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Supplementary Information for

New simple method for Point Contact Andreev Reflection (PCAR) using a self-aligned atomic filament in transition-metal oxides

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S1. Calculation of components composing the measured resistance

For the PCAR measurement, we used the four-probe method. In detail, four contacts were formed, two on the top Nb film and the other two on the bottom Pt film. Consequently, we can exclude the lead resistance. Then, the measured consists of (1) R_{Pt} (resistance of the Platinum in the part from the wire contact to the Ni filament), (2) Ni filament (R_{Ni}), and (3) the point contact resistnace (R_{pc}). The first is assumed to be negligible considering the thickness and the area of the Pt film. The second is estimated to be less than 10 Ω, which is described below. In a resistive memory device using a transition metal oxide, the conducting filament is known to have a conical shape which has the larger contact at the cathode.[1] The resistance ($R_{filament}$) of a conical shaped filament is given by the following equation.

$$R_{filament} = (\frac{1}{a})\frac{\rho d}{\pi r^2}$$

Here, ρ, d, and r are the resistivity of Ni, the length and the smaller radius of the conical filament, respectively. a means the ratio of the larger radius of the filament to the smaller one, which should be larger than 1. ρ is known to be 10~50 nΩm at T=1.7 K.[2] In our device, d is 130 nm, which is the thickness of the NiO_x film. And r is calculated to be about 2~3 nm from the Sharvin resistance. Finally, a is estimated to be about 50~70 from a TEM image presented in the aforementioned paper.[1] Using these values, we can estimate R_{Ni} less than 10 Ω. In our PCAR measurement, the measured resistance was about 100~200 Ω, implying the dominance of R_{pc} in the measured resistance.

S2. Fitting of experimental data to the modified BTK model

We performed the BTK model calculation using the formulation described in ref. 1 and ref. 7~10 in the main text. Because the BTK model requires the numerical integration for calculating the current, we used a graphical method to calculate the optimum fitting parameters. With varying (*P*, *Z*, *T*, Δ_{sc}), we searched for a point where the variance of the experimental data from the modified BTK model calculation has the minimum. The range of variation was [0.35, 0.45] for *P*, [0, 0.2] for *Z*, [1.7 K, 5 K] for *T*, and [0.3 meV, 1.2 meV] for Δ_{sc}, respectively. After a few iterations, we found the minimum point at (*P*, *Z*, *T*, Δ_{sc})=(0.4± 0.01, 0.05± 0.01, 3.1 ± 0.1 K, 0.55 ± 0.05 meV) with the variance of about 0.002. Because of the broad dip structure from 2 mV to 10 mV, which is usually observed in the PCAR measurement but not reproduced in the BTK model, we calculated the variance only in the (0, 2 mV) region. In the Figure S1, we plotted a few contour plots to show the variance in the parameter space. In addition, we plotted the fitting curve with the experimental data (Figure S2).

