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Quantum Point Contact Switch using Solid Electrochemical Reaction

Tsuyoshi Hasegawa,[1,2] Kazuya Terabe,[1,2] Tomonobu Nakayama,[1,2] and Masakazu Aono[1,2,3]

Senior Research Scientist, [1]Surface and Interface Laboratory, RIKEN (The Institute of Physical and Chemical Research), Hirosawa 2-1, Wako, Saitama, 351-0198, Japan
Phone: +81-48-467-9303 Fax: +81-48-462-4656 E-mail: t-hasega@postman.riken.go.jp
[2]CREST, Japan Science & Technology Corporation (JST)
[3]Department of Precision Science and Technology, Osaka University, Yamadaoka 2-1, Suita, Osaka, 565-0871, Japan

1. Introduction

Quantum conductance in metallic nanowires has been extensively investigated since the first report of an experiment using a gold nanowire [1]. In most cases, nanowires showing conductance quantized in units of ($2e^2/h$) have been formed by contacting two electrodes using mechanical positioning systems such as a scanning tunneling microscope (STM) [2]. Recently, a quantum point contact (QPC) switch has been demonstrated by repeatedly bringing a sharpened metallic wire into contact with a gold surface using a STM [3]. However, in view of introducing QPCs into actual devices, a QPC is required to be controlled electrically.

We developed a new type of QPC using a solid electrochemical reaction, whose conductance is controlled simply by applying a certain bias to it. Since it works in air at room temperature without a mechanical positioning system, this QPC is easily introduced into actual devices.

Here, we report the new QPC, particularly its function as a switching device.

2. Principle of the QPC

A silver wire covered by silver sulfide (Ag2S) crystal, which is a mixed ionic and electronic conductor [4], is used as one of two electrodes. Pt wire is used as the other electrode, which is set at a distance of 1 nm from the Ag2S electrode. When a negative bias is applied to the Pt electrode with respect to the Ag2S electrode, silver ions in Ag2S are neutralized to silver atoms by electrons flowing from the Pt electrode, resulting in the precipitation of the silver atoms at the surface of Ag2S, as shown in Fig. 1(a). Between the two electrodes, the silver atoms form an atomic bridge whose conductance can be quantized. When the opposite bias is applied, silver atoms in the bridge are ionized and dissolved into the bulk of Ag2S, as shown in Fig. 1(b), which results in the thinning and breaking of the bridge. In this manner, the formation and destruction of the QPC can be controlled by applying a bias between the electrodes.

3. Experimental

Ag2S single crystal was prepared by the reaction of a silver wire with sulfur vapor [5]. Needlelike single crystals of Ag2S with lengths of 0.01 - 0.1 mm grown at the end of a silver wire were used as one electrode. Figure 2 shows one of the Ag2S crystal used in the experiment. A chemically polished Pt wire was used as the other electrode. First, the two electrode were brought sufficiently close to each other so that a tunneling current flowed between them with a bias lower than the threshold bias of QPC formation [5]. Then, they were fixed with resin and the formation and annihilation of the QPC were controlled simply by changing the bias between them.

4. Result

First, growth and shrinkage of a silver protrusion on the Ag2S crystal was studied by STM. As shown in Fig. 3, these phenomena can be controlled simply by applying a certain bias. Plateaus in Fig. 3 indicates that the phenomena have threshold bias and current to be caused. Figure 4 shows the silver protrusion grown in the STM experiment.

To make a switch, the two electrodes were fixed, as mentioned above. Figure 5 shows a cyclic formation and deformation of the silver atomic bridge between the two electrodes, which can continue endlessly. Using binomial biases, the QPC functions as a switching device. Figure 6 shows an example in which +500 mV and -500 mV were applied to a sample alternately at 100 kHz. Since +500 mV and -500 mV are much higher than the threshold biases of bridge formation and destruction, these phenomena occurred immediately when the bias was changed.

Switching between conductances quantized in units of ($2e^2/h$) has also been demonstrated using a certain bias. Logic gates, such as AND, OR and NOT gates, consisting of the QPCs also worked well.

5. Conclusion

A quantum point contact (QPC) switch was realized by a solid electrochemical reaction. The growth and shrinkage of a silver nanotip at the apex of a Ag2S tip were controlled simply by applying a bias between two electrodes. The QPC has the function of switching which can be used in actual devices.

References

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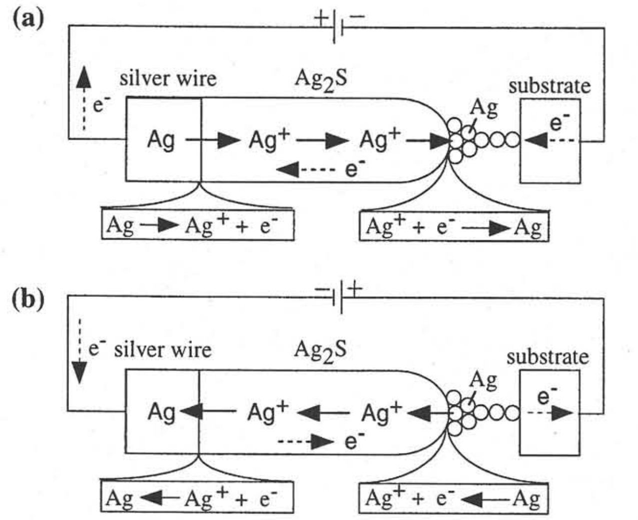

Fig. 1 Principle of a QPC switch. (a) Formation process, and (b) destruction process of the QPC.

