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Nano-scale Cu metal patterning by using an atomic force microscope

Y. Tomita*, Y. Hasegawa, K. Kobayashi

Department of Materials Research and Chemical Engineering, Shizuoka University, 3-5-1 Johoku, Hamamatsu 432-8561, Japan

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Abstract

Nano-scale Cu metal patterning was achieved by the use of an atomic force microscope. When the scanning with the cantilever of atomic force microscope (AFM) covered with the solid electrolyte was carried at a negative voltage, the Cu metal was deposited on TiO_2 substrates. The Cu metal on TiO_2, a glass and Si substrates was absorbed at the positive voltage. The deposition and the absorption of Cu could be repeated and carried out at room temperature without a specific treatment. The letters "Y" and "T" were written with 50 nm resolution by the scanning. The reaction between the tip of the cantilever and substrate is a simple electrochemical reaction.

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Keywords: Atomic force microscope; Ionic conductor; Metal patterning; Nano-fabrication

1. Introduction

Developing top-down lithography techniques capable of fabricating structures below the 100 nm scale is indispensable for future device miniaturization, and many techniques were developed. It is, however, difficult to fabricate a metal nano-pattern on various substrates without chemical treatment such as dry and wet etching. Recently, nano-lithography using selective growth on Si, self-assembly of Au and an electron-beam etching was reported. But these methods could not be applied to an arbitrary substrate due to the limiting experimental condition [1–3]. A scanning probe microscopy (SPM) is a highly promising technique to obtain nano-scale patterns effectively and used to modify and manipulate the structure of the surfaces [4–6]. Using an atomic force microscope (AFM) as a lithographic tool, several methods to fabricate nano-scale patterns have been developed [7–9]. Previously, we could make nano-scale patterns of oxygen on TiO_2 substrates [10,11]. This technique is also one of the most promising methods to prepare nano-patterns with AFM, accomplished by a field-assisted reaction on the substrate surface, and

* Corresponding author. Tel.: +81 53 478 1195; fax: +81 53 478 1189.
E-mail address: tytomit@ipc.shizuoka.ac.jp (Y. Tomita).

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consecutive supply of source ion or element has an important problem to apply to the fabrication of the nano-scale electronic circuits. We introduce a new fabrication method of a nano-scale metal pattern using an atomic force microscope with a cantilever coated by a solid electrolyte. The reaction between the tip of the cantilever and substrate is a simple electrochemical reaction. This method can be carried out at room temperature without a specific treatment.

2. Experimental

Measurements of a topograph and a conductivity map were carried out by an AFM (SPI 3800N SEIKO) in an ambient controlled chamber. A cantilever was coated with CuI by a vacuum evaporation method in a degree of vacuum of 10^{-3} Pa. TiO_2 substrate and Cu thin films prepared by RF magnetron sputtering method on Si and glass substrates were used for the patterning. For the metal patterning and measurement of current–voltage (*I*–*V*) characteristics, a bias voltage from 10.0 to -10.0 V was applied between tip and substrates.

3. Results and discussion

Fig. 1 shows a diagram of contact between AFM tip and substrate surface. A bias voltage from -10 to 10 V can be applied by AFM between the tip and the surface. CuI was used as the cationic conductor in our

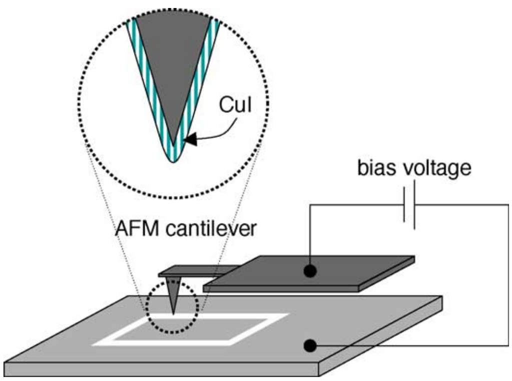

Fig. 1. The schematic diagram of the experimental setup highlighted tip-surface contact. The upper illustration shows a surface of substrate below an AFM cantilever.

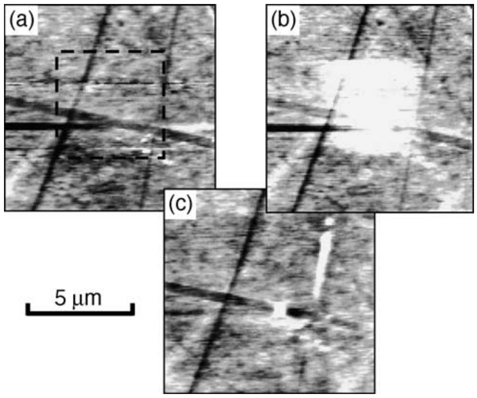

Fig. 2. AFM images of TiO_2 surface (a) before and (b) after applying a negative electric field, and (c) after applying positive field to white area in (b).

study because of superiority of Cu metal for a wiring material in the electronic circuit. CuI thin film was prepared by vacuum evaporation method on the cantilever for AFM (enlarged illustration in Fig. 1). TiO_2 substrate used for initial Cu metal patterning was reduced by annealing at 800 °C in 2% H_2 atmosphere to n-type semiconductor and show a fine surface with a roughness less than 1 nm.

Fig. 2 shows AFM surface images of TiO_2 substrates before and after applying an electric field in Ar atmosphere. The area enclosed by the dotted line in Fig. 2(a), which measures 5 μm × 5 μm in the initial TiO_2 surface was scanned under a bias voltage of -10 V. Scan speed was 1 Hz and the value of flowing current was 100 nA in this scanning. CuI has the p-type conductivity as well as the ionic conductivity and the direction of this bias voltage was a forward bias for a pn-junction between TiO_2 and CuI. After scanning, a Cu metal deposit with 2 nm height (white area in Fig. 2(b)) was observed in the area consistent with the scanning area. When the bias voltage of -10 V applied, Cu^+ ions in the CuI film coating the cantilever were reduced to Cu atoms at TiO_2 surface. Thus, Cu metal was deposited at the area scanned under the negative bias. This Cu deposit became higher by a low speed scanning or applying the voltage in the same area repeatedly. After the area of 6 μm × 6 μm, inclusive of the Cu deposit (in Fig. 2(b)), was scanned under a positive bias of +10 V, the deposit was almost disappeared and the surface of TiO_2 returned to initial as shown in Fig. 2(c). In the