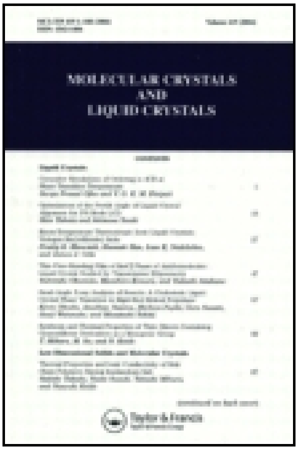

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Scanning near-field optical microscope (SNOM) is hybridized with scanning tunneling microscope (STM) in order to achieve a higher spatial resolution by introducing a doubly metal-coated optical fiber tip with a nm-scale aperture. The result of a simultaneous SNOM/STM imaging of Au(111) indicates the boundary-sensitive detection in SNOM mode, which is not an artifact caused by z-motion crosstalk.

Keywords: scanning near-field optical microscope; scanning tunneling microscope; doubly metal-coated optical fiber tip; boundary-sensitive detection

INTRODUCTION

Scanning near-field optical microscope (SNOM) [1,2] is a powerful tool to investigate optical properties of samples non-destructively in a localized area. One of the disadvantages in SNOM is, however, a low spatial resolution caused by a poor sample-probe distance control. For instance, in the case of an optical feedback, the probe cannot reach to the close proximity down to nm-scale due to the intrinsic nature of the evanescent field, although the sample-probe distance must be almost as small as the sample size to achieve a high resolution and a high sensitivity [3]. To realize such a requirement and improve the performance of SNOM, we designed a hybrid system of SNOM with scanning tunneling microscope (STM) [4] (hybrid SNOM/STM) by introducing a doubly metal-coated optical fiber tip with a nm-scale aperture.

According to literature, there have already been several reports which described the combination of SNOM and STM. Kawata *et al.* designed the system where an *apertureless*-type metallic tip was used [5]. However, neither "illumination" nor "collection" mode is accessible with this method. Either a metal-coated micropipette [6] or an optical fiber tip whose side is metalized by an angled evaporation [7] can be used for both modes, although the contour map of an optical image has a certain displacement with respect to that of an STM image in the case of such aperture-type probes [8]. In order to overcome such difficulties in using an aperture-type probe, we employed a new scheme of the tip fabrication. A simutaneous SNOM/STM imaging by using our homemade system will be also presented.

EXPERIMENTAL

The fabrication procedure of a metal-coated optical fiber tip is firstly developed by Ohtsu *et al.* [9]. A GeO_2-doped optical fiber is etched in the two solutions with two different volume ratios of NH_4F : HF : H_2O successively to form a tapered fiber. Pt ion-coating (100 nm) is performed in low vacuum chamber. The tip is dipped in an acrylic resin solution afterwards. Due to its surface tension, the sub-micron (or less) top region of the sharpened core is exposed from the resin. The uncovered portion is etched in a KI-I_2 solution to form an extremely small aperture down to a few tens of nanometers with high reproducibility. The second coating of Pt ultra-thin layer must be performed in order for the top of the aperture to act as an STM probe. This step is original in our paper. The optimized value of the Pt layer thickness (*ca.* 25 nm) results in a half-transparent metallic aperture. An atomic-resolution STM image of a highly oriented pyrolytic graphite (HOPG) was obtained with this type of optical fiber tip. Nanometer-scale Pt grains that compose the half-transparent metallic layer may be attributed to such a high resolution. The scanning electron microscope (SEM) image (S-900, Hitachi, Japan) is shown in FIIGURE 1. The cone angle, the size of the aperture and the curvature of the tip are about 25°, 100 nm and 30 nm, respectively.

