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Andreev reflection in s-type superconductor proximized 3D topological insulator. Supplemental Material.

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DIFFERENTIAL RESISTANCE IN A WIDE BIAS RANGE

In all N-TI-S devices studied the differential resistance, R_{diff} , behaves similarly to the reference N-TI-N device and exhibits no AR related features. This is verified in Figs. 1a and 1b for two representative devices in a wide bias range. Just like in the reference N-TI-N device, see Fig. 1c, the small zero bias feature in B = 0 develops into a pronounced resistance peak in a magnetic field $B \sim 1$ T. This behavior is qualitatively consistent with a scenario of competing quantum corrections, weak anti-localization and Altshuler-Aronov, among which the former is suppressed by a perpendicular magnetic field and both are suppressed by a high bias owing to dephasing, see, e.g. Ref.¹.

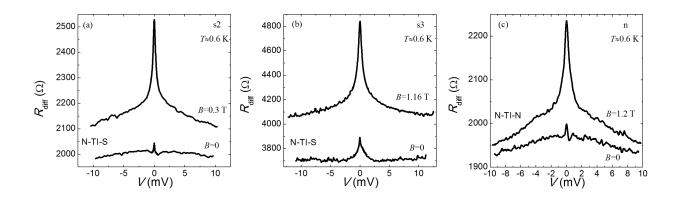


FIG. 1. Differential resistance in N-TI-S devices s2 (a) and s3 (b) and reference N-TI-N device n (c). The data is taken simultaneously with the main text noise data in Fig. 3 (s2), Fig. 4 (s3) and Fig. 2 (n).

ELECTRON-PHONON ENERGY RELAXATION

As discussed in the main text, at large biases, |V| > 0.8 mV, the data deviate below the q = e fit, both in zero and finite *B*-field, which is a result of shot noise suppression via electron-phonon (e-ph) energy relaxation^{2,3}. We have checked that for $T_N > 5 \text{ K}$ the e-ph cooling dominates the noise response and is consistent with the linear dependence $P_J \propto T_N^{\alpha} - T^{\alpha}$, where P_J is the total dissipated Joule heat power and the exponent varies between $\alpha \approx 3$ and $\alpha \approx 4$ in different devices, see Fig. 2. A cooling rate of this type might arise from the interaction with two-dimensional (e.g., surface) acoustic phonons^{4,5}, similar to graphene^{6–8}, or the interplay of *e-ph* and impurity scattering⁹. Note, that the doping dependence of the surface electrons' cooling rate in 3D TI¹⁰ Bi₂Se₃ at much higher T is consistent with the relaxation via surface acoustic phonons.

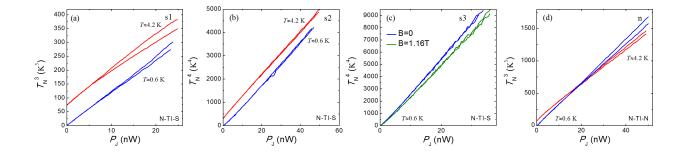


FIG. 2. E-ph energy relaxation in the strongly non-equilibrium transport regime. Close to linear dependence $T_N^{\alpha} \propto P_J$ at bath temperatures of T = 0.6 K (blue curves) and T = 4.2 K (red curves) in devices s1(a), s2(b), n(d) and at bath temperature of T = 0.6 K at zero (blue curve) and nonzero (green curve) magnetic field in device s3(c).

- [1] H.-Z. Lu and S.-Q. Shen, Phys. Rev. Lett. **112**, 146601 (2014).
- [2] K. E. Nagaev, Physics Letters A 169, 103 (1992).
- [3] Y. Blanter and M. Büttiker, Physics Reports **336**, 1 (2000).
- [4] S. S. Kubakaddi, Phys. Rev. B **79**, 075417 (2009).
- [5] J. K. Viljas and T. T. Heikkilä, Phys. Rev. B 81, 245404 (2010).
- [6] A. C. Betz, F. Vialla, D. Brunel, C. Voisin, M. Picher, A. Cavanna, A. Madouri, G. Fève, J.-M. Berroir, B. Plaçais, and E. Pallecchi, Phys. Rev. Lett. 109, 056805 (2012).
- [7] A. M. R. Baker, J. A. Alexander-Webber, T. Altebaeumer, and R. J. Nicholas, Phys. Rev. B 85, 115403 (2012).
- [8] K. C. Fong and K. C. Schwab, Phys. Rev. X 2, 031006 (2012).
- [9] A. Sergeev and V. Mitin, Phys. Rev. B **61**, 6041 (2000).
- [10] Y. H. Wang, D. Hsieh, E. J. Sie, H. Steinberg, D. R. Gardner, Y. S. Lee, P. Jarillo-Herrero, and N. Gedik, Phys. Rev. Lett. 109, 127401 (2012).