Atomic-scale Flattening of SiC Surfaces by Electroless Chemical Etching in HF Solution with Pt Catalyst

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Silicon carbide (SiC) is a representative hard material with a Knoop hardness of 24.5–31.4 GPa. Recently, the surface flattening of SiC has attracted a great deal of attention for electronic devices operated under extreme conditions such as high power and high temperature. However, conventional flattening processes are not effective for SiC surfaces because of high strength and chemical inertness of SiC.

The authors have found that the use of a Pt plate as a catalyst is effective for flattening SiC surfaces in HF solution. We evaluate the flattening performance on the atomic scale by scanning probe microscopy (Fig. 1).

An unpolished 4H-SiC(0001) wafer (Fig. 1(a)) was placed on a Pt plate in concentrated HF solution. Among many polytypes of SiC, 4H-SiC(0001) is the most promising substrate for SiC-based electronics. Both the Pt plate and the SiC sample were rotated independently in the same plane.

Figure 1(b) shows an atomic force microscopy (AFM) image of the flattened 4H-SiC(0001) surface. Figures 1(a) and 1(b) demonstrate that the SiC surface is flattened. The flattened terraces in Fig. 1(b) show regularly alternating large and small widths with straight step edges. The 4H-SiC(0001) surface has two kinds of terraces (4H1 and 4H2), depending on the physical relationship with the bilayers. Outermost Si atoms on 4H1 and 4H2 terraces sit at hexagonal and cubic sites, respectively. We deduce from theoretical energetics that the wide and narrow areas in Fig. 1(b) correspond to the 4H1 and 4H2 terraces, respectively, as shown in Fig. 1(c).

Figure 1(d) shows a scanning tunneling microscopy (STM) image of this surface. Atomic images are clearly resolved. The distance between neighboring bright dots is equal to 0.30–0.33 nm. An electron diffraction image exhibits a sharp and bright 1×1 pattern, as shown in the inset of Fig. 1(d). They indicate that an ordered surface with two-dimensional SiC-bulk periodicity is formed. X-ray photoelectron spectra revealed that the 1×1 phase is composed of coexisting of OH- and F-terminated Si atoms (Fig. 1(e)), which originate from the polarization of the underlying Si–C bonds.

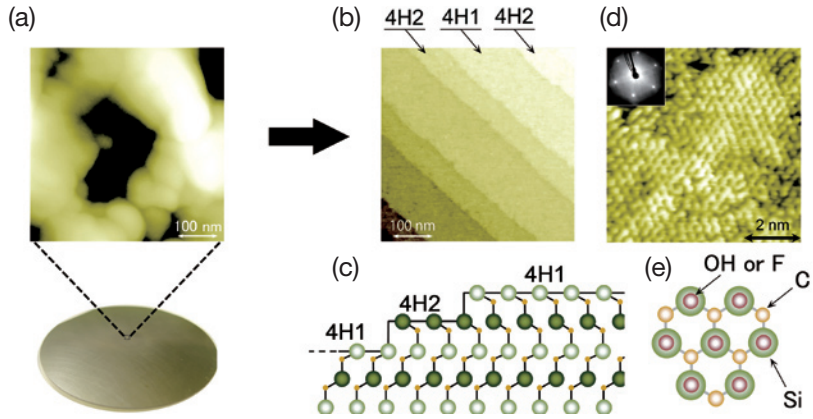

Fig. 1 (a) Unpolished 4H-SiC(0001) surface. (b) AFM image of flattened SiC surface. (c) Schematic model of 4H-SiC crystal. Deep and pale green circles represent Si atoms at cubic and hexagonal sites, respectively. Brown circles represent C atoms. (d) STM image. Electron diffraction image is superimposed. (e) Schematic drawing of OH- (or F-) terminated SiC surface.

High-Resolution Confocal Microscopy by Saturated Excitation of Fluorescence

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Fluorescence microscopes have been used as inevitable tools for medical and biological research because of its capability of observation living biological specimens. The recent development of fluorescence probes that enables to monitor biological activities is further accelerating the significance of the microscope for these fields. However, the spatial resolution of the microscopes has been limited to around 200 nm because of the wave nature of light.

In the present research, we have developed a technique to improve the spatial resolution of fluorescence microscopes by using a saturation effect seen in fluorescence excitation. As shown in Fig. 1, the fluorescence intensity can be saturated under high light irradiance to fluorescence molecules because of a limited number of fluorescence molecules under excitation and delayed emission of fluorescence after excitation. This saturation effect is prominently seen when the molecules are excited with high laser intensity.

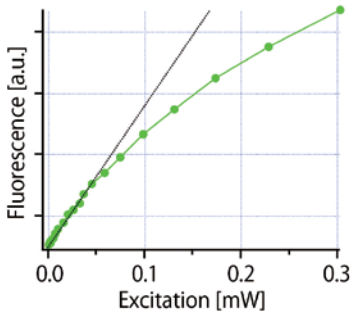

Fig. 1 The saturation effect in fluorescence excitation of Rhodamine 6G molecules.

We found that this saturation of excitation can be induced at a small region in a laser focus because the laser intensity can be extremely high at the center of the focus and, therefore, it can be used to improve the spatial resolution. By extracting fluorescence signal under the saturation condition, we can detect fluorescence molecules in a smaller volume than that of the laser focus.

To extract the saturated fluorescence signal, we introduced a harmonic demodulation technique in fluorescence microscopy, in which we modulate the excitation laser intensity and demodulate the fluorescence signal at the harmonic frequencies. Under the condition of the saturation, the modulated fluorescence signal is distorted because of the nonlinear relationship between excitation and fluorescence intensity as in Fig. 1 and can be separated from non-saturated fluorescence. By using this technique, we can observe small structures unable to be resolved by conventional microscopes. Fig. 2 shows the images of fluorescence beads with a diameter of 200 nm. From the comparison of images in Fig. 2, we confirmed the improvement of the spatial resolution by the developed technique.

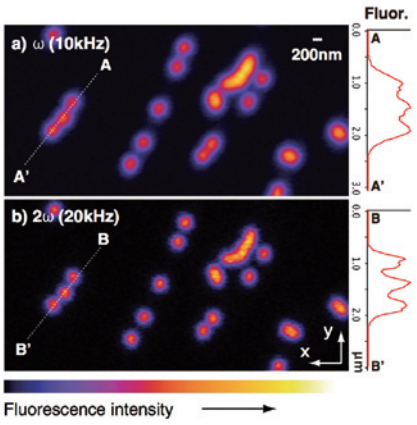

Fig. 2 The fluorescence images of fluorescence beads with a diameter of 200 nm by a) a conventional and b) the developed microscope.