Charging process simulation of a resist film on Si substrate under electron beam irradiation

M. Kotera[1,2], A. Osada[2], M. Otani[1], Y. Ohara[1]

[1]*Dept. of Electronics, Information and Communication Engineering*

Osaka Institute of Technology, Japan, 535-8585

[2]*Nanomaterials Microdevices Research Center*

Osaka Institute of Technology, Japan, 535-8585

kotera@elc.oit.ac.jp

It is known that insulating specimens charge negatively or positively depending on the experimental circumstance during electron beam (EB) irradiation. This charging phenomenon disturbs the conditions in various EB applications. It is important to analyze the mechanism of the charging process in the specimen. In the present study, a simulation model is introduced to express a time-dependent charging process of electrically insulating resist on Si substrate under EB irradiation. Spatial distributions of the electron deposition and the energy deposition in the resist are obtained by a Monte Carlo simulation of electron trajectories.[1] The potential distribution in and above the resist layer is obtained by solving the Poisson equation in the boundary conditions shown in Fig. 1. The electron trajectory bending due to the electric field in and out the specimen is calculated. The electron beam induced conduction (EBIC) is calculated based on the energy deposited. The resist considered here is 300-nm thick PMMA on Si substrate, and the acceleration voltage (Vacc) of EB varies from 0.3 to 20kV and the beam current is 50 pA. The electron density distribution of EB is assumed to be a disk with the radius of 100nm.

Surface potential averaged within the radius of irradiated EB is obtained for various Vacc's, and the potential variation as a function of EB exposure time is plotted in Fig. 2. If Vacc is low from 0.3 to 1.2 kV, or Vacc is large from 3.5 to 20 kV, the saturated potential is positive. However, if Vacc is between 1.3 and 3.5 kV, the surface potential saturates toward a negative value. The saturated surface potential as a function of Vacc is shown in Fig. 3, and they are compared with the experimentally obtained results for various Vacc just after 1 minute EB irradiation is stopped at the surface of 300 nm-thick FEP film on Cr film on a bulk glass substrate.[2] These values are obtained by our newly developed electrostatic force microscope system in the scanning electron microscope. Although the material of the resist is different, the both results show a good agreement.

In the variation of Fig. 2, it is found that the time constant is a function of the Vacc. In this case we can quantify the time constant for the potential build-up. On the contrary, in the experimental results, we can measure the time constant for the surface potential decay. Although these two values are defined for the opposite physical events, and their absolute value differs in several decades, their characteristic tendency is quite similar as shown in Fig. 4. In this situation, if it takes a longer saturation time in charging, it takes the longer time in discharging, and vice versa. Assuming that the present system is evaluated by a series circuit of capacitance and resistance as an equivalent circuit, the time constant is mainly determined by the resistivity. In the present calculation of the EBIC, the intrinsic resistivity of $10^{13}\Omega$cm for PMMA is decreased typically to the order of $10^{5}\Omega$cm. The eight orders of magnitude difference in the figure might be explained by this assumption.

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[1] M. Kotera, J. Vac. Sci. and Tech., B19(6), 2516-22519 (2001).
[2] M. Kotera et al., J. Vac. Sci. Tech., B 29(6) (2011) 06F316-1.

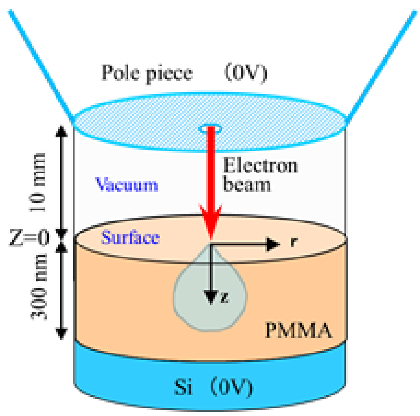

Figure 1: Schematic of the boundary condition of the present calculation.

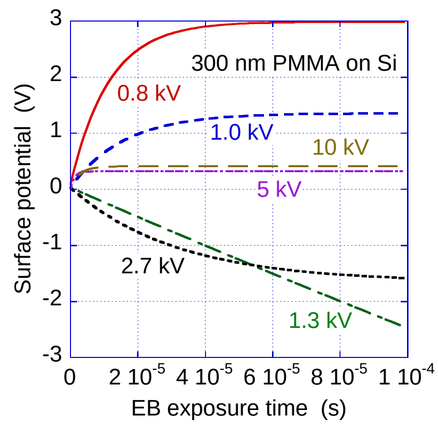

Figure 2: Surface potential variations with time for various Vacc voltages.

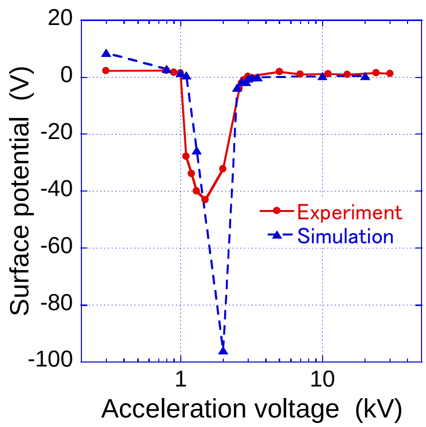

Figure 3: The saturated surface potential as a function of Vacc voltage.

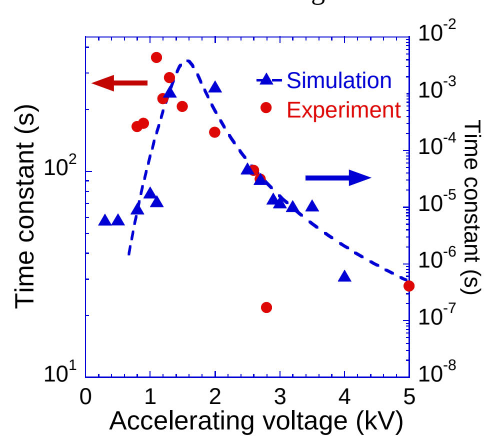

Figure 4: Comparison between the time constants obtained by experiment and by the present calculation.