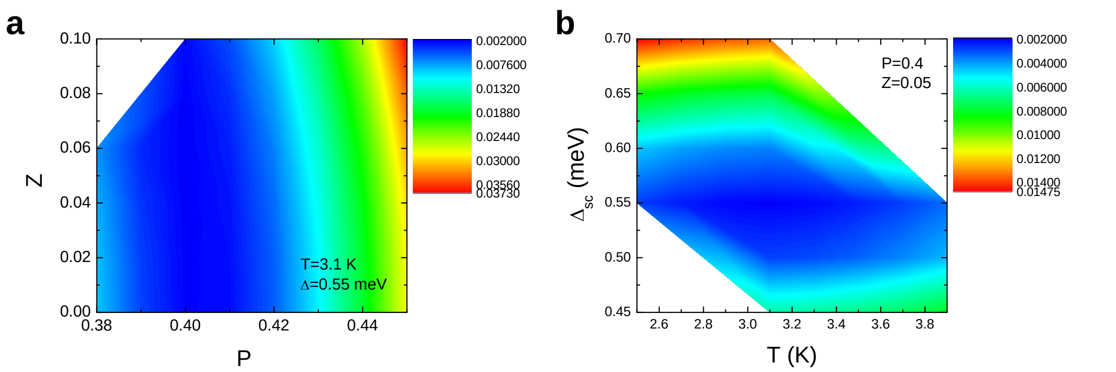

Figure S1. Contour plots of the variance in the parameter space (*P, Z, T,* Δ_{sc}). (A) In the (*P*, *Z*) space, where (*T*, Δ_{sc}) is fixed at (3.1 K, 0.55 meV), (B) In the (*T*, Δ_{sc}) space, where (*P*, *Z*) is fixed at (0.4, 0.05).

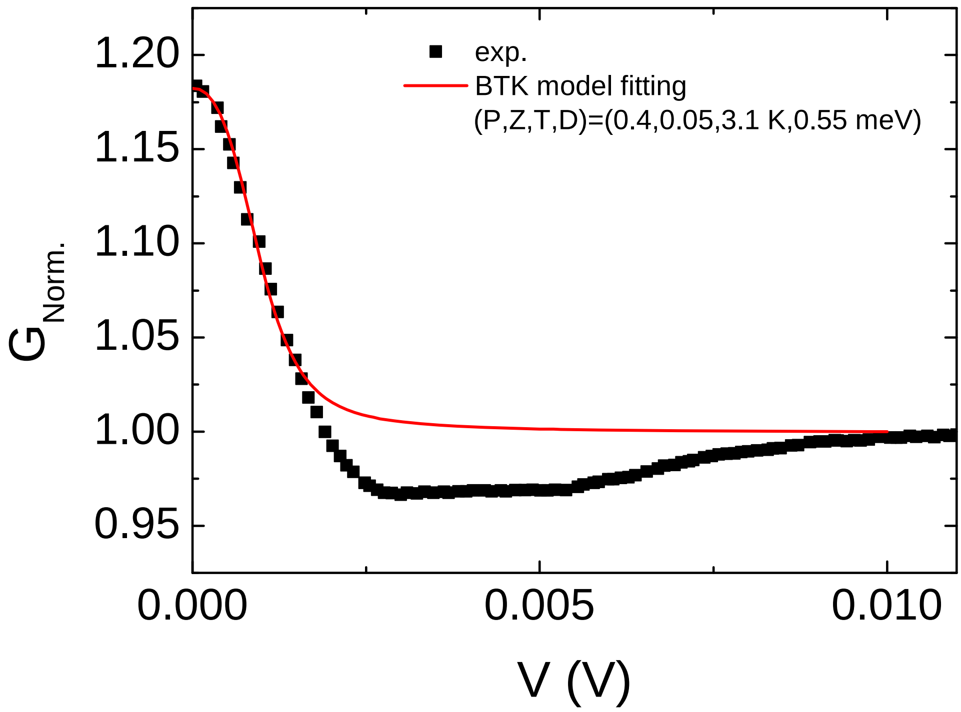

Figure S2. Normalized conductance (*$G_{Norm.}$*) vs. bias voltage (*V*) curve. Symbols represent the experimental data at *T*=1.7 K. The red solid line represents the BTK fitting curve using (*P*, *Z*, *T*, Δ_{sc})=(0.4, 0.05, 3.1 K, 0.55 meV).

Supplementary references

1 Yang, Y. C., Pan, F., Liu, Q., Liu, M. & Zeng, F. Fully Room-Temperature-Fabricated Nonvolatile Resistive Memory for Ultrafast and High-Density Memory Application. *Nano Letters* **9**, 1636-1643, doi:10.1021/nl900006g (2009).

2 De Vries, J. W. C. Temperature and thickness dependence of the resistivity of thin polycrystalline aluminium, cobalt, nickel, palladium, silver and gold films. *Thin Solid Films* **167**, 25-32, doi:http://dx.doi.org/10.1016/0040-6090(88)90478-6 (1988).