Static and Dynamic Electric and Magnetic Imaging

IM.5.105
Charging process simulation of PMMA film on Si substrate irradiated by electron beam

M. Kotera[1], M. Otani[1], S. Hosoi[1], K. Kumagai[1]

[1]Osaka Institute of Technology, Osaka, Japan

kotera@elc.oit.ac.jp
Keywords: Monte Carlo simulation of electron trajectories, PMMA film, charging process simulation

Electron beam (EB) has been used in microscopy and lithography, etc. and it is indispensable in recent nano-technologies. However, if the electric conductivity of the materials to be observed or processed is low, they charge-up during the EB irradiation. In order not only to avoid the charging, but also to make use of the characteristics in the application, quantitative knowledge of the charging process is important. We develop a simulation to calculate individual electron trajectory in and above the specimen, and try to find the charging mechanism during EB irradiation. In the present study, a simulation model is introduced to express a time-dependent charging process of PMMA film on Si substrate under EB irradiation.

Spatial distributions of the electron deposition and the energy deposition in PMMA are obtained by a Monte Carlo simulation of electron trajectories.[1,2] The potential distribution in and above the PMMA layer is obtained by solving the Poisson equation. The electron trajectory bending due to the electric field is calculated. The electron beam induced conduction (EBIC) is calculated based on the energy deposited. The thickness of PMMA is 300 nm, and the acceleration voltage (Vacc) of EB varies from 0.8 to 20 kV and the beam current is 50 pA. The electron density distribution of EB is assumed to be a Gaussian, where the radius at 1/e of its maximum is 100nm. Figure 1 shows the calculation flow. Since the trajectories of electrons less than several eV cannot be treated by the Monte Carlo simulation, electron diffusion by drift is considered by the transport equation. The local electric conductivity is given by the energy deposited by the beam, and the charge drift is calculated by the equation of continuity, and the final charge distribution is obtained in a time step. A typical time step is 1 ns, and after numerous loops of the calculation, the time dependent surface potential is obtained.

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 Figure 2. If Vacc is low, like 0.8-1.0 kV, or Vacc is large, like 3-10 kV, the saturated potential is positive. However, if Vacc is between 1.3 kV and around 3 kV, the surface potential saturates toward a negative value. This tendency agrees quite well with our experiment for 300-nm thick FEP film on 70nm-thick Cr on a glass substrate.[2] The reason of a positive value for low Vacc is that the secondary electron (SE) yield is above unity. The positive value for high Vacc is that almost all primary electrons transmit to the substrate and almost no charge is accumulated in the film, and only a small amount of SE emission at the surface makes the surface slightly positive. It is known that the tail of the depth distribution of energy density distribution almost reaches the bottom of the PMMA layer at Vacc=2.7 kV by the simulation. Because of the EBIC, it is expected that if Vacc is above 2.7 kV, electron charge stored in the PMMA will be leaked to the substrate. On the other hand, if primary electrons stop at a relatively shallow region and build a negative potential at e.g. Vacc=1.3 kV no conducting mechanism is present in the film around the deposited charge, unless the electric field becomes strong enough to release the charge toward the surface by EBIC in the film. Then, the saturated potential is negative at those Vacc's. The time constant of the saturation may depend on the size of the volume and the amount of stored charge, or the velocity of carriers in the specimen, etc.

The saturated surface potential as a function of Vacc's shown in Figure 3 is quite similar to the one obtained by our experiment.[3] However, the absolute value of the potential is different. For example, in the experiment the maximum negative potential is about -40V at the Vacc=1.5 kV. Here, the electric field is 40V/300nm=1.3MV/cm, and it is almost at the electric breakdown field. If only intrinsic resistivity ( ) and resistivity due to EBIC ( ), which is given above, are taken into account, [2] the maximum negative potential reaches more than -150V. This potential cannot be reached, because it is more than the break-down voltage of the material. Then, we introduce a consideration of the space charge limited current (SCC) process in the material to the simulation. Space charge limited current is considered by the following equation:

– — – —,

where the is determined tentatively by —.

Overall current regarding intrinsic, EBIC and SCC processes is written by the following equation.

By introducing the SCC, as shown in Figure 4, if the potential is less than 15 V, the attained potential does not change so much, but if the absolute potential increases more than 40 V, the resultant negative value saturates. If the Vacc is 1.8 kV, the maximum negative value attained is about -50V, which is almost comparable to the experimental results.

1. M. Kotera, K. Yamaguchi and H. Suga, Jpn. J. Appl. Phys. 38, 7176 (1999).
2. M. Kotera, J. Vac. Sci. And Tech., B19(6), 2516-22519 (2001).
3. M. Kotera and A. Osada, M. Otani and Y. Ohara, J. Vac. Sci. and Tech., B29(6), 06F316-1 (2011).