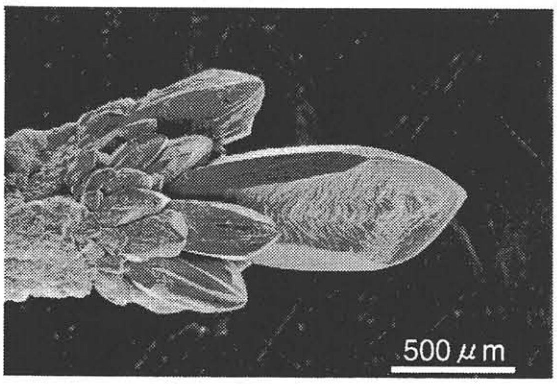

Fig. 2 Ag_2S crystal grown at the end of silver wire.

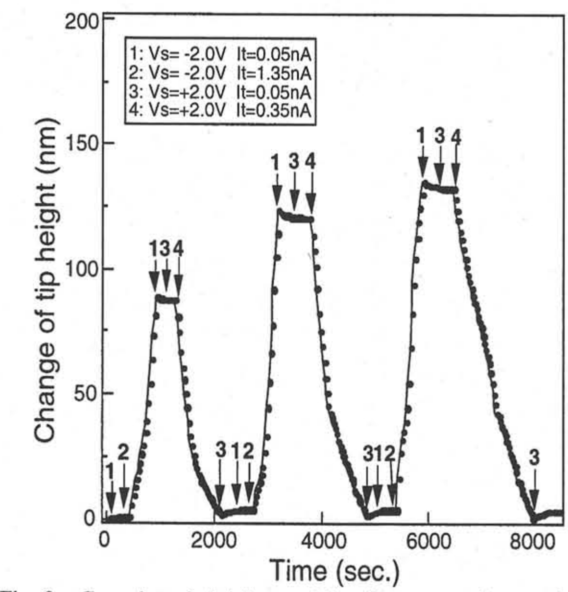

Fig. 3 Growth and shrinkage of the silver protrusion on the Ag_2S crystal. The Ag_2S crystal was used as a tip of a scanning tunneling microscope, and the change in the tip height was measured.

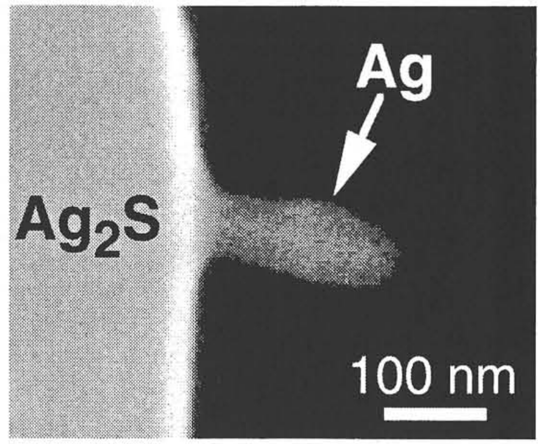

Fig. 4 The silver protrusion grown at the apex of the Ag2S tip.

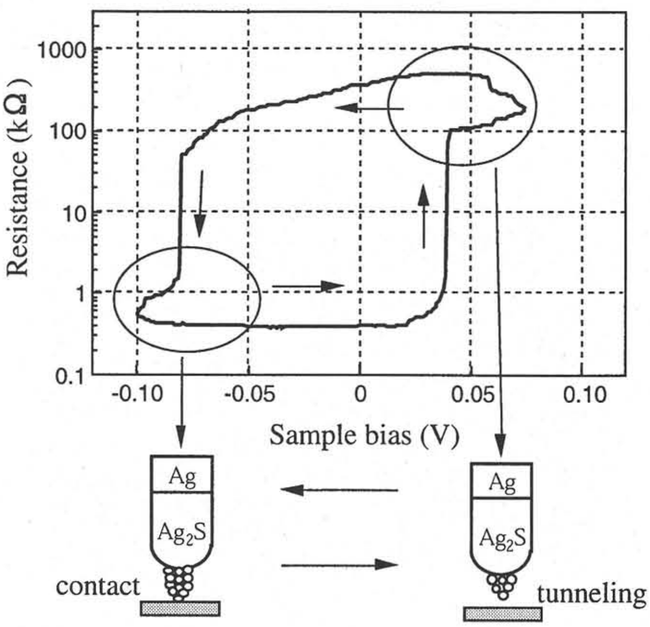

Fig. 5 Formation and deformation of a silver atomic bridge between the Ag_2S tip and the sample.

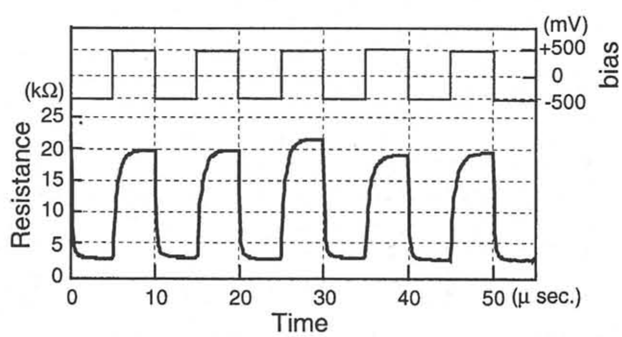

Fig. 6 Switching at 100 kHz.