Nanoscopic Characterization of Silicon Surfaces Using Tunneling AFM

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Characterization of defects and trace metal contaminants at Si wafer surface is significant issues for device manufacturing process. Scanning probe microscopy is a powerful tool for nanoscopic characterization of various properties of the wafer surface, not only the topological properties such as surface roughness but also electric and mechanical properties. In the present work, a tunneling AFM (TunA), which enables to aquire topological and electric information at the surface simultaneously in nm scale, is applied to investigate the effect of the trace metal contamination and surface defects on the properties of the Si wafers.

The wafers used for the present work were P-type Si(100) (ρ = 8.5-11.5 Ω cm). The wafers were cleaned with SPM (sulfuric peroxide mixture, 96%H_2SO_4: 30%H_2O_2=4:1) at 120 ºC for 10 min followed by rinsing with ultra pure water (UPW > 18MΩ) and 0.5 % HF for 1 min to obtain clean, hydrogen terminated surface. Then some of the wafers were immersed into UPW containing trace metal ion species such as Cu. Also, pit-like defects were intentionally formed on the some of the clean wafers using nanoindentation method with a diamond probe. After these treatments, SiO_2 layer were formed on the surfaces using plasma CVD. These wafers were subsequently observed by contact mode AFM and TunA, both were simultaneously performed to the identical area using a NanoScope IIIa scanning probe microscope (Digital Instruments).

The wafer treated with the UPW containing 200ppb of Cu was observed by TunA. In the case with lower applied bias voltage, the current flow was not detected. On the other hand, with an increase in applied bias voltage, the current flow was detected at the sites where the metal particles deposited. Figure 1 shows representative AFM and corresponding TunA images (applied bias -10.5V). In the TunA image, darker points indicate the region with larger current flow, clearly indicating that Cu particles degraded the formation condition of the SiO_2 layer.

Fig.2 shows Current-Voltage (I-V) spectroscopy of single points at the surface of the hydrogen-terminated wafer, the wafer immersed in the UPW, and the wafer immersed in the UPW containing 200ppb or 500ppb of copper. All wafers were covered with SiO_2 layer using plasma CVD after the treatment. Note that the I-V spectroscopy was carried out at the point without the deposited Cu particle in the case of the specimen prepared with the Cu spiked UPW. The leakage current was detected from the lower bias voltage in the case of the wafer treated with the Cu spiked UPW. Furthermore, the current leakage was detected with lower bias voltage on the wafer immersed in the UPW containing 500ppb of copper than on the wafer immersed in the UPW containing 200ppb of copper, suggesting that Cu exists not only in the deposited particles but also dispersed to the entire surface.

Fig.3 shows AFM image (a) and corresponding TunA image (b) of the wafer with intentionally formed defects covered with the SiO_2 layer. The leakage current is detected with the lower bias voltage at the defect sites than at the non-defect sites. Moreover, the leakage current was detected with lower bias voltage at the defects formed with larger loading force, i.e. higher degree of "defectivity".

As described above, effects of trace metal contamination and defects on the surface characteristics of the wafers were investigated at the nanoscopic scale by TunA. The results suggest that Cu deposited not only at the particulate sites but also in the entire surface and degraded the surface properties. It was also found that pit-like surface defects also degraded the surface properties, according to the degree of "defectivity".

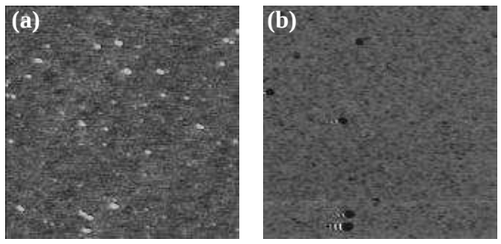

Figure 1. AFM image (a) and TunA image (b) of Si(100) wafer surfaces after immersing into Cu 200ppb contaminated UPW for 5 min. Applied bias voltage: –10.5V. Scan area: 3.0μm x 3.0μm; Z scale: 5nm (a) and 15pA (b), SiO_2 thickness: 10.4nm

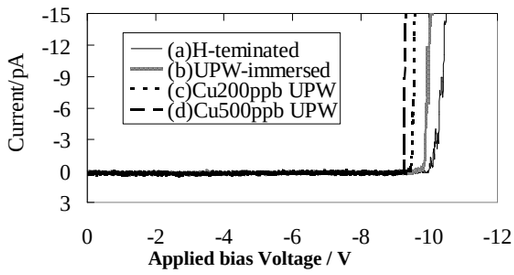

Figure 2. I-V spectroscopy at single points on Si(100) wafer surfaces; (a) H-terminated, (b) UPW-immersed, (c) Cu 200ppb contaminated UPW immersed, and (d) Cu 500ppb contaminated UPW immersed.

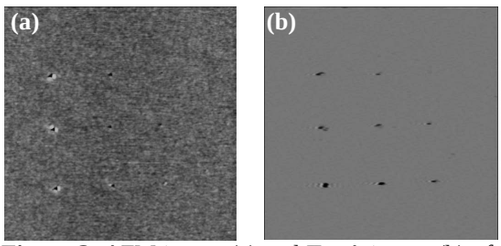

Figure 3. AFM image (a) and TunA image (b) of Si(100) wafer surfaces with nano-defects formed using nanoindentation method. Applied bias voltage: –0.5V. Scan area: 3.0μm x 3.0μm; Z scale: 5nm(a) and 15pA(b);SiO_2 thickness:1.2nm

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