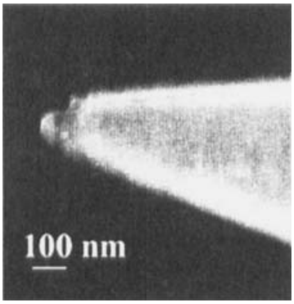

FIGURE 1 SEM image of a doubly Pt-coated optical fiber tip. Aperture: 100 nm, Curvature: 30 nm

RESULTS AND DISCUSSION

The doubly Pt-coated optical fiber tip with a homemade SNOM/STM head, which is compatible with a commercially available NanoScope II (Digital Instruments, CA, USA), was utilized to observe Au(111) thin film deposited on a mica substrate as shown in FIGURE 2 ((a) STM, (b) SNOM). Note that these images are taken simultaneously. 650 nm laser light from the aperture illuminated the sample surface locally and the far-field component of the scattered light was collected as an optical signal by a photo-diode detector without any phase sensitive detecting technique. The distance control was performed under the constant current (gap-width) condition. The scan size, the tunneling current and the sample bias voltage are 600 nm, 1.0 nA and 1.0 V, respectively. The mean optical power in the SNOM image is *ca.* 500 pW. Many terraces are separated by deep valleys in FIGURE 2(a), which is frequently observed in the case of the Au(111) thin film deposited on a mica. Atomic-level steps are also visible, which assures a sufficient vertical resolution down to a few Å in STM mode.

It is seen that the optical power decreases at deep valleys, possibly indicating that the top of the tip goes into the valleys and the scattered light cannot reach to the detector. In addition, the sharp peaks in the optical signal seem to appear at atomic-level steps. To make the point much clearer, the cross-sectional profiles of both modes are taken along the solid lines in two images as shown in FIGURE 3. Each peak in the SNOM profile corresponds to the location of a step edge in the STM profile without any displacement (boundary-sensitive detection). This result is completely different from previous reports where aperture-type tips were used, since in our case the tunneling current is measured at the top of the aperture.

An auxiliary gap-width regulation in z-direction could lead to artifacts called *crosstalk* as reported by Pohl *et al.* [8]. However an optical image usually looks like an exact photo copy of a topographic image in such artifacts. This is not our case as can be easily seen with comparing two images

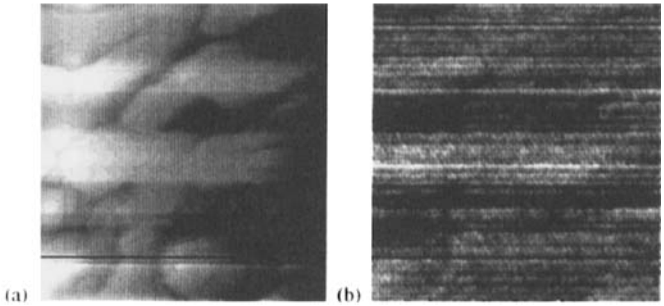

FIGURE 2 Simultaneous SNOM/STM imaging of Au(111) surface. (a) and (b) correspond to STM and SNOM images, respectively.

in FIGURE 2. In addition, it may be the intrinsic property of the near-field that the interference of the evanescent field standing on the aperture by the sample surface changes depending on the profile of the sample. Especially at the edges of the sample surface, this phenomenon may be strong.

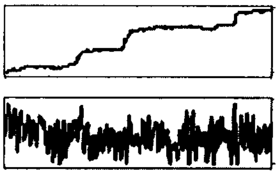

FIGURE 3 Cross-sectional profiles of the SNOM and STM images in FIGURE 2. Upper: STM, Lower: SNOM

To understand the details of this interaction, we must continue to study extensively from both experimental and theoretical view points. It is worth while mentioning, however, that the lateral resolutions that we obtained in both modes are quite high, which are not achievable with using other conventional distance control schemes.

CONCLUSION

We confirmed the capability of our homemade hybrid SNOM/STM system as a tool to investigate nanoscopic phenomena by a simultaneous SNOM/STM imaging of Au(111). The procedure of the tip fabrication with 2-step Pt-coating was successfully established. Thus, the system showed sufficient vertical and lateral resolutions down to nm-scale in both STM and SNOM modes. The boundary-sensitive detection occurred in SNOM mode, which is not an artifact caused by z-motion crosstalk.

Acknowledgments

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