nature physics

SUPPLEMENTARY INFORMATION

DOI: 10.1038/NPHYS2154

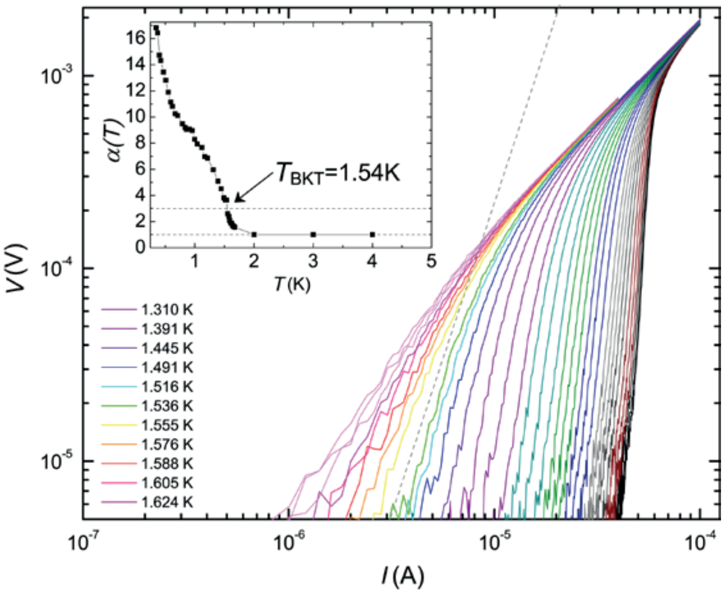
Approaching zero-temperature metallic states in mesoscopic superconductor–normal–superconductor arrays

[1]Serena Eley, [1]Sarang Gopalakrishnan, [2]Paul M. Goldbart, [1]Nadya Mason

[1] Department of Physics and Frederick Seitz Materials Research Laboratory, University of Illinois Urbana-Champaign, 104 South Goodwin Ave, Urbana, Illinois 61801-2902, USA
[2] School of Physics, Georgia Institute of Technology, 837 State Street, Atlanta, Georgia 30332-0430, USA

Extracting T_2 from *IV* curves

The Berezinskii-Kosterlitz-Thouless (BKT) transition temperatures T_2 discussed in the main text were extracted from *IV* measurements of the devices. SNS arrays are known to undergo a BKT (i.e., vortex-antivortex binding) transition to a fully superconducting state[1]. Below T_2, applying a finite excitation current creates a Lorentz force on bound vortex pairs, causing some pairs to unbind. Dissipation caused by current-induced free vortices may overwhelm that caused by thermally unbound vortices near T_2, causing a significant resistance at temperatures less than T_2. For $T > T_2$, free vortices cause the array to exhibit Ohmic resistance. For $T < T_2$, the *IV* characteristics are nonlinear such that



Identification of BKT Transition. a, Non-linear *IV* characteristics at different temperatures for 340-nm spaced islands in array with 87 nm Nb, where $V \propto I^{\alpha(T)}$ A slope of $\alpha(T_2) = 3$ is marked by the dotted line. The inset shows the evolution of the slope of the *IV* curves, $\alpha(T)$, and identifies the Nelson-Kosterlitz jump in $\alpha(T)$ at T_2.

$V \propto I^{\alpha(T)}$, where $\alpha\left(T\right) = 2(T_2 / T) + 1$ for $T \le T_2$ and $\alpha(T) = 1$ for $T > T_2$, leading to $\alpha(T_2) = 3$. This Nelson-Kosterlitz jump in the temperature-dependent exponent $\alpha(T)$ is a universal signature of a BKT transition, although finite-size effects and weak magnetic fields can smear this transition. Consequently, it is standard practice to extract T_2 from *IV* characteristics[2]. (In contrast, it is often difficult to accurately fit resistance vs. temperature data to theory, which predicts the flux flow resistance form $R \propto \exp(-b\sqrt{T - T_2})$). For our devices, *IV* curves were measured for a wide range of temperatures above and below T_2. All measurements above 1.5 K were performed in a pumped He-4 cryostat, and lower temperature measurements were performed in a He-3 refrigerator. To minimize Joule heating, *IV* characteristics were measured using rectangular current pulses, with a current-on time of 3.5 ms and current-off time of 3 ms. Figure 4 shows a log-log plot of *IV* curves at different temperatures for the 340-nm spaced array with 87-nm thick Nb islands, as an example. The dotted line shows where the slope of the curves is $\alpha(T_2) = 3$, while the inset shows the temperature dependence of α, extracted from the slope of each curve. Note the jump in $\alpha(T)$ at $T_2 = 1.54K$. Results for the other devices showed similar jumps in $\alpha(T)$, which allowed us to extract T_2 as a function of array spacing.

---

[1] Resnick, D.J., Garland, J.C., Boyd, J.T., Shoemaker, S. & Newrock, R.S. Kosterlitz-Thouless Transition in Proximity-Coupled Superconducting Arrays. *Physical Review Letters* **47**, 1542 (1981); Abraham, D.W., Lobb, C.J., Tinkham, M. & Klapwijk, T.M. Resistive transition in two-dimensional arrays of superconducting weak links. *Physical Review B* **26**, 5268 (1982).

[2] Nelson, D.R. & Kosterlitz, J.M. Universal Jump in the Superfluid Density of Two-Dimensional Superfluids. *Physical Review Letters* **39**, 1201 (1977).