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Atom-by-Atom Creation and Evaluation of Composite Nanomaterials at RT based on AFM

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Atomic force microscopy (AFM) [1] can now not only image individual atoms but also construct atom letters using atom manipulation method [2]. Therefore, the AFM is the second generation atomic tool following the well-known scanning tunneling microscopy (STM). The AFM, however, has the advantages that it can image even insulating surfaces with atomic resolution and also measure the atomic force itself between the tip-apex outermost atom and the sample surface atom. Noting these advantages, we have been developing a novel bottom-up nanostructuring system, as shown in Fig. 1, based on the AFM. It can identify chemical species of individual atoms [3] and then manipulate selected atom species to the designed site one-by-one [2] to assemble complex nanostructures consisted of many atom species at room temperature (RT). In this invited talk, we will introduce our results toward atom-by-atom assembly of composite nanomaterials based on the AFM at RT.

To identify chemical species, we developed the site-specific force spectroscopy at RT by compensating the thermal drift using the atom tracking. By converting the precise site-specific frequency shift curves, we obtained short-range force curves of selected Sn and Si atoms as shown

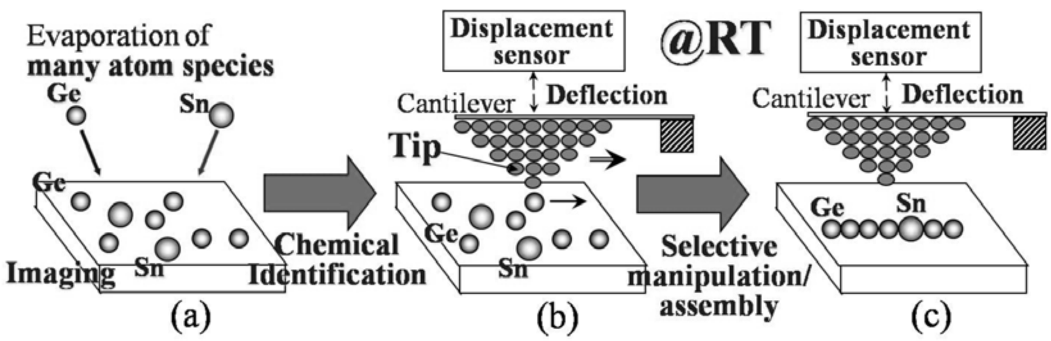

Fig. 1. A novel bottom-up nanostrucruring system based on the AFM, which can (a) image individual atoms, (b) identify chemical species, and then (c) manipulate selected atom species to the designed site one-by-one at RT.

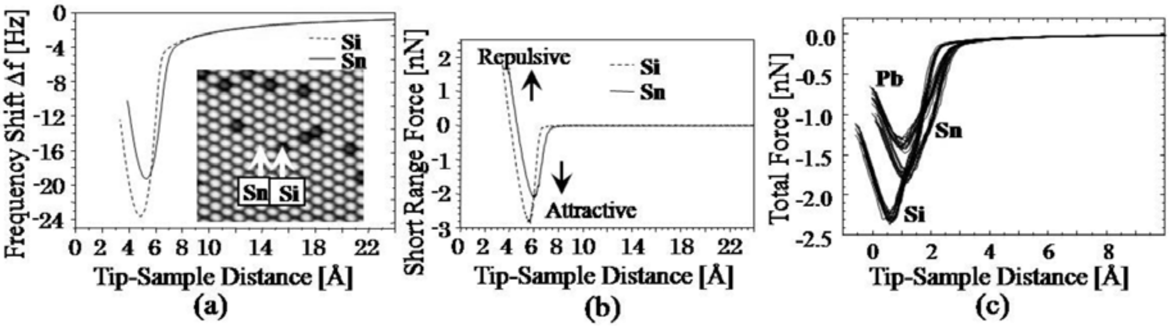

Fig. 2. (a) Site-specific frequency shift curves of selected Sn and Si adatoms indicated in the inset non-contact AFM topographic image of Sn/Si(111)-(√3×√3) surface at RT [4], (b) short-range force curves of selected Sn and Si adatoms [4], and (c) atom-by-atom chemical identification of Pb, Sn and Si intermixed Si(111)-(√3×√3) surface at RT [3].

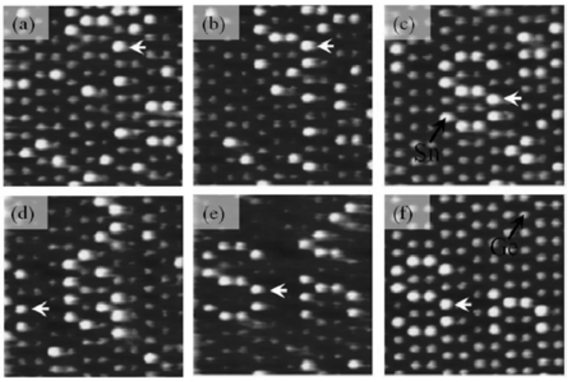

Fig. 3. (a)~(f) Nanostructuring process of the atom letters “Sn” consisted of a little large Sn adatoms embedded in a little small Ge adatoms at RT [2]. These non-contact AFM topographic images were successively obtained after sequential lateral atom interchange manipulations under near-contact region [2].

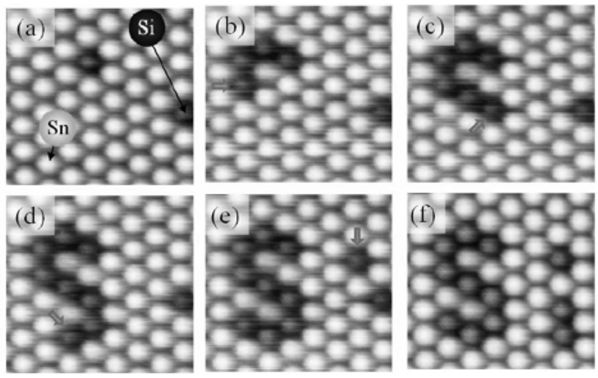

Fig. 4. (a)～(f) Nanostructuring process of the atom letters "Si" consisted of a little smaller Si adatoms embedded in a larger Sn adatoms at RT [5]. These non-contact AFM topographic images were successively obtained after sequential vertical atom interchange manipulations under near-contact region [5].

in Fig. 2(a) and 2(b) [4]. Then using the atom-by-atom force spectroscopy at RT, we succeeded in chemical identification of intermixed three atom species in Pb/Sn/Si(111)-(√3´√3) surface as shown in Fig. 2(c) [3].

To create composite nanostructures, we found the lateral atom interchange phenomenon at RT, which enables us to exchange embedded heterogeneous atoms [2]. By combining this phenomenon with the modified vector scan, we constructed the atom letters “Sn” consisted of substitutional Sn adatoms embedded in Ge adatoms at RT as shown in Fig. 3(a)～(f) [2]. Besides, we found another kind of atom interchange phenomenon at RT that is the vertical atom interchange phenomenon, which directly interchanges the surface selected Sn atoms with the tip apex Si atoms [5]. This method is an advanced interchangeable single atom pen at RT. Then using this method, we created the atom letters “Si” consisted of substituted Si adatoms embedded in Sn adatoms at RT as shown in Fig. 4(a)∼(f) [5].

In addition to the above results, we will introduce the simultaneous evaluation of the force and current at the atomic scale using the combined AFM/STM at RT.

References

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