液槽外の静電気によるソリッドナノポアメンブレンの絶縁破壊

Static Charge outside Chamber Induces Dielectric Breakdown to Solid-state Nanopore Membranes

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To achieve DNA sequencing using solid-state nanopores, it is necessary to reduce a noise current by reducing the capacitance of the device [1, 2]. However, in our previous reports, we found that pinhole-like shaped defects were generated in the membrane of the low capacitance devices (< 100 pF) when electrolytes were poured into the chambers of the flow cells [2]. The defects were turned out to be generated by dielectric breakdown due to an unexpected high voltage between the electrolytes (Figure 1). This generation of the voltage is an intrinsic problem, but the main origin of the voltage had not been clarified. In this study, we determined the main origin of the voltage was the static charge on flow cells.

Figures 2 show the process by which the membrane ruptured by the static charge. If there is no static charge on the flow cell (Figure 2(a)), the high voltage does not occur at the membrane. When there is the static charge (Figure 2(b)), the static charge generates the electric field. If the static charge is positively charged, the electric field attracts chloride ions in the electrolytes and produces high voltage to the membrane. This high voltage caused a dielectric breakdown and produced many defects in the membrane.

Figure 3(a) shows an equivalent circuit with series capacitor when the static charge was generated. The voltage V_e of the electrolyte was calculated from the following equation $V_e = V_s \times C_f / (C_f + C_d)$ where V_s is the surface voltage on the flow cell, C_f = 3.1 pF is the capacitance of the flow cell, and C_d = 1000 pF is the capacitance of the device. To verify this equation, V_e and V_s were respectively measured by a voltmeter and a surface potential sensor, and the correlation between V_e and V_s was investigated. As shown in Figure 3(b), the red theoretical line almost matches with the black regression line. A Student's t test was used to determine whether the experimental data follows the theoretical line. A p-value was calculated to be 0.37(> 0.05), and there was no significant difference at the 5 percent significance level. This result strongly supports the validity of the proposed hypothesis that the static charge increases V_e.

This founding in the above implies that the generation of the defects can be prevented by removing the static charge on the flow cells. Then, we studied yields using the flow cells with and without the anti-static agent using low capacitance devices (< 100 pF). By measuring leakage current through the membrane at 0.1 V, we could determine whether or not the membrane had defects [2]. As shown in Table 1, the yields using the flow cells with and without anti-static agent were 19 % (5 of 27) and 75 % (6 of 8), respectively. This result verifies the hypothesis that the generation of the defects was mainly due to the static charge on the flow cells, and the defects could be prevented using the anti-static flow cells.

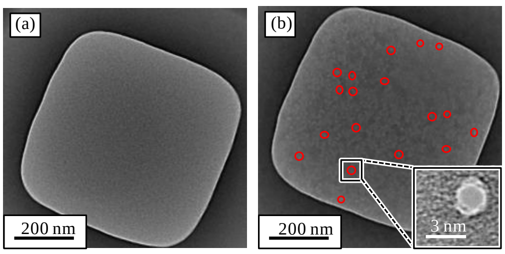

Figure 1. TEM images of membranes (a)before and (b)after pouring into the flow cells. Defects are marked by red circles.

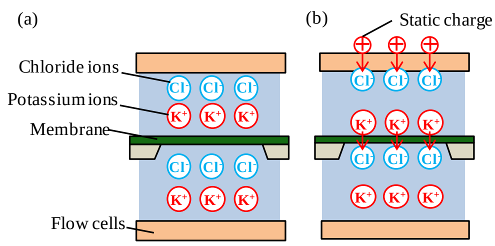

Figure 2. Schematic images of setups when there is (a) no static charge and (b) static charge on the flow cells.

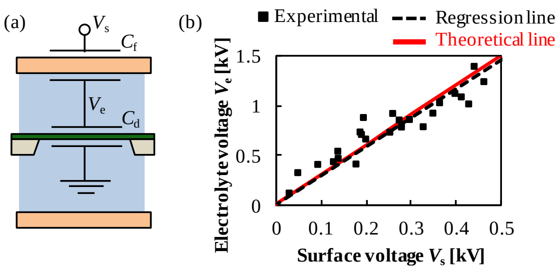

Figure 3. (a) Equivalent circuit of the setup (b) The correlation between V_e and V_s.

Table 1. Yields using flow cells without and with anti-static agent.

	Yield [%]
Without anti-static agent	19
With anti-static agent	75

References

[1] Balan, A. *et al.*, *Nano Lett.* DOI: 10.1021/nl504345y (2014).
[2] Matsui, K. *et al.*, *Sci. Rep.* DOI:10.1038/srep17819 (2015).