Charging Simulation of Insulating Layers on a Conducting Substrate Irradiated by Ion and Electron Beams

K. Ohya
Institute of Technology and Science, The University of Tokushima,
Tokushima 770-8506, Japan
ohya@ee.tokushima-u.ac.jp

Due to shrinking device dimensions, ion and electron beams have been increasingly used in device fabrication for performing inspection, metrology, and failure analysis. Scanning ion microscopes (SIMs) using a gas field ion source, like conventional scanning electron microscopes (SEMs), has attracted interest for its impressive capability not only to observe nanostructures but also fabricate them. Although the image formation mechanisms of the SIM are similar to those in the SEM, there are some differences in image properties.

We have recently developed a Monte Carlo model for secondary electron (SE) emission from SiO_2 that accounts for the charging induced by electron and ion beam irradiation.[1,2] The model performs a self-consistent calculation to model projectile and SE transport, charge accumulation, and the resultant electric field in the material and in the vacuum. When the sample consists of a thin SiO_2 layer formed on Si substrate, the model calculation shows that the charging strongly depends not only on the layer thickness at the range of 100 nm or less, but also on the projectile energy and species. In the present paper, we investigate the charging characteristics of 25-250 nm thick SiO_2 layers, the surface of which are irradiated with He, Ne and Ga ion beams in the tens-of-keV energy range relevant to the SIM. The calculation is also done with electron beams of 100 eV to 10 keV for comparison with conventional and low-voltage SEMs.

A 250-nm-thick layer became positively charged by 300-1600 eV electron beams due to a balance between incoming and outgoing electrons. For higher energies, the surface was negatively charged. However, when the electron beam reaching the substrate (e.g., 4 keV or more), it was positively charged again. By irradiation of a 100-nm-thick layer with positive Ga ions, it became charged positively and the SE yield vanished due to successive charging. The charging of the layer irradiated with He ions was strongly limited where the surface voltage saturates a few eV and the SE yield did not clearly decrease. The intermediate behavior of the charging was obtained with Ne ions. The charging voltage was increased with increasing thickness of the layer. These charging characteristics were closely related to the projectile range and lateral broadening in the sample.

[1] K. Ohya, K. Inai, R. Kawasaki et al. , J. Electron Microsc. 59 (2010) S189.

[2] K. Ohya, T. Yamanaka, Nucl. Instr. Meth. Phys. Res. B315 (2013) 295.

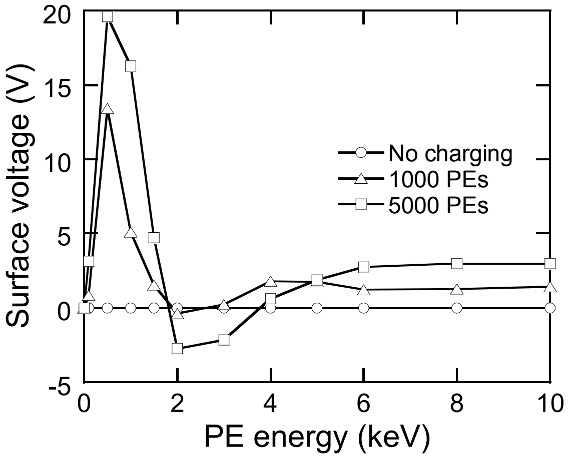

Figure 1: Electron beam energy dependence of surface voltage of a 250-nm-thick SiO_2 layer on a Si substrate.

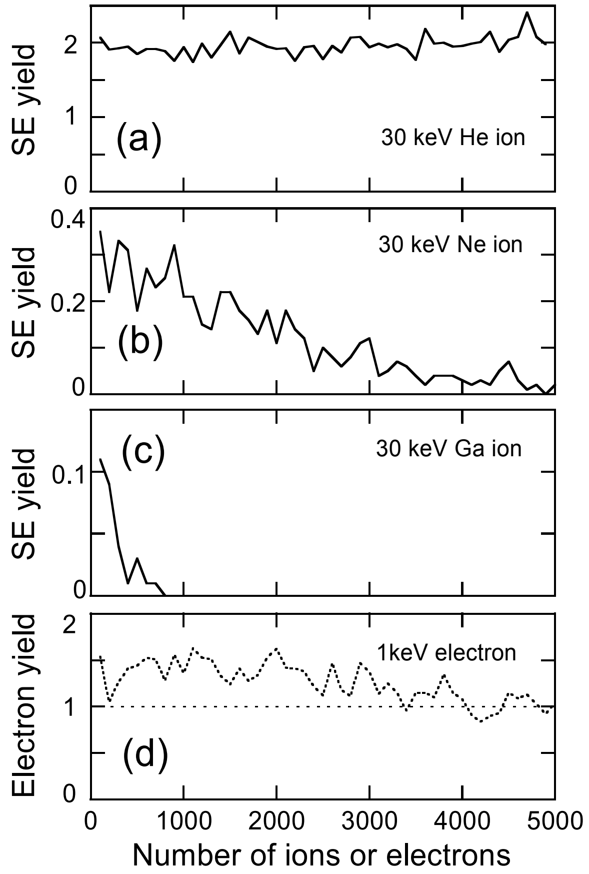

Figure 3: Dynamic change in SE yield from a 100-nm-thick SiO_2 layer on Si irradiated with (a) He, (b) Ne and (c) Ga ions at 30 keV, along with the change in the total electron (SE+ BSE) yield with 1 keV electrons.

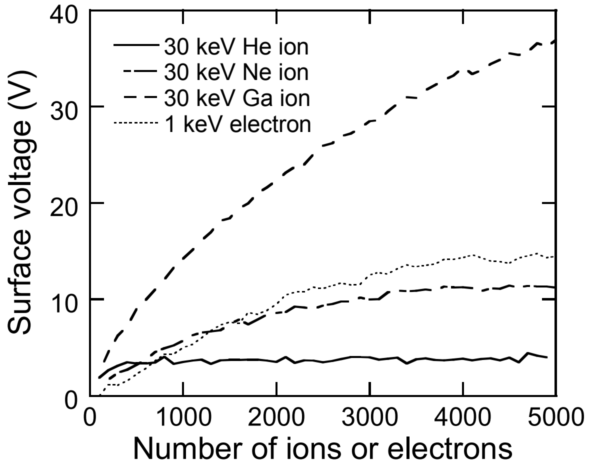

Figure 2: Dynamic change in surface voltage at the irradiation point of a 100-nm-thick SiO_2 layer on Si. The surface is irradiated with (a) He, (b) Ne and (c) Ga ions at 30 keV, and (d) 1 keV electrons.