, f) are measured, respectively. For each sample, R^ω and $R^{2\omega}$ are measured at the temperature where R^ω at $B = 0$ is close to the half of the normal state resistance.



Supplementary Figure 7 | Nonreciprocal response when magnetic field is tilted to the -z direction. Color plots of γ in the B_z - T plane for $\theta = -8.8^\circ$. γ shows similar sign-change to that for $\theta = 4.5^\circ$ (Fig. 3(e) in the main text), This observation indicates $R^{2\omega}$ is an even function of B_z .



Supplementary Figure 8 | Band structure of PdTe₂ (1 layer)/Bi₂Te₃ (6 layers)/PdTe₂ (1 layer). The lattice constant for the in-plane direction is that of PdTe₂. The red and blue lines correspond to the states originating from PdTe₂ and Bi₂Te₃, respectively.

Supplementary note 1| Estimation of the friction coefficient η

The friction coefficient η for the vortex motion is a temperature dependent quantity to be precise. In the fitting procedure in Fig. 4(a)-(c) of the main text, we used a constant value $\eta(T_{\text{BKT}})$ because the boundary in γ is dependent on T very weakly at around T_{BKT} . Since $\text{Bi}_2\text{Te}_3/\text{PdTe}_2$ can be regarded as a dirty superconductor as discussed in the next paragraph, we use the expression of η for a dirty superconductor to estimate $\eta(T_{\text{BKT}})$, $\eta = \frac{\phi_0^2}{2\pi\xi_0^2 R_N} \left(1 - \frac{T}{T_{c0}}\right)$ with ξ_0 being the Ginsburg-Landau (GL) coherence length at $T = 0$ K^{1,2}. At $T = T_{\text{BKT}}$, by using the values of $\xi_0 = 29$ nm evaluated from $B_{c2}^\perp(T)$, $R_N = 150 \Omega$, $T_{c0} = 1.174$ K, and $T = T_{\text{BKT}} = 1.025$ K, we obtain $\eta \sim 0.68 \text{ nm}^2\text{T}^2\Omega^{-1}$ at $T = T_{\text{BKT}}$.

In two-dimensional systems, the Fermi velocity v_F is given by $v_F = \hbar\sqrt{2\pi n}/m$ (m : electron mass, n : two-dimensional carrier density). By using the relationships for the mobility $\mu = 1/(eRn)$ and the momentum scattering time $\tau = \mu m/e$, the mean free path l can be expressed as $l = (h/e^2)(1/\sqrt{2\pi n}R)$, where R is two-dimensional resistance. From the Hall carrier density $p = 1.3 \times 10^{16} \text{ cm}^{-2}$ and the normal state resistance $R = 150 \Omega$, l in $\text{Bi}_2\text{Te}_3/\text{PdTe}_2$ can be estimated to be 6.0 nm, which is shorter than the GL coherence length at $T = 0$, $\xi_0 = 29$ nm. Therefore, the system can be regarded as a dirty superconductor.

References

- ¹ B.I. Halperin and D.R. Nelson, J. Low Temp. Phys. **36**, 599-616 (1979).
- ² Y.B. Kim and M.J. Stephen, in *Superconductivity*, edited by R.D. Park (Marcel Dekker, New York, 1969).