INVENTION, DEVELOPMENT AND APPLICATION OF THE ATOMIC SWITCH

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In the course of a research project on “Exploring Novel Functionality of Artificial Nanostructures” (1995-2000) directed by the author under the sponsorship of the CREST* program of the Japan Science and Technology Agency (JST), we developed a novel nonvolatile two-terminal switch, which is referred to as the “atomic switch”. The atomic switch consists of two electrodes separated by a nanoscale gap; one of the two electrodes is made of a solid electrolyte in which both ions and electrons contribute to electrical conduction, and the other electrode is made of an ordinary metal. Typical solid electrolytes suitable for the atomic switch are metal sulfides such as Ag_2S and Cu_2S, in which metal ions are moving in the rigid lattice of sulfur ions. If we take the case of Ag_2S as an example, when we apply an appropriate positive bias voltage to the Ag_2S electrode, tunneling electrons flow from the counter electrode to the Ag_2S electrode, so that part of Ag^+ ions in the Ag_2S electrode are deposited at the surface of the Ag_2S electrode forming a nanoscale cluster of Ag atoms through a solid electrochemical reaction ($Ag^+ + e- \rightarrow Ag$). The deposited Ag atoms eventually bridge the two electrodes to turn on the two-terminal switch. By applying an appropriate negative bias voltage to the Ag_2S electrode, the deposited Ag atoms dissolve into the Ag_2S electrode again through a reverse electrochemical reaction ($Ag + e- \rightarrow Ag^+$), so that the switch is turned off. Since the conductivity of the nanoscale atomic switch is quantized in units of $2e^2/h$, we often call the atomic switch “Quantized Conductance Atomic Switch (QCAS)”. For more detailed studies of the QCAS including its practical application, a project on “Application of Quantized Conductance Atomic Switch to Practical Functional Devices” (2001-2004) and another project on “Nanoscale Quantum Conductor Array” (2004-2009) have been organized by the author in collaboration with NEC Corp. under the sponsorship of the SORST** and ICORP*** programs, respectively, of JST . In these projects, it has been revealed[1)] that the QCAS is 1) much smaller in size than the conventional transistor switch (about 1/30 in area), 2) nonvolatile (stable for months at least at RT), 3) considerably fast in switching speed (1 GHz can be expected at least), 4) simple and easy in micro- and nano-scale fabrication, 5) low in power consumption (as low as about 1 nW). Also in these projects, a) a memory cell array of 1 kb and b) a crossbar-type switch array for reconfigurable LSI have been manufactured successfully and their good performance was confirmed[2)].

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1) For example, K. Terabe, T. Hasegawa, T. Nakayama, and M. Aono, Nature 433 (2005) 47.
2) For example, S. Kaeriyama, T. Sakamoto, H. Sunamura, M. Mizuno, H. Kawaura, T. Hasegawa, K. Terabe, T. Nakayama, and M. Aono, IEEE J. Solid-State Circuits 40 (2005) 168.