Nanopore perforation in various membrane material by focused electron beam in transmission electron microscope

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The fabrication of sub-10 nm solid state nanopore to detect and control the transport of biomolecules by a focused electron beam in a transmission electron microscope has now become a common practice adopted by many research groups. We believe that understanding this mechanism is quite important in order to make a drastic progress in this area. It is more critical since the nanopore structure will be more complicated in a future with the incorporation of few electrodes in the membrane.

In this presentation, we will undertake a theoretical consideration of the energy transfer from the fast electrons to the solid through such mechanisms as elastic and inelastic scattering just in order to explain the sculpturing of nanopore by electrons. From the theoretical consideration, we can calculate the cross section of elastic scattering resulting the direct atomic displacement and that of inelastic scattering which results in the ionization, excitation and the temperature increment. Based on the calculation, we can extract that the incident electron energy is the critical parameter in order to explain the nanopore drilling phenomenon. Then, we preformed nanopore drilling in a Si_3N_4 and TiN membrane using two different electron energies, 200kV and 300kV, to identify the drilling mechanism since the calculation of the scattering cross section clearly reveals that the cross section of direct atomic displacement increases with increasing incident electron energy, while the ionization cross section and temperature increment decrease. The experimental results of the nanopore drilling on the incident electron energy strongly support that the nanopore is perforated by the direct atom displacement. We can also calculate the direct atomic displacement energy of Si_3N_4 and TiN from the movement of contrast curve which is introduced as characteristic plot of normalized drilling volume as a function of electron dose.

We also investigated the nanopore evolution on metal membrane through focused e-beam in transmission electron microscopy. Al, Ti, Cr, Cu and Au are selected to investigate the effect of sputtering energy and atomic mass in nanopore drilling. Figure 1 shows the calculation of displacement cross-section of metals. As the increase of atomic mass, the effect of elastic scattering is decreased. In Ti, Cr, and Cu membrane, atomic mass is Ti, Cr, and Cu sequence but sublimation energy is vice versa. Experimental cross-section obtained from normalized drilled volume vs. electron dose (characteristic contrast curve) is well matched with the calculated atomic displacement cross-section based on elastic scattering. Sputtering energy of Ti, Cr, and Cu was extracted about 10 eV, 9 eV, and 7 eV, respectively, which is shown with sputtering energy range reported.

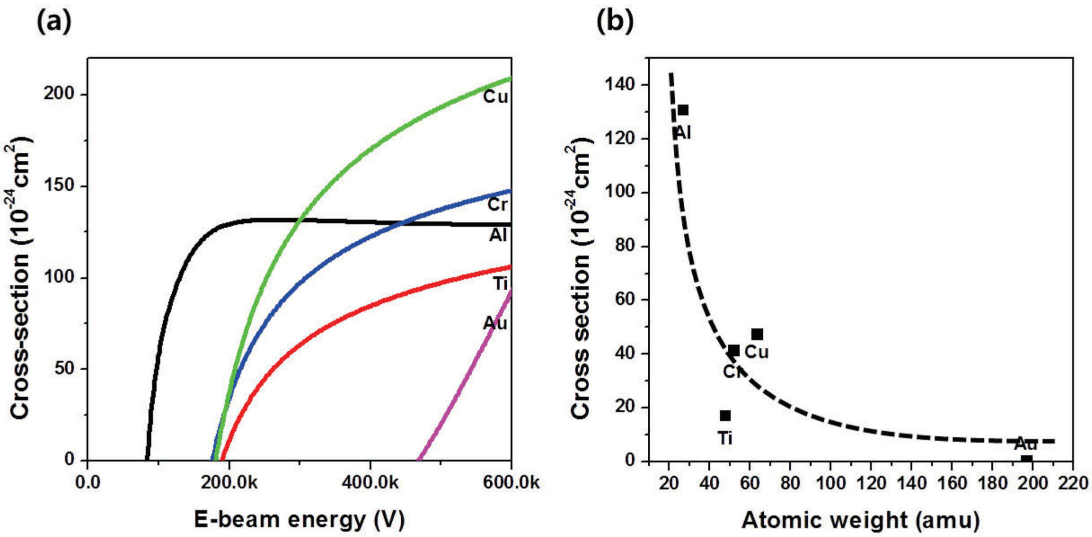

Figure 1: (a) Calculation of displacement cross-section of Al, Ti, Cr, Cu and Au as a function of e-beam energy (b) displacement cross-section at 200kV e-beam energy as a function of atomic weight