Kinetics underlying the switching time of a silver sulfide atomic switch

Alpana Nayak, Kazuya Terabe, Tohru Tsuruoka, Tsuyoshi Hasegawa, and Masakazu Aono

WPI Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan.

NAYAK.Alpana@nims.go.jp

Nanoionics based atomic switches have been attracting much attention in recent years to overcome the limitations of conventional semiconductor technology. Prior to their use in actual devices, a fundamental understanding of the switching mechanism is necessary. Accordingly, we investigated the switching time of a Ag_2S atomic switch as a function of bias voltage and temperature. A Ag_2S atomic switch[1], in which the formation and annihilation of Ag atomic bridge is controlled by a solid-electrochemical reaction, is realized across a nanogap between a solid-electrolyte electrode (Ag_2S) and a counter metal electrode (Pt tip of STM). Increasing the bias voltage decreases the switching time exponentially[2] with a greater exponent for the lower range of bias than that for the higher range. The two distinct exponential decay components indicate an existence of different rate-limiting processes for lower and higher bias voltages. Furthermore, the switching time shortens with raising temperature, following the Arrhenius relation. The activation energy extracted from the Arrhenius plots yielded values of 0.58 eV and 1.32 eV for the lower and higher bias ranges, respectively. On the basis of these results, we infer that, there are two main processes which govern the switching mechanism; first, the electrochemical reaction $Ag^+ + e^- \rightarrow Ag$, and second, the diffusion of Ag^+ ions, and that the rate-limiting process depends on the range of bias applied. We believe that the switching time is reaction-limited for lower bias voltages and diffusion-limited for higher bias voltages. This investigation advances the fundamental understanding of the switching mechanism of the atomic switch which is essential for its successful device application.

References

[1] K. Terabe, T. Hasegawa, T. Nakayama, and M. Aono, Nature, **433** (2005), 47.
[2] A. Nayak, T. Tamura, T. Tsuruoka, K. Terabe, S. Hosaka, T. Hasegawa, and M. Aono *The Journal of Physical Chemistry* Letters **1** (2010), 604.

Figure1. (a) Schematic representation of the operation of an electrochemically controlled Ag_2S atomic switch with a nanogap, (b) Switching time t_{sw} measured as a function of bias V_{sw} at room temperature for an initial off-resistance of 1 MΩ. The dashed lines show the two distinct exponential decay components with different activation energy E_a. The temperature dependence of t_{sw} is shown in the inset.