Measurement of Surface Potential of Insulating Film on Conductive Substrate in a Scanning Electron Microscope

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It is well known that insulating materials charges during electron beam (EB) irradiation. Not only to avoid charging problems, but also to control them in a future instrumentation, it is necessary to find the mechanisms. Quantitative measurements of the surface potential and the charge distribution are especially important. In the present study we measured directly the surface potential of an insulator, which was irradiated by EB in a specimen chamber of an ordinary scanning electron microscope (SEM), and analyzed by a numerical calculation.

The surface potential and its decay after EB exposure have been measured by a Kelvin probe electrometer.[1] However, the spatial resolution is around mm size, because the sensor was 1 mm above the specimen surface. In the present study, we develop a surface potential measurement system based on the Kelvin probe force microscopy (KFM). The probe we used adopts a self-sensing cantilever, and the radius of the probe apex is 20 nm, the length of the cantilever is 400 μm, and the spring constant is 4 N/m. The schematic diagram of the present system is illustrated in Fig. 1. Here, the specimen is 300 nm-thick FEP171 resist film on Cr substrate with 30 mm on a side, and the working distance to the objective lens is 20 mm. EB is irradiated by raster scanning in a square with 100 μm on a side at a current of 50 pA in one minute. Just after this exposure, the KFM measurement starts just above the center of the irradiated region. In every measurement the stress variation is obtained as a function of applied voltage to the holder, and the surface potential is acquired.

The surface potential is obtained for various EB accelerating voltages (Vacc) from 0.3 kV to 30 kV as a function of time, and some examples are shown in Fig.2. It is found that the potential stays almost constant, as Vacc is less than 1 kV or it is above 3 kV. If Vacc is between 1 kV to 3 kV, the potential is negative and it decays as a function of time. If the variation is approximated by $V(t) = V_0 + V_1 \cdot \exp(-t/\tau)$, the potential just after the irradiation is expressed by $V(0) = V_0 + V_1$. By approximating all the variations as shown in Fig. 2, $V(0)$ is plotted in Fig. 3 as a function of Vacc. The largest negative potential is obtained, when Vacc is 1.5 kV.

To analyze the mechanism of results obtained in Figs. 2 and 3, a Monte Carlo

(MC) simulation of electron trajectories in the specimen is developed. The energy density distributions deposited in PMMA film on Si substrate for three Vacc are shown in Fig. 4. The reason to choose PMMA instead of FEP is that they are both polymers, and the physical properties of PMMA are known. Previous MC gives much shorter electron ranges at low Vacc. According to the MC results, electrons are distributed around the surface, as Vacc is below 1.3 kV, on the contrary if Vacc is more than 2.7 kV, electrons are transmitted to the conductive substrate. At the same time it is known that the secondary electron yield is more than unity, if Vacc is less than 1 kV for most materials. During EB exposure, it is also known that an electron-beam-induced-conduction occurs in a region where electron energy is deposited, and if EB is transmitted through the insulating film, it is expected that charges in the film is evacuated toward the substrate. Mechanisms expected by MC will be presented at the conference.

[1] M. Bai, R. F. W. Pease, C. Tanasa, M. A. McCord, D. S. Pickard and D. Meisburger, and J. Vac. Sci. Technol., B 17 (1999) 2893-2896.

This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for (C) 22560026

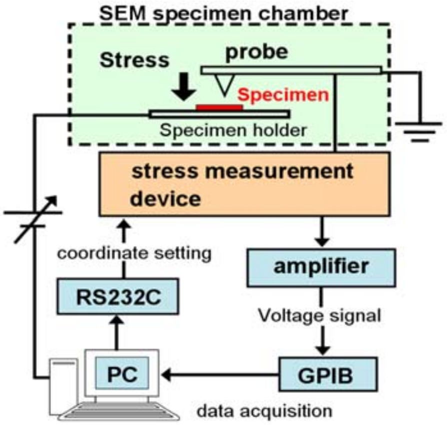

Figure 1: Schematic diagram of the measurement system based on the KFM.

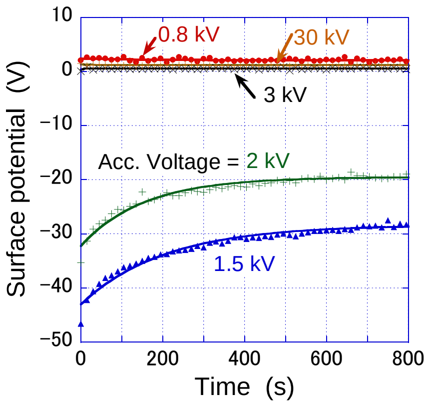

Figure 2: Surface potential variations for various Vacc voltages.

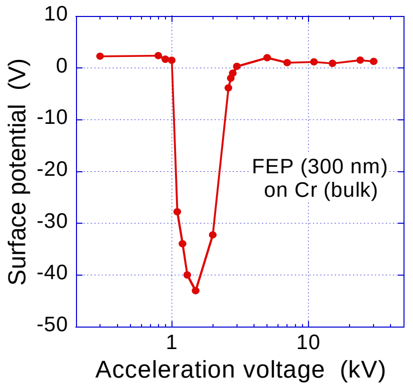

Figure 3: Surface potential $V(0)$ as a function of Vacc voltage.

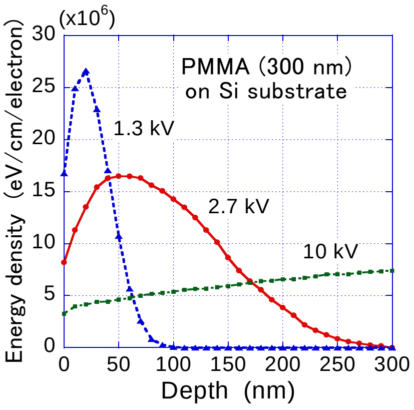

Figure 4: Monte Carlo results of depth distribution of energy deposited.