

Supplementary Information: Approaching Zero-Temperature Metallic States in Mesoscopic Superconductor-Normal-Superconductor Arrays

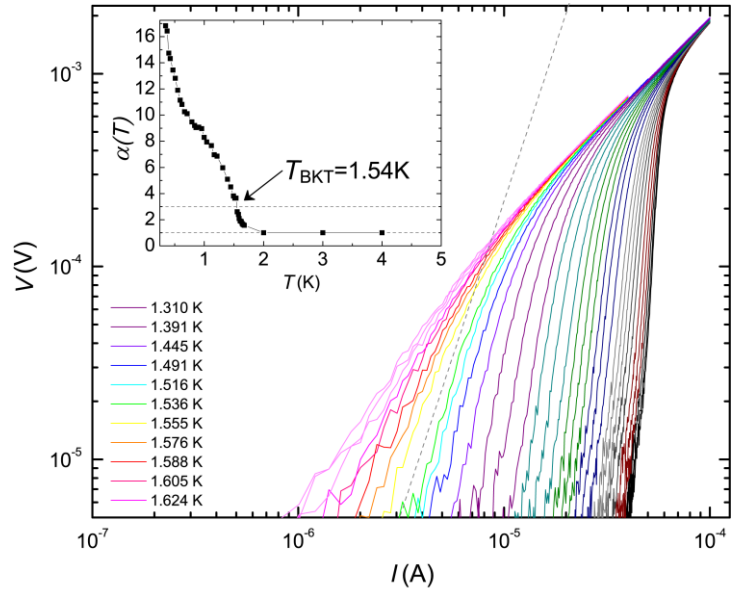
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Extracting T_2 from IV curves

The Berezinskii-Kosterlitz-Thouless (BKT) transition temperatures T_2 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 state¹. 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 $\alpha(T) = 2(T_2/T) + 1$ for $T \leq T_2$ 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 characteristics². (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).