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 Si₃N₄ 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 \( V_{P1} \) (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.

**References**