Sapphire Supported Aluminum Nitride Nanopore towards Stable and Low-Noise Biomolecule Sensing

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Solid-state nanopores have garnered significant attention from the research community over the past two decades due to its unique features, such as flexibly adjustable pore size, stability in electrolytic solutions, heightened mechanical stress tolerance, and seamless integrality with other electronic devices. However, conventional silicon-supported (SiS) Si_3N_x nanopores encounter challenges, notably high device capacitance stemming from the silicon's conductivity, which restricts high-frequency sensing applications. Previously, we demonstrated a solution through the wafer-scale fabrication of sapphire-supported (SaS) Si_3N_x solid-state nanopores with significantly reduced capacitive noise during high-frequency sensing[1]. Yet, Si_3N_x membrane still suffers with stability issues during long-term biomolecule sensing.

This study focuses on the potential of aluminum nitride (AlN) as a membrane material. Employing the same wafer-scale sapphire-supported SiN nanopore fabrication approach, a 15 nm thin AlN layer, deposited using atomic layer deposition, replaces the Si_3N_x thin film deposited via LPCVD techniques. AlN has higher breakdown potential compared to SiN suggests greater stability in electrolytic solutions while maintaining low noise.

We conducted translocation tests (Figure 2) of 1000bp double-stranded (ds) DNA molecules to characterize noise, biosensing, and stability performance under a 100 kHz bandwidth and 250 mV bias voltage. Compared with sapphire-supported SiN chips and Si-supported SiN chips, the signal-to-noise ratio (SNR) for AlN membranes was found to be ~67, significantly higher than the 21 for sapphire-supported SiN and 11 for silicon-supported SiN as reported earlier[2]. Additionally, in the same electrolytic solution and bias voltage, nanopores with AlN membranes exhibited greater stability compared to those with SiN membranes, whereas the nanopore area increase 40.5% was 54.6% smaller than that compared to SiN membrane (87%) during the same testing period and voltage (250 mV). This demonstration underscores the potential of sapphire-supported AlN nanopores for high-frequency, low-noise, and stable biomolecule sensing through wafer-scale fabrication.

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References:

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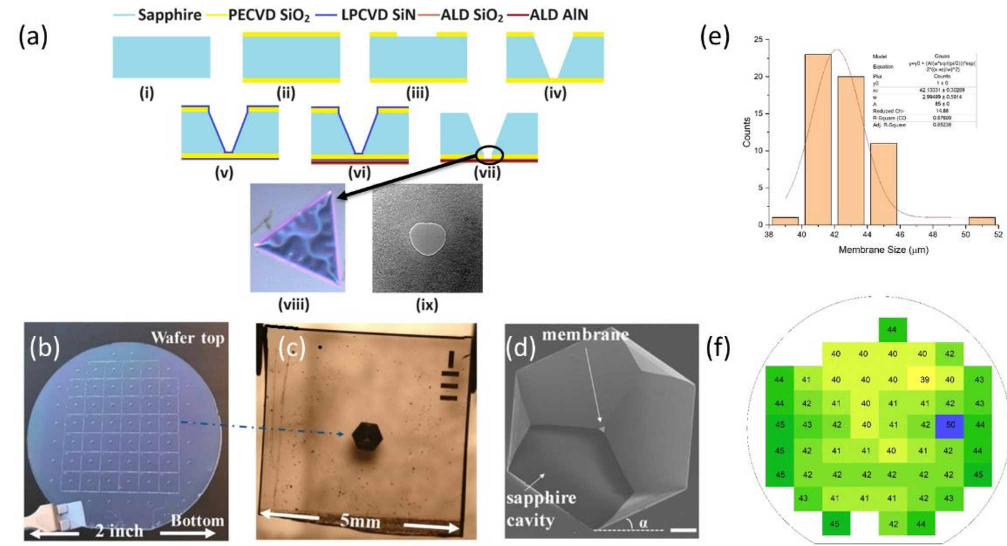

Figure 1: (a) Key Steps of nanopore fabrication: (i) A 250 μm C-plane sapphire wafer, (ii) PECVD SiO_2 (~1 μm) has been deposited, (iii) A hexagonal window is opened up,(iv) The sapphire is etched through to get membrane, (v) A thin of LPCVD SiN (~50 *nm*) membrane is deposited, (vi) A thin sandwiched ALD AlN (~15 *nm)* between top and bottom ALD SiO_2 (~3 *nm* on each side) is deposited, (vii) The AlN membrane is formed after selectively etching of SiO_2 and SiN, (viii) optical image of triangular AlN membrane, (ix) TEM image of nanopore; (b) optical image, (c) optical image of chip, (d) SEM image of hexagon, (e) gaussian distribution of membrane size, (f) size of membrane across the wafer.

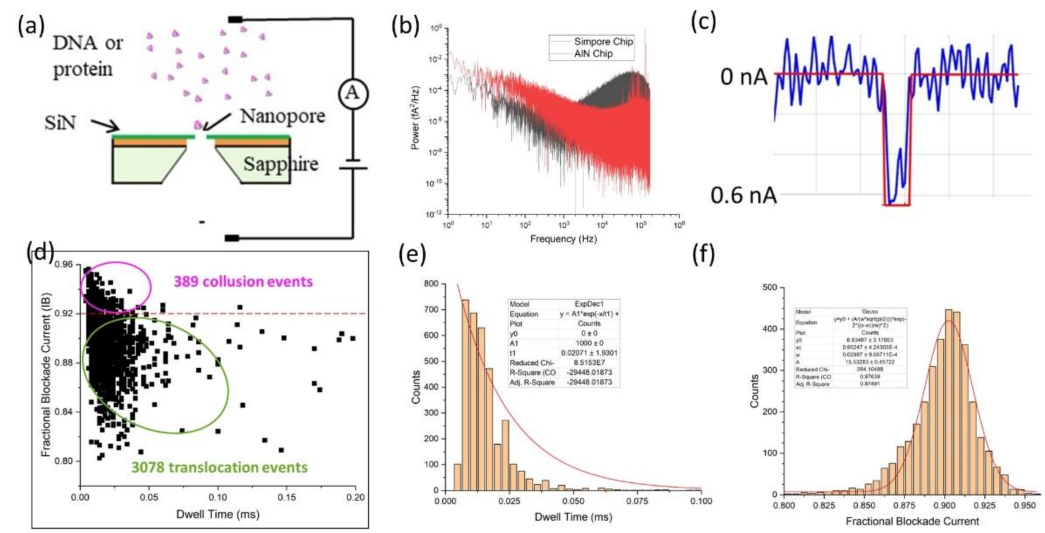

Figure 2: Characterization of AlN nanopore, (a) Schematic showing the DNA translocation, (b) power density spectra of SiS chip and SaS AlN chip, (c) translocation event, (d) scattered plot of fractional blockade current, (e) exponential decay fitting of the dwell time, (f) gaussian fitting of the fractional blockade current.