4. This work was supported by KAKENHI (C) 22560026.

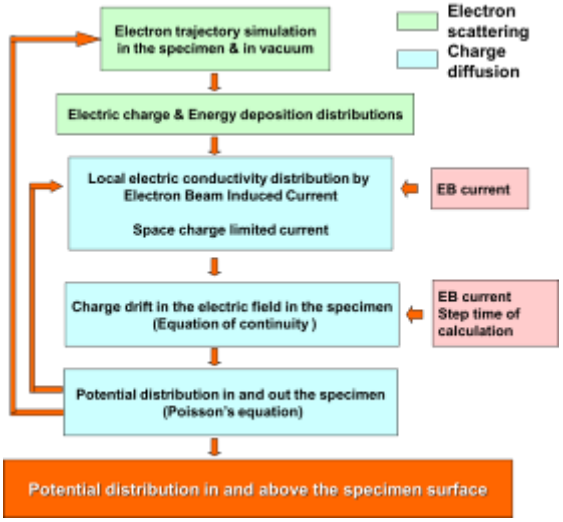

Figure 1. Simulation flow of the present.

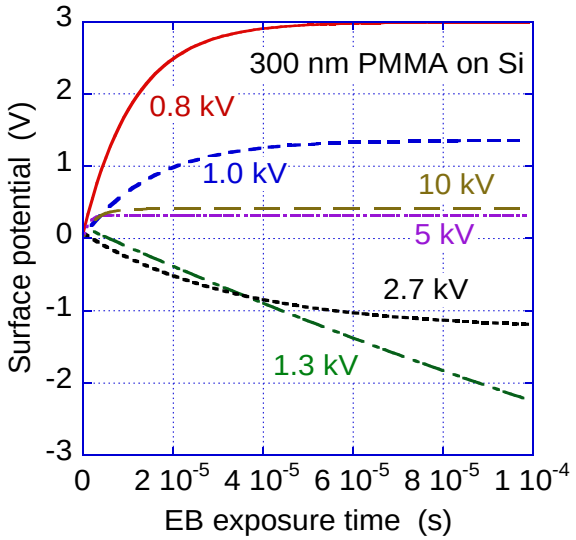

Figure 2. Surface potential variations with time of EB irradiation for various Vacc's

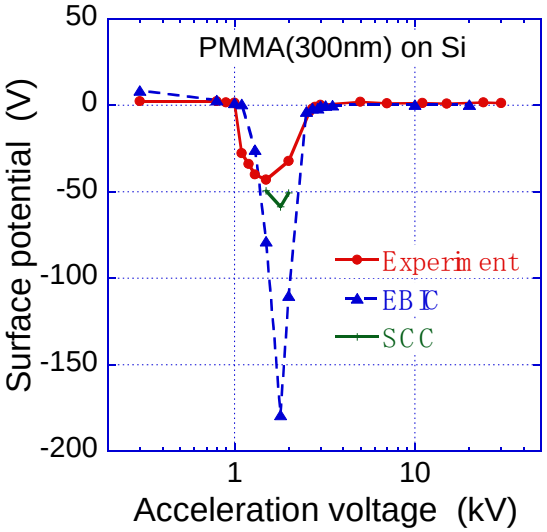

Figure 3. Saturated surface potential obtained as a function of Vacc by the calculation is comparing to the experimental results obtained by our recently developed measurement system.

.

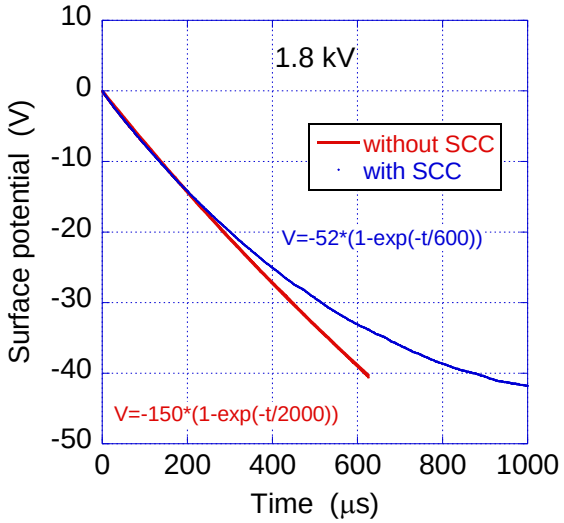

Figure 4. Surface potential variation with time. The initial variation is the same, but after the electric field is increased, difference becomes obvious between results of with and without SCC is considered