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Invited

Single Atom Manipulation and Its Real-Time Detection by STM

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Examples of single-atom extraction, deposition, and displacement on the Si(111)7×7 surface using a scanning tunneling microscope tip are shown. A method of real-time detection of these processes is also shown.

1. INTRODUCTION

The scanning tunneling microscope (STM) is a promising tool for atomic-scale structure fabrication, although it is also useful for nanometer to submicron structure fabrication. In this paper, I will concentrate on atomic-scale structure fabrication by single-atom manipulation.

The elemental processes of single-atom manipulation are to extract, deposit, and displace single atoms one by one. It is also important to detect these processes in real time. I would like to show several experimental results concerning these obtained in our group, all of which were obtained at room temperature, and discuss physical mechanisms involved(*).

2. ATOM MANIPULATION BY THE STM

A. EXTRACTION OF ATOMS

By using a local field created by a voltage applied to an STM tip, we can extract single atoms one by one from a sample surface if a certain condition is satisfied. When we want to extract many atoms in this way to create a predetermined structure, it is important to remove the extracted atoms from the tip during the process; if the extracted atoms are adsorbed to the tip, some of them will be re-deposited onto the sample.

A recent example is shown in Fig.1, in which two chains of atomic vacancies were created on the Si(111)7×7 surface by extracting surface Si atoms using a Pt (20% Ir) tip [1].

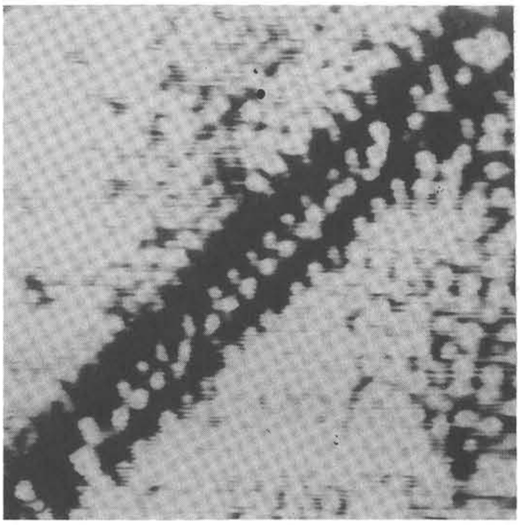

Fig.1 Two chains of atomic vacancies created on the Si(111)7×7 surface by extracting surface Si atoms using an STM tip [1].

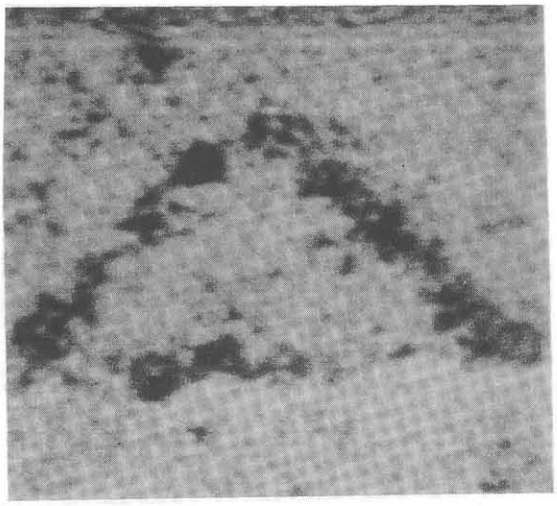

Fig.2 A pattern created on the Si(111)7×7 surface by depositing H atoms from an STM tip made of Pt(20% Ir) [2].

B. DEPOSITION OF ATOMS BY THE STM

For the deposition of single atoms, there are three methods. First, the atoms of the tip itself can be deposited. Second, we can pick up atoms by the tip from a sample surface and deposit them at other places. Third, by continuously supplying foreign atoms to the tip, we can deposit them on a sample.

An example of the third method is shown in Fig.2, in which H atoms were deposited on the Si(111)7×7 surface from an STM tip made of Pt(20% Ir) tip [2].

C. DISPLACEMENT OF ATOMS BY THE STM

Atoms on a sample surface can be displaces by using an interaction between a dipole moment created by the atom and a field gradient near the tip produced by a voltage applied to the tip if a certain condition is satisfied. It is also possible to excite the motion of surface atoms through an electrostatic force between the surface atoms and an STM tip; if the electrostatic force is suddenly decreased, a kinetic energy is given to the surface atoms.

