Atom manipulation of bright and dark spots on Cu(111) surface by scanning tunneling microscope

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Using a low-temperature scanning tunneling microscope, atom manipulations were performed on Cu(111) surface. We succeeded in manipulating single Cu atoms which were deposited on the Cu substrate at low temperature, and arranging them in an intended pattern. Besides the brightly contrasted Cu adatom, we also successfully moved single dark spots, presumably an adsorbed molecule of carbon monoxide, by using the same manipulation technique. [DOI: 10.1380/ejssnt.2004.165]

Keywords: Scanning tunneling microscope; Atomic manipulation; Copper adatom; Cu(111)

I. INTRODUCTION

In 1990, Eigler et al. [1] surprised the world by demonstrating a single atom manipulation. Using low-temperature scanning tunneling microscope (LT-STM), they moved several Xe atoms one by one on Ni(110) surface to create nano-size characters. A decade later the atom manipulation technique using scanning probe microscope (SPM) is one of the key technologies for constructing nanostructures in a bottom-up manner. It has been used to confine surface electrons [2], to form low-dimensional structures [3], and recently to investigate a frictional force in an ultimate atom-atom interaction [4].

In this paper, we present atom manipulation on Cu(111) surface. A designed pattern was formed by arranging Cu atoms which are intentionally deposited on the surface. We also demonstrate manipulation of darkly contrasted species. A motion of the dark spots in the manipulation process suggested us that those are adsorbates, not defects, and presumably CO molecules. This demonstrates capability of atom manipulation to identify unknown entities observed in STM images [5].

II. EXPERIMENTAL

Our experiments have been carried out using a commercial LT-STM produced by Unisoku Co.(USM-1300). The system can be operated in ultrahigh vacuum (UHV, < 5 x 10^{-9} Pa at room temperature), low temperature (cooled by liquid helium) and high magnetic field (up to 11 T). In fact, the vacuum around the sample must be further better because most of the residual gases have negligibly low vapor pressure at the liquid helium temperature. The sample temperature, which is measured with a resistive temperature sensor (Cernox, cx-1030), can be controlled from 3K to 30K by activating a heater or pumping liquid helium in a dewar like a lambda-point refrigerator. The magnetic field up to 11 T can be applied perpendicular to the sample surface by a superconducting coil.

In this study, we used an electrochemically etched polycrystalline tungsten tip as a probe. After degassing in the UHV chamber, the oxide layer on the tip was removed by field evaporation with in-situ field ion microscope (FIM).

FIG. 1: STM images taken during manipulation of single Cu atoms. A brightly contrasted Cu atom is moved from site A in (a) to B in (b). The atoms indicated with dashed circle C in (b) are accidentally transformed into the Cu cluster as shown as B’ in (c) during moving tip from site C to B’. The parameters for the STM imaging are following; scanned area: 18 nm × 10 nm, I_t: 300 pA, V_b: 350 mV.
FIG. 2: Using the atom manipulation technique an alphabet letter of 'M' was constructed. These images are parts of a series of the STM images taken at intervals in each step of the construction process. A large bright protrusion pointed by a green arrow in (a) indicates identical sites in these images as a marker. A yellow arrow is one example of dark spots. The imaging parameters are $10 \text{ nm} \times 12 \text{ nm}$, $I_t = 250 \text{ pA}$, $V_b = 200 \text{ mV}$. A complete set of the drift-corrected images is shown in a form of animation, which you can find in the electronic appendix.

Before introduced into the UHV chamber, the Cu(111) sample was etched electrochemically using nitric acid solution. Clean Cu(111) surface was prepared by repetitive Ar-ion sputtering and annealing around 750 K. We confirmed the cleanness of the Cu(111) surface by STM observation.

In order to locate individual metal atoms on the metal substrate the substrate has to be cooled down during the deposition, because at room temperature (RT) deposited metal atoms diffuse over the surface and stick each other to make clusters or islands. During the copper deposition the substrate was refrigerated on a stage cooled by flowing liquid helium. The substrate temperature was kept below 30 K during the deposition, which was measured with AuFe(0.07%)-chromel thermocouple.

III. RESULTS AND DISCUSSIONS

An atom manipulation process performed in this study is basically the same method as that developed by Eigler et al. [1]. The tip is set above an atom we wanted to move. Then the tip is moved vertically toward the target atom by increasing the tunneling current with the STM feedback circuit kept active, until significant interaction is formed between the tip and the atom. We can detect the interaction formation by monitoring the tunneling current: A wave form of the tunneling current changes at the moment of the atom trapping. One can thus judge whether the atom is trapped or not by listening sound produced with the current. With lateral motion of the tip below which the target atom is trapped, the atom moves following the tip. After being moved to a designated site, the tip is retreated back to normal tunneling condition, releasing the atom from the trapping. Before and after the controlled tip motion, STM images are taken to check whether the atom was indeed moved in an intended manner.

A series of STM images demonstrating our atom manipulation of copper atoms on the Cu(111) substrate is shown in Fig. 1. The sample bias voltage ($V_s$) and tunneling current ($I_t$) was set at 370 mV and 300 pA, respectively for the imaging. In these images the smallest bright protrusions are single Cu atoms and large bright spots are Cu clusters. In addition to those bright features, there are some dark spots. Using the atom manipulation method mentioned above, we moved a single Cu atom on the surface as is shown in the STM images.

From Fig. 1(a) to (b), one atom is moved from site A to B. And then the atom at site B formed a cluster by collecting atoms around site C (Fig. 1(b) and (c)). In the upper left of the images there is a monatomic step acting as a marker to prove the identical location.

According to Hla et al.[2], tunneling resistance ($R_t$), which is a measure of the distance between the tip and sample, is a key parameter deciding whether the atom will
By using a low-temperature STM we succeeded in manipulation of single Cu atom and presumably CO molecule, demonstrating a construction of atom-made nano letter ‘M’ using 11 Cu atoms. This technique will make us possible to control and manipulate electron motion, which is crucial for investigation of nanometer scale science.

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