

## UvA-DARE (Digital Academic Repository)

## Andreev Reflection in an s-Type Superconductor Proximized 3D Topological Insulator

Tikhonov, E.S.; Shovkun, D.V.; Snelder, M.; Stehno, M.P.; Huang, Y.; Golden, M.S.; Golubov, A.A.; Brinkman, A.; Khrapai, V.S.

DOI [10.1103/PhysRevLett.117.147001](https://doi.org/10.1103/PhysRevLett.117.147001)

Publication date 2016

Document Version Other version

Published in Physical Review Letters

### [Link to publication](https://dare.uva.nl/personal/pure/en/publications/andreev-reflection-in-an-stype-superconductor-proximized-3d-topological-insulator(10c14fc8-4d69-4cc1-9d09-c0316e5b6f17).html)

#### Citation for published version (APA):

Tikhonov, E. S., Shovkun, D. V., Snelder, M., Stehno, M. P., Huang, Y., Golden, M. S., Golubov, A. A., Brinkman, A., & Khrapai, V. S. (2016). Andreev Reflection in an s-Type Superconductor Proximized 3D Topological Insulator. Physical Review Letters, 117(14), [147001].<https://doi.org/10.1103/PhysRevLett.117.147001>

#### General rights

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

#### Disclaimer/Complaints regulations

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: https://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (http*s*://dare.uva.nl)

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

E.S. Tikhonov,<sup>1,2</sup> D.V. Shovkun,<sup>1,2</sup> V.S. Khrapai,<sup>1,2</sup> M. Snelder,<sup>3</sup> M.P.

Stehno,<sup>3</sup> Y. Huang,<sup>4</sup> M.S. Golden,<sup>4</sup> A.A. Golubov,<sup>3,2</sup> and A. Brinkman<sup>3</sup>

<sup>1</sup>Institute of Solid State Physics, Russian Academy of Sciences, 142432 Chernogolovka, Russian Federation <sup>2</sup>Moscow Institute of Physics and Technology, Dolgoprudny, 141700 Russian Federation  $3MESA + Institute for Nanotechnology,$ University of Twente, Enschede, the Netherlands  $4$  Van der Waals - Zeeman institute, University of Amsterdam, the Netherlands.

#### DIFFERENTIAL RESISTANCE IN A WIDE BIAS RANGE

In all N-TI-S devices studied the differential resistance,  $R_{\text{diff}}$ , 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.  $Ref<sup>1</sup>$ .



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<sup>2,3</sup>. We have checked that for  $T<sub>N</sub> > 5$ 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<sup>4,5</sup>, similar to graphene<sup>6-8</sup>, or the interplay of e-ph and impurity scattering<sup>9</sup>. Note, that the doping dependence of the surface electrons' cooling rate in 3D  $TI^{10}$  Bi<sub>2</sub>Se<sub>3</sub> 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).