The mechanism of nano-sculpturing by focused electron beam for DNA translocation control

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The fabrication of sub-10 nm solid state nanopore to detect and control the transport of DNA by a focused electron beam in a transmission electron microscope has now become a common practice adopted by many research groups. However, it is still not yet clear how the membrane structure is perforated by the focused electron beam. 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.

We undertake a theoretical consideration of the energy transfer from the fast electrons to the solid through the scattering mechanisms such 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 or sputtering 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 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.

We introduce the characteristic contrast curve which is a normalized drilling volume as a function of deposited electron dose. The contrast curve is related with the scattering cross section. Figure 1 shows the contrast curve at different incident electron energy, 200 kV and 300kV. The experimental results of the nanopore drilling on the incident electron energy shown in Figure 1 strongly support that the nanopore is mainly perforated by the direct atom displacement through the elastic scattering between fast electron and rest atom. We can also extract the scattering cross section from the contrast curve and calculate the direct atomic displacement energy.

In this presentation, we will introduce the theoretical background on the electron scattering in the material. Based on the theoretical prediction, we perform the nanopore drilling as a function of incident electron energy on various membrane materials such as Si_3N_4, TiN, and other single metals.

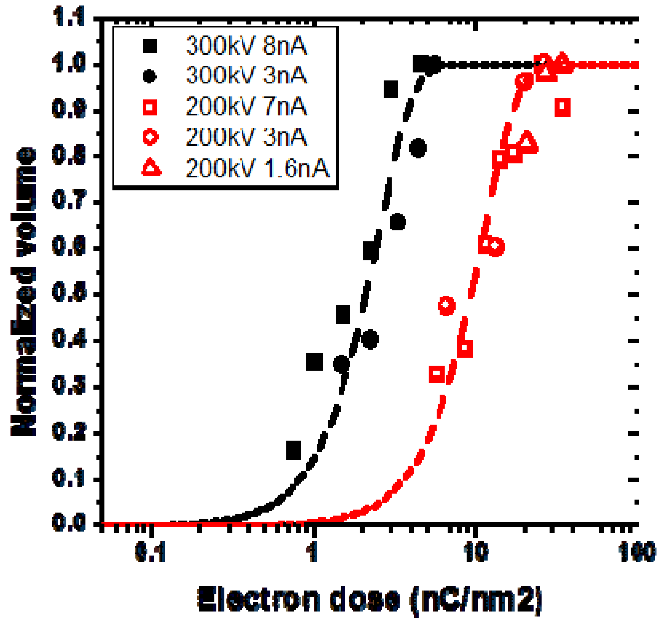

Figure 1: The contrast curve of nanopore drilling on Si_3N_4 membrane as an incident electron energy: the solid mark is at 300 kV e-beam and the open mark is at 200 kV e-beam. When we used the 200kV e-beam, the higher electron dose need on the nanopore drilling. That is well match that the nanopore drilling by fast electron is governed by the direct atomic displacement or surface sputtering.