Supplementary material – From stochastic single atomic switch to nanoscale resistive memory device

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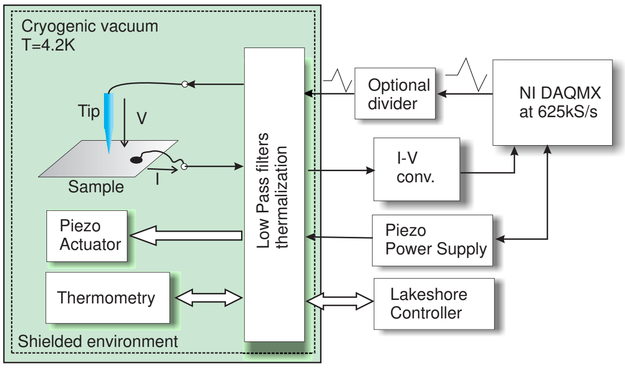
Experimental technique



S. 1 *Schematic drawing of the experimental setup.*

Nanoscale contacts were created by gently touching an Ag thin film sample with an electrochemically sharpened W tip. For coarse adjustment a screw thread mechanism was used, whereas for the fine positioning a 3D piezo actuator was applied. All measurements were performed at cryogenic temperature ($T = 4.2$ K) in order to ensure the appropriate mechanical stability of the contacts. Numerous contacts were created with variable conductances at different lateral positions of the sample using this setup.

All the contacts are characterized by I-V curve measurements applying the scheme in S. 1. The bias voltage was applied to the junctions utilizing a National Instruments data acquisition card. The output voltage is divided and filtered in order to ensure low noise on the contact. The current was measured using a variable range I-V converter and then processed by the data acquisition card. The current-voltage characteristic of the junctions were taken by linearly ramped voltage. A full cycle was recorded in 400 ms.

Sample preparation and characterization

The Ag thin layer samples were produced by vacuum evaporation on a Si wafer. The nominal layer thickness of the evaporated Ag samples was 20 nm. We have observed reproducible resistive switching after exposing the samples to air for more than seven days. Control experiments on samples stored in inert Ar atmosphere on the same time scale and just exposing the sample to air for a few minutes to load the sample to the cryostat have not shown similar effect. Samples that have been exposed to air for several months have also shown the reproducible resistive switching.

The thin films were analyzed by Rutherford backscattering (RBS). The RBS data have shown an average density of 15 atom/nm^2 of sulfur and 51 atom/nm^2 of oxygen on the surface. The precise structure of the surface layer is not known, and presumably the distribution of sulfur on the surface is not uniform. We note that an isolating oxide layer is easily crashed through by our technique.

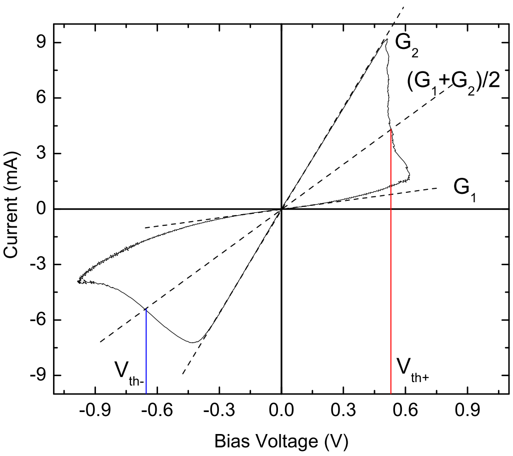
Determination of the junction area

The size of the junctions was estimated by the Sharvin equation that provides the contact resistance R in the ballistic transport regime ($r < l_m$, where r is the contact radius and l_m is the mean free path of the electrons):

$$R = \frac{4\rho l_m}{3A} = \frac{4\rho l_m}{3r^2\pi}$$

Based on the measurement of the low temperature residual resistivity $\rho = 7.2 \times 10^{-8}\ \Omega$m, the mean free path in the Ag thin film sample is estimated to be $l_m = 12$ nm. The estimated junction areas are consistent with the assumption of being in the ballistic limit.

For junctions with a non-transparent barrier in the contact area the above formula should be multiplied by the trans-



S. 2 *Definition of the switching threshold voltages on a typical I-V curve.*

mission probability, τ through the contact barrier. For inhomogeneous junctions, where less transparent regions are also present, an average transmission of $\tau \approx 0.1$ would correspond to approximately three times larger contact diameter compared to the case of fully transparent contacts.

Scaling of the I-V curves

After an appropriate linear transformation the I-V curves can be scaled together in order to investigate the uniform character of the shape of the switching characteristics, as shown in Fig. 3 of the manuscript. This transformation is performed by the following method:

(i) the voltage scale is normalized to the average threshold switching voltage, $V' = 2V/(V_{\text{th+}} - V_{\text{th-}})$, where the threshold voltages $V_{\text{th+}}$ and $V_{\text{th-}}$ are determined by the method demonstrated in S. 2.

(ii) a linear transformation, $I' = aI + bV'$ is applied on the current scale, where the coefficients a and b are chosen to obtain $G'_{\text{ON}} = 2$ and $G'_{\text{OFF}} = 1$ for the transformed ON and OFF state zero bias conductances, $G' = I'/V'$.