Preparation of Sustainable Metal Thin Wire Showing Quantized Conductance in Solution

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Construction of metal nano-wire and nano-junction is in the central issue of the recent nano-technology. If one can control metal nano-structure precisely, the resulting structure could be used for various novel devices based on their characteristics, such as quantized conductance properties, single-electron charging, electronic transport properties of single molecules. Thus, the way to prepare the metal nano-structure should be developed. We have shown the possibilities of chemical techniques to apply to the fabrication of nano-structures on solid surfaces as novel, effective, and low-energy processes.[1] Among them, an electrochemical method should be one of the most promising techniques to fabricate nano-structures. The controlled absolute potential of the electrode in solution results in precise control of atomic processes on solid surfaces. Recently interesting examples have been reported on the fabrication of nano-junctions via electrochemical processes and on the observation of the conductance quantization. The nano-junctions are prepared either at a gap between the tip and the substrate of a scanning tunneling microscope (STM) or a gap between two micro-electrodes prepared by photolithography. Another interesting method is to use the electrochemical dissolution and deposition of a thin metal wire in solution. This method is one the simplest and very useful if sustainable nano-contacts can be prepared reproducibly.

In this paper, we report the preparation of nano-contacts of several metals such as Ag by use of the electrochemical deposition and dissolution of the metals at a stable gap such as an Au gap. This gives an interesting way to prepare nano-contacts of a variety of metals, for the fabrication of nano-contacts in solution are now mainly limited to Cu.[2]

The metal nano-contacts were prepared as follows. A Au wire (30 μm in diameter) was attached to a glass plate with adhesive insulating tapes, with a region of a few hundred μm's in width being left as a gap, at which the metal wire could be in contact with an electrolyte solution. The electrochemical dissolution of the metal wire at the gap resulted in the formation of a thin metal wire with the diameter less than a few μm (Figure 1). The further dissolution led to the disconnection of the wire, which was easily detected by simultaneous measurement of its conductance. The nano-contact was formed just before the wire was disconnected. The formation of Ag nano-contacts was performed by the controlled deposition and dissolution of Ag at a gap of an Au wire.

We succeeded in preparing sustainable metal nano-contacts at a gap between two thin Au wires. The dissolution of an Au wire (d = 30 μm) proceeded in KCl solution, leading to the formation of a thin Au wire and final disconnection. After the formation of a gap in a thin Au wire, metals such as Cu, Ag, and Ni was deposited on it. Several repeated metal deposition and dissolution led to the formation of metal nano-contacts showing a unit of the quantized conductance ($G_0 = 2e^2/h$) lasting for 100 s or more. The result indicates that a gap between two thin Au wires can be used effectively for the fabrication of sustainable nano-contacts of other metals.

Ag was deposited on Au when the potential of Au was kept at –0.3 V in 0.05 M H_2SO_4 + 1 mM $AgNO_3$, which is about 0.7 V more negative than the equilibrium potential for the Ag dissolution (0.4 V). The deposition Ag was dissolved at 0.44 V. The stepwise changes of the conductance were observed both for the deposition of Ag and the dissolution of it. In the latter case, the unit conductance, G_0, was observed for a long time of more than a thousand seconds. The results again clearly show the formation of sustainable metal nano-contacts showing the quantized conductance, indicating the effectiveness of the present method.

It may be noted that the conductance at several current plateaus whose conductance are different from integral multiples of the unit conductance (G_0). Such deviations are often observed in electrochemical systems.[3] The formation of certain characteristic configurations of metal atoms in electrolyte solutions may be responsible for the deviations, since it is plausible that the structure of the metal nano-contacts depends on the kinds of solvent and electrolyte ions used.

In conclusion, sustainable metal nano-contacts showing the conductance quantization were successfully prepared by electrodeposition and dissolution of metals at a gap of Au wires.[4] The technique may be applied easily to various other materials, whose structures can be controlled by electrochemical process, to investigate detailed properties of nano-contacts in solution.

References

(1) K. Murakoshi and Y. Nakato, *Adv. Mater.*, **12**, 791 (2000).
(2) C. Z. Li, A. Bogozi, W. huang and N. J. Tao, *Nanotechnology*, 1999, **10**, 221.
(3) C. Shu, C. Z. Li, H. X. He, A. Bogozi, J. S. Bunch and N. J. Tao, *Phys. Rev. Lett.*, 2000, **84**, 5196.
(4) J. Li, Y. Yamada, K. Murakoshi, and Y. Nakato, *Chem. Comm.*, 2170 (2001).

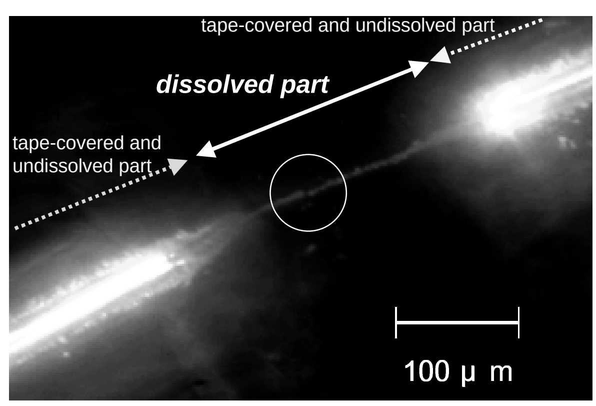

Figure. 1 Optical microscopic image of a thin metal wire (d = 1-2 μm) prepared by electrochemical dissolution. The circle shows the broken part of the wire.