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# 多段パルス電圧制御による絶縁破壊を用いた径 1 nm 以下から 3 nm までのナノポア形成

# Fabricating nanopores with diameters of sub-1 nm to 3 nm using multilevel pulse-voltage injection

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To date, solid-state nanopores have been fabricated primarily through a focused-electronic beam via TEM. For mass production, however, a TEM beam is not suitable and an alternative fabrication method is required. Recently, a simple method for fabricating solid-state nanopores was reported by Kwok, H. *et al.* and used to fabricate a nanopore (down to 2 nm in size) in a membrane via dielectric breakdown [1]. In the present study, to fabricate smaller nanopores stably—specifically with a diameter of 1 to 2 nm (which is an essential size for identifying each nucleotide)—via dielectric breakdown, a technique called “multilevel pulse-voltage injection” (MPVI) is proposed and evaluated [2].

The setup for fabricating the nanopores by MPVI is illustrated in Figure 1. Separated by a $Si_3N_4$ membrane with a thickness of 10 nm, two chambers (*cis* and *trans* chambers) are formed in a flowcell. Both chambers are filled with 1 M KCl aqueous solution. Two Ag/AgCl electrodes (*cis* and *trans* electrodes) are immersed in aqueous solutions and connected to a pulse-voltage generator and an ammeter. A pulse chart for MPVI is presented in Figure 2. After a high voltage pulse ($V_{P1}$) is applied between the *cis* and *trans* electrodes to generate a nanopore in the membrane, an electrical current between the electrodes ($I_{Tot.}$) at a low voltage ($V_R$) is measured to verify whether a nanopore is generated. After the nanopore has been generated, it can be slowly widened to the intended size via the application of mid-voltage pulses ($V_{P2}$). The dependence of $I_{Tot.}$ at $V_R$ on the cumulated time ($t_{sum.}$) of applied-pulse ($V_{P1}$ and $V_{P2}$) durations is shown in Figure 3. $V_{P1}$, $V_{P2}$ and $V_R$ were set to 7 V, 2.5 V and 0.1 V respectively. The number of the applied pulses ($V_{P1}$) per decade of time was 24. This figure illustrates that the nanopore-generation point could be detected very easily and clearly. TEM images of the fabricated nanopores with MPVI are presented in Figure 4. These images confirm at a glance that nanopores with diameters less than 2 nm could be fabricated.

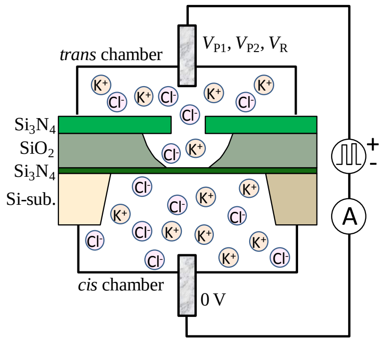


Fig. 1. Schematic diagram of MPVI

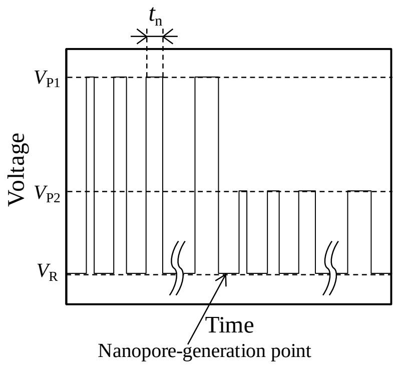


Fig. 2. Pulse chart of MPVI

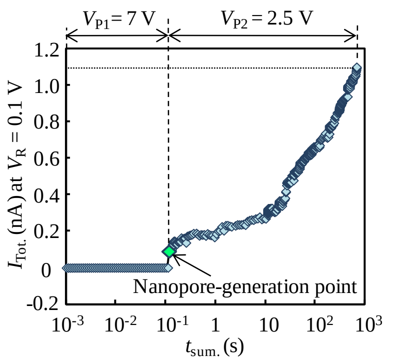


Fig. 3. Time-dependent characteristics of current ($I_{Tot.}$) during MPVI.

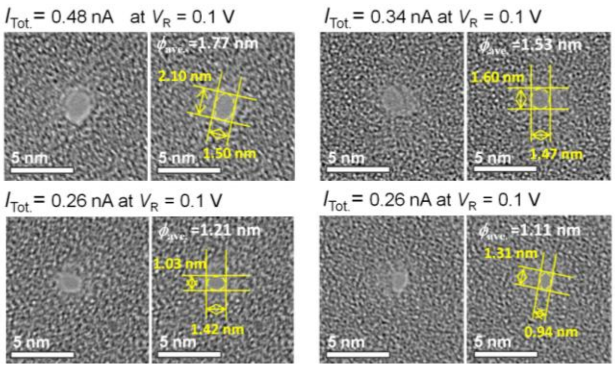


Fig. 4. TEM images of nanopores fabricated via MPVI.

**References**

[1] Kwok, H. *et al.*, PLoS ONE 9(3): e92880. doi:10.1371/journal.pone.0092880

[2] Yanagi, I., *et al.*, Sci. Rep. 4, 5000; DOI:10.1038/srep05000 (2014).