Ultimate Microscopy for Surface and Nanostructure Analysis

Real space chemical imaging in an atomic resolution is an ultimate goal for surface science and nanotechnology. For the structural analysis of surfaces or nanostructures, a scanning tunneling microscopy (STM) is one of the best tools to achieve surface observation with an atomic-scale resolution. With the assistance of an energy-tunable photon source from synchrotron radiation (SR), we have observed chemical information using an STM. Ni and Fe micro patches can be observed selectively by an STM with irradiation of SR light, the energy of which is at the absorption edge of Ni or Fe. A spatial resolution of about 10 nanometer has been achieved in real space chemical imaging.

If the observation of a surface structure in an atomic resolution with chemical sensitivity were achieved, one could determine surface and nanomaterial structures in a straightforward manner. Thus, development of such microscopy is a dream of material scientists. For the structural analysis of surface or nanomaterials, scanning probe microscopy (SPM) such as scanning tunneling microscopy (STM) and atomic force microscopy (AFM) is one of the most powerful tools that can provide surface structural images at an atomic resolution. These techniques, however, usually do not have chemical sensitivity. On the other hand, synchrotron radiation (SR) is a useful tool for obtaining chemical information from materials. X-ray absorption and photoemission are typical examples of methods for chemical analysis using SR. However, the spatial resolution of such methods is usually poor.

In order to combine chemical-sensitive techniques with high-spatial resolution structural analysis by SPM, we have developed an STM system that can measure surfaces during irradiation by SR light, with the aim of obtaining information related to core-level electron excitation.

In X-ray absorption, some decay processes, such as Auger decay, always follow core electron excitation, and the decay process produces a large number of secondary electrons. The number of secondary electrons is proportional to the X-ray absorption intensity. Thus, one can know the X-ray absorption probability by detecting the secondary electron intensities, and if one can detect it with an STM tip, one may observe the chemical information of surfaces with a high-spatial resolution.

The system of our SR-assisted STM (SR-STM) is illustrated in Fig. 1. As shown in the illustration, energetically tuned photons from an undulator impinge on the sample surface after being modulated in intensity by an optical chopper with a frequency of 1 kHz. Electrons, including tunneling electrons and emitted electrons from the surface by photo-excitation, are detected by a glass-coated tungsten tip [1], and the photo-induced signals are selectively detected by a lock-in technique.

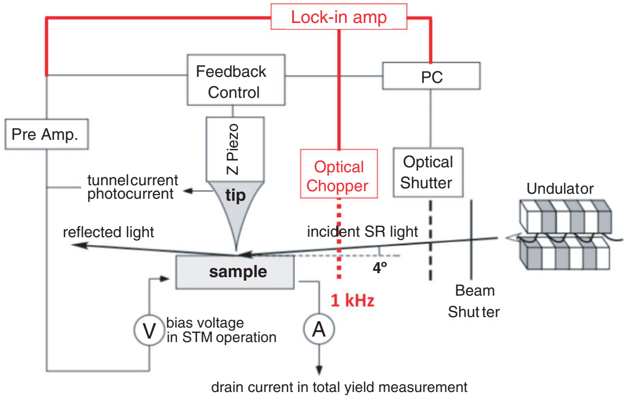

Figure 1
Illustration of SR-STM measurement.

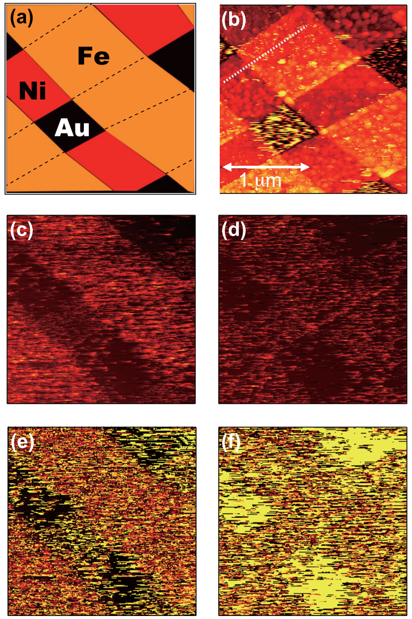

Figure 2
Images taken by SR-STM of the Fe and Ni checkerboard pattern illustrated as shown in (a). Topographic image (b) and photo-current images taken at (c) Fe and (d) Ni *L* absorption edges as well as the difference images obtained by the images at the top and bottom of Fe absorption edge (e) and of Ni absorption edge (f) are shown.

Figure 2 shows the results of SR-STM measurement using a checkerboard-patterned Fe and Ni microstructure. As shown in Fig. 2 (a), Fe and Ni stripes are fabricated on Au film on a Si substrate by electron lithography, and observed clearly, as shown in the topographic image in Fig. 2(b). Figures 2(c) and (d) show the photo-current images taken by the STM tip during light irradiation at the photon energy of Fe and Ni *L* absorption edges, respectively. Although one can see the images induced by photon irradiation, the difference between the two is not obvious. However, if one makes a difference image using images taken at the X-ray absorption top and the bottom edges, an apparent difference appears at different photo-excitation energies. That is, in Fig. 2(e), which is obtained at the Fe L_2 absorption edge, the Fe stripes become brighter. In contrast, the Ni patches become brighter at the Ni L_2 absorption edge, as shown in Fig. 2(f). Thus, we could selectively observe the Fe and Ni areas by tuning the excitation photon energy at the Fe and Ni absorption edges. The spatial resolution of the chemical imaging is approximately estimated as 10-nm order by taking the line profile of the photo-excitation images [2].

Although the mechanism of the high-spatial resolution in the chemical imaging is not clear at present, one possible explanation is that the relatively high spatial resolution is achieved by a tip-proximity effect. Namely, in the tunneling condition, the surface barrier probably be reduced by an image potential and the secondary excited electrons can easily transfer from the surface to the tip, especially at the tip bottom. In addition, some excited electrons may contribute to the tip current via the tunneling process. Further theoretical and experimental investigations are, however, expected to solve the precise mechanism.

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