Sapphire Supported AlN Membrane Solid State Nanopore for Low-Noise and High-Resolution Biomolecule Sensing

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Nanopores are a powerful platform for single-biomolecule analysis, enabling the detection of different biomolecules, their interactions, and information-encoded nanostructures.[1] Compared to biological nanopores, solid-state nanopores are tunable in pore geometry, mechanically robust, and compatible with integrated electronic and photonic systems, thus supporting large-scale integration. However, conventional silicon-supported silicon nitride (SiN) nanopores suffer from high noise current arising from large stray capacitance. Previously, we demonstrated wafer-scale fabrication of sapphire-supported SiN membrane nanopores that significantly reduce the ionic current noise by reducing device capacitance from nano-farad to pico-farad range[2]. Yet, one remaining challenge lies in the difficulty in control of SiN stoichiometry, poor wettability and gradual nanopore dilation in electrolyte solutions, which compromise long-term stability and sensing reproducibility. In this work, we introduce aluminum nitride (AlN) as a novel membrane material and demonstrate the fabrication of sapphire-supported AlN nanopores with superior noise performance and stability (Figure 1).

The sapphire-supported AlN membranes exhibit a small root mean square (RMS) noise current, small device capacitance (< 5 pF), and a high signal-to-noise ratio (SNR, ~33) **(Figure 2c,d)**. The SNR was 11 better compared to SiN/Si chips and 50% better than our SiN/sapphire chips[3]. Leveraging this enhanced performance, we demonstrate detection of DNA nanostructures by translocating four-helix-bundle (4HB) DNA origami carriers tagged with six-way junctions, which act as "bits" for information encoding. The AlN/sapphire chips demonstrate with a minimum spatial separation of 50 nm, which could not be resolved using SiN/sapphire chips[3] **(Figure 3)**. This higher resolution suggests the feasibility of higher density of coding 'bit' information for enhanced security during readout. Furthermore, the AlN membranes also demonstrate improved pore size stability during prolonged translocation experiments (under a 250 mV bias for 8 hours in LiCl 1M salt), reducing pore size expansion rate by half compared to using SiN membranes. These results establish sapphire-supported AlN nanopores as a promising platform for high-resolution, low-noise, and stable single-molecule sensing.

Reference:
1 P. Xia, J. Zuo, et al., *Biosens Bioelectron*, 2021, 174, 112829.
2 P. Xia, M.A.R. Laskar et al, *ACS Appl Mater Inter*, 2023, 15, 2656–2664.
3 P. Xia, D. Satyabola et al, *Adv Fun Mater,* DOI:10.1002/adfm.202523998.

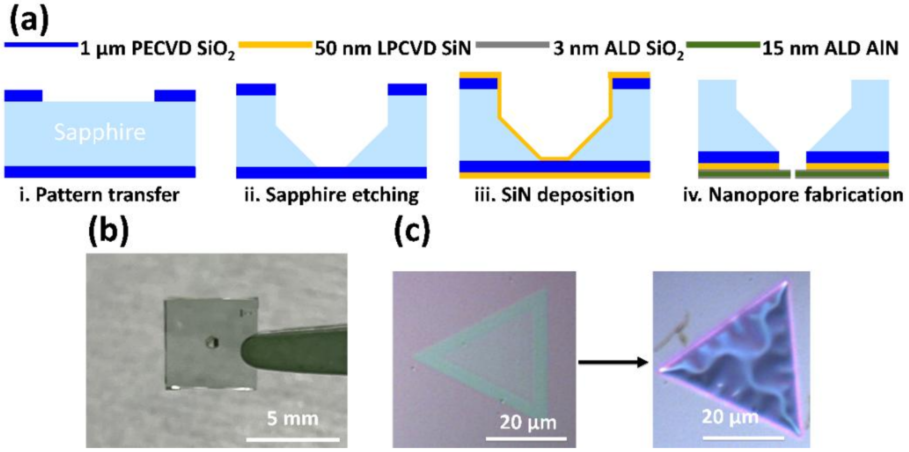

Figure 1: Fabrication of sapphire supported AlN membrane nanopore chip. (a) fabrication process flow, (b) optical image of representative nanopore chip, (c) Optical image of AlN membrane evolution following sapphire etching and subsequent SiO_2 /SiN removal.

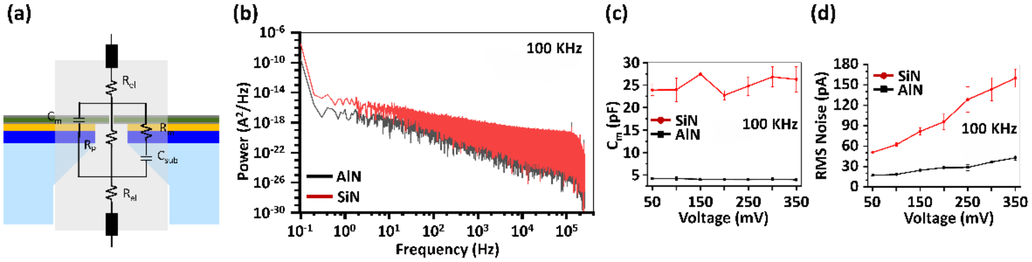

Figure 2: Noise comparison between sapphire supported AlN chip and SiN chip (a) equivalent circuit model; (b) power spectral density of the current noise (c-d) membrane capacitance, and RMS noise vs voltage.

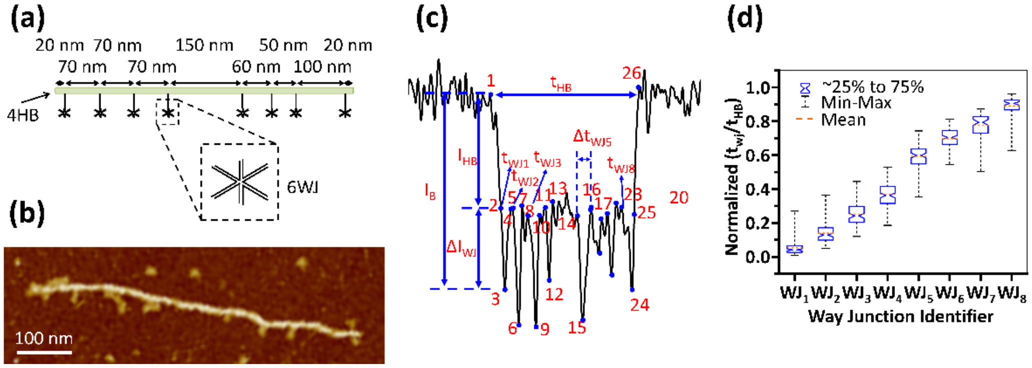

Figure 3: Nanopore translocation of 4HB DNA origami with six-way junction (6WJ) tags: (a) schematic, (b) AFM image, (c) representative translocation, (d) dwell-time statistics resolving individual 6WJ positions.