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Charging of a Structured Material during Electron Beam Exposure

M. Kotera and Y. Ishida

Osaka Institute of Technology, EICE Dept. Omiya, Asahi-ku, Osaka, 535-8585, Japan

A charging of materials by an electron beam exposure has been one of the most interested problems and has been discussed in various aspects of electron beam applications. Although some kinds of simulations have been developed to explain certain experimental results [1-3], the charging phenomena depending on the structure of the material have not been discussed. If the pattern has a narrow bridge structure, the central part of the bridge will be charged positively immediately after the primary electron beam (EB) exposes the structure. If the amount of electric current flows through the cross section of the bridge from the both ends is not enough, the positive charging may be saturated. However, if the current cannot be high enough, the electric breakdown occurs. We solve the current continuity equation and quantify the saturated distributions of the charge density and the potential in and around the material in the present study.

Figure 1 shows the illustration of the structure assumed. An isolated line with 0.4μm wide and 1.9μm long is present at the center of the region of 5μmX5μm in 2μm-thick Si. This is so called the bridge structure. The current density of the primary EB is 0.01A/cm^2. The accelerating voltage of EB considered is 100kV. Figure 2 shows the deposited electron distribution obtained by a Monte Carlo simulation of electron trajectories after EB is irradiated. Because of the material structure, the reentrance and the reemission of SEs from one surface to the opposite surface are taken into account, as we have presented before [4]. The lower left in Fig.2 shows the rendered volume of the density distribution of deposited electrons at the region calculated, and three other figures show the cross sectional views of the distribution, obtained by cutting the region by the numbered planes displayed in the lower left. If incident electrons cannot escape from the surface at some part of the material, the charge is stored inside the material, and the part is charged negatively. Because of the SE emission from all surfaces of the structure, all surfaces are charged positively, especially around the walls of the bridge. The potential distribution can be obtained by solving the Poisson equation three-dimensionally with the boundary condition. It is assumed that the whole EB exposure field is 1mmX1mm square, and the exposed area considered here (5μmX5μm) as shown in Fig.1 is located at the center of the field. It is also assumed that the same pattern as shown in Fig.1 is exposed laterally side by side in the whole field, and the potential is grounded at the circumference of the whole volume (1mmX1mmX1mm). The region is divided by cubic cells, and the size for every side is 0.1μm. Because of the charge drift and the diffusion, the charge distribution is modified from the deposited electron distribution by the incident EB. This movement of electrons can be expressed by the current continuity equation as follows:

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla \mathbf{J}_n - G, \qquad (1)$$

$$\nabla \mathbf{J}_n = n\nabla(\mu \mathbf{E}) + \mu \mathbf{E}\cdot\nabla n + D\nabla^2 n + \nabla n \cdot \nabla D, \qquad (2)$$

where $\mathbf{J}_n$ is the electric current flow due to the drift and the diffusion, G is the electron deposition rate by an incident EB. The values of μ and D are the mobility and the diffusion coefficient of electrons, and since we assume the intrinsic Si as the material, they are 0.12 $(m^2/V\cdot s)$ and 0.003$(m^2/V\cdot s)$, respectively. Because the diffusion coefficient D is assumed to be constant in the calculation, the fourth term in the right side of eq.(2) is neglected. This equation is solved every $5X10^{-13}$ second. If the current flow in the whole field becomes negligible, it is considered that the values are saturated, and the saturated distributions of the potential and the charge are obtained.

Figure 3 shows the potential variation with time at the center of the bridge structure. The potential increases to a positive value, and after 0.1µs the potential is almost saturated to be about 0.23V, if the exposure area is 1mmX1mm. Figure 4 shows the saturated potential distribution in the central 5µmX5µm area. If the material is made with higher resistivity, the saturated potential should be appreciably large and electric breakdown may occur, and this kind of analysis will be done in future.

References
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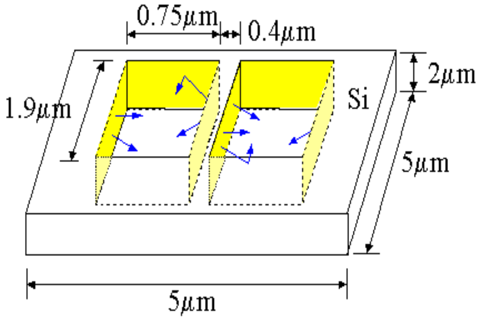

Fig.1 Illustration of the structure of the material assumed.

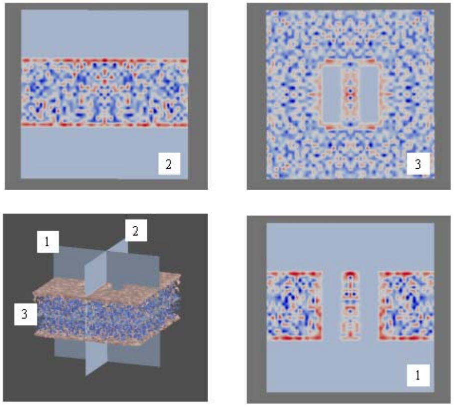

Fig.2 Deposited charge distribution at the material obtained by the simulation of electron trajectories introduced by EB.

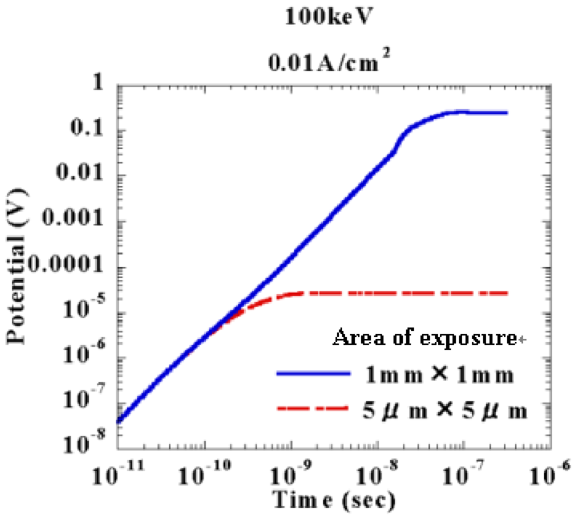

Fig.3 Time dependent potential variation at the center of the bridge structure.

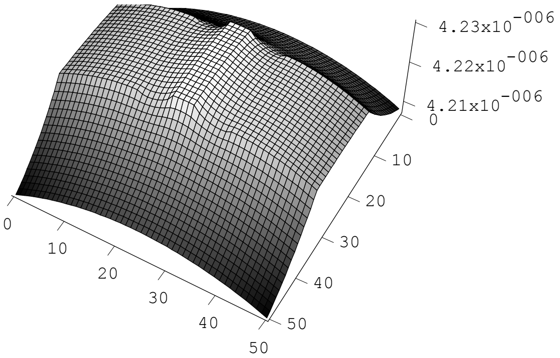

Fig.4 Saturated potential distribution obtained at the cross section 1 in Fig.2. The area is 5µmX5µm.