An example of the latter is shown in Fig.3, in which the motion of Si atoms on the Si(111)7×7 surface was excited by sudden changes of bias voltage between tip and sample [3]. Analysis shows that the elemental process of the motion of atoms is a

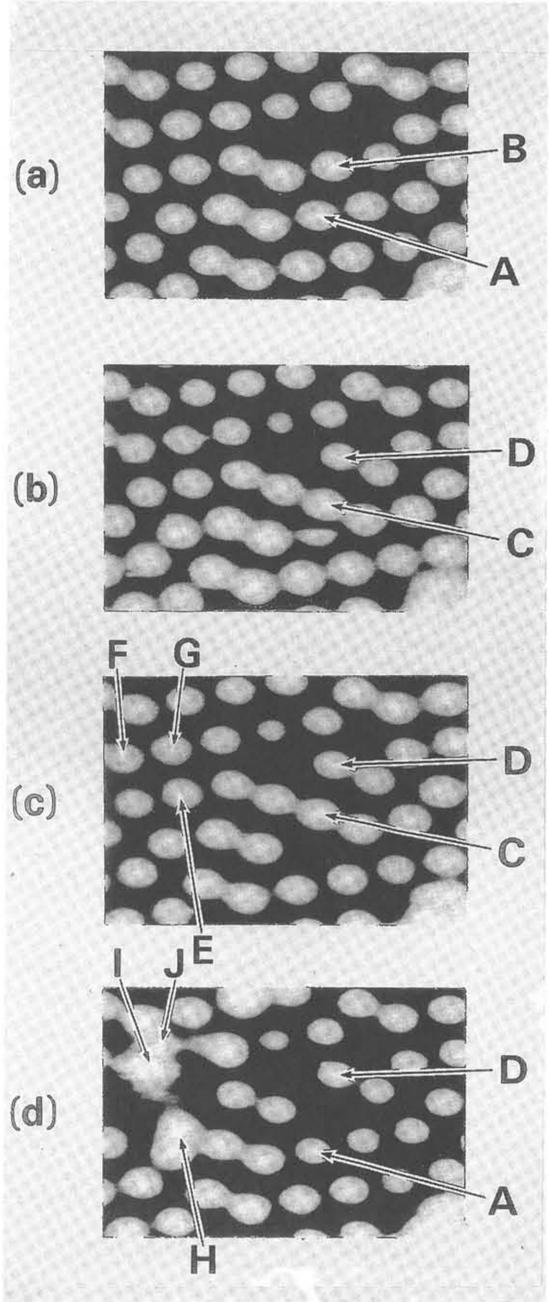

Fig.3 A series of STM images of the Si(111)7×7 surface in a region containing an out-of-phase boundary. Movement of surface Si atoms is observed [3].

simple jump from an occupied T_4 site to a neighboring T_4 site, as we see in Fig.4.

D. REAL-TIME DETECTION OF ATOM MANIPULATION

We can detect the single atom extraction and deposition in real time without observing STM images after the modifications. This is possible by monitoring the height of tip from the sample surface [4].

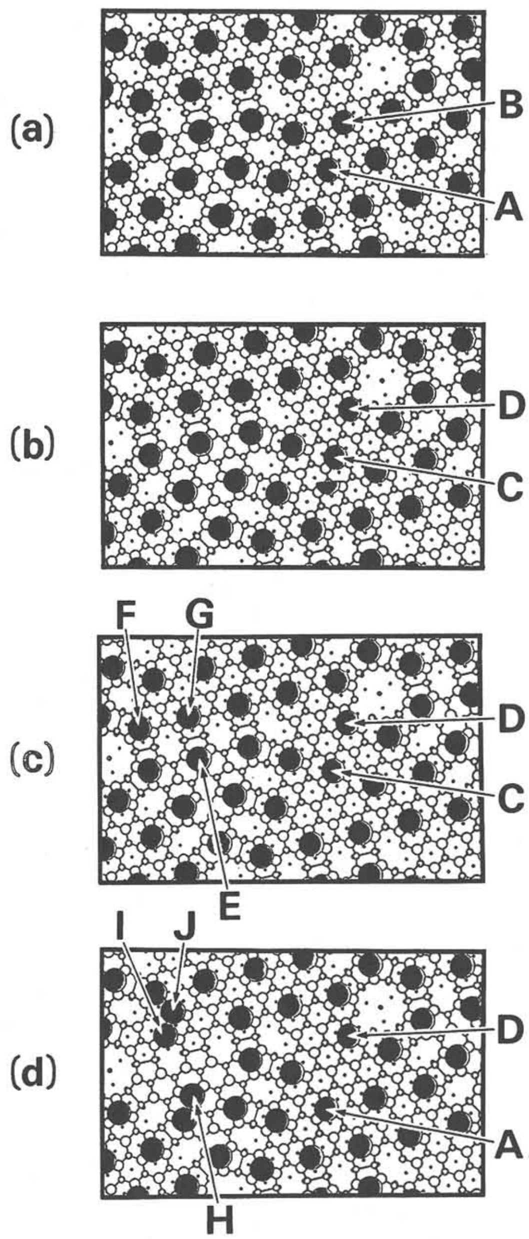

Fig.4 Positions of surface Si atoms observed in Fig.3 (a)-(d). A-J indicate the positions of moved Si atoms before and after the movement [3].

(*) See the Activity Report No.2 of the Aono Atomcraft Project (December, 1993).

[1] D.-H. Huang, G. Grey, and M. Aono, to be published.

[2] H. Kuramochi, H. Uchida, and M. Aono, Phys. Rev. Lett. 72 (1994) 932.

[3] T. Nakayama, T. Eguchi, and M. Aono, to be published.

[4] F. Grey, D.-H. Huang, A. Kobayashi, E. J. Snyder, H. Uchida, and M. Aono, J. Vac. Sci. Technol., in press.