# Fabrication of sapphire-supported nanopore sensors with reproducible micrometer membranes

Pengkun Xia, Jiawei Zuo, Pravin Paudel, Md Ashiqur Rahman Laskar, Siying Liu, Chao Wang*

*School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, AZ, USA*

Solid-state nanopores have great potential to achieve high-speed and low-cost detection. However, suffering from the high electrical noise associated with the large device capacitance that originates from the electrical conductivity of silicon (Si) substrate, the conventional Si based nanopores are seriously limited in sensing accuracy and recording speed. Approaches to minimize the device capacitance require manual and non-scalable fabrication techniques, and face challenges in precisely controlling the membrane dimensions. Recently [1], we demonstrated a novel approach to create thin triangular membranes on a crystal insulating sapphire wafer to completely eliminate the parasitic device capacitance. Briefly, a triangular shaped window was formed in $SiO_2$ film on c-plane sapphire, and a batch-processing-compatible sapphire etching in concentrated sulfuric and phosphoric acids anisotropically etched sapphire to form a cavity and suspended membrane (Figure 1a). This process enabled 2-inch wafer-scale fabrication of suspended dielectric membranes on sapphire for the first time.

In this study, we discovered that by using hexagonal instead of triangular etching mask design, we could also create triangular membranes (Figure 1c). Importantly, the membrane dimension is much less sensitive to the alignment of the patterned mask to the sapphire crystal, making this approach even more reproducible, particularly for small membranes (Figure 1d-e). We also established a method to predictably control the membrane dimensions at 6 μm precision (Figure 2d). As a first demonstration, 58 membrane chips were created on a 2-inch wafer (58/60=97% yield with two membranes not opened), with an average membrane size of 4.7 μm with 3.9 μm deviation (Figure 2e).

To characterize the noise and biosensing performance of the sapphire-supported (SaS) nanopores, we translocated 1kbp double-stranded DNA under 100kHz bandwidth (Figure 3d, f) and compared to the results from a silicon-supported (SiS) nanopore (Figure 3c, e). Even though our SaS nanopore had a larger pore size and a thicker SiN membrane (6.9 nm pore and 32 nm SiN, Figure 3b) than that of the SiS nanopore (4 nm pore and 23nm SiN, Figure 3a), it still showed higher signal-to-noise ratio (SNR, 21 versus 11). This is attributed to the low root-mean-square (RMS) noise performance of the SaS nanopore. The SNR is expected to be boosted by using smaller nanopores and thinner SiN or even 2D material membranes. Our demonstration paves the way for the high-accuracy, inexpensive and wafer-scale solid-state nanopore sensor manufacturing, with applications from biosensing of DNA and proteins to new optoeletronic and microelectromechanical systems (MEMS) devices.

References: [1] P. Xia *et al.*, Biosensors and Bioelectronics **174,** 112829 (2020).

* Contact information: wangch@asu.edu.

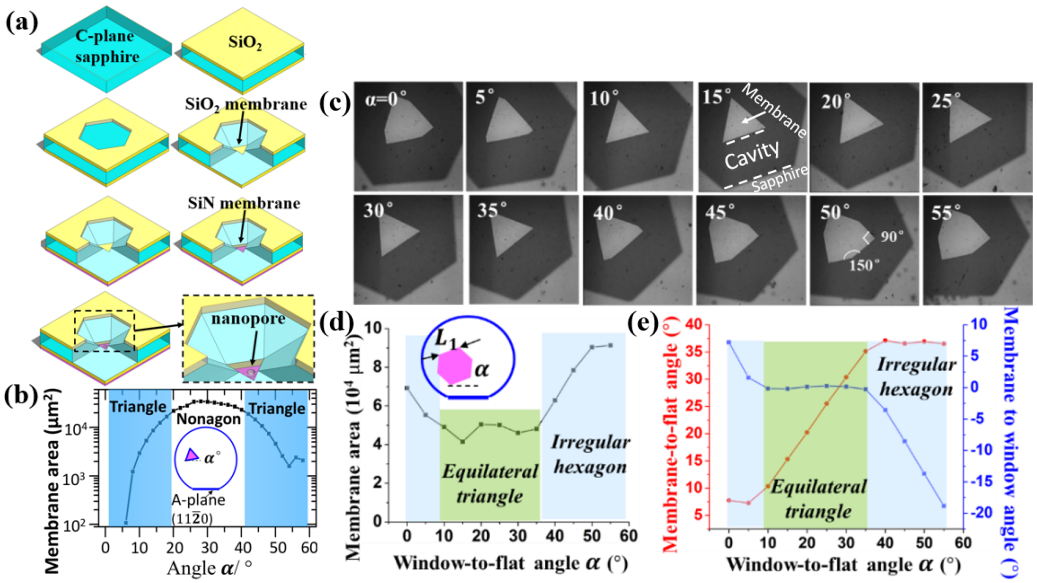


*Figure 1:* (a) Nanopore sensors fabrication by hexagonal mask. (a corner in the schematic is hidden). (b) Controlling membrane shape and dimensions by triangular-mask and (c-e) the improvement by the hexagonal-mask design.

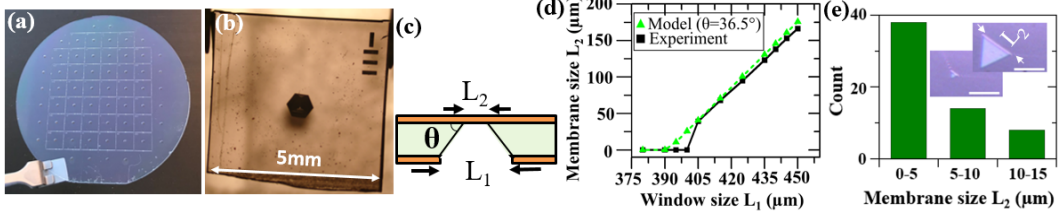


*Figure 2:* Fabrication of membranes on sapphire by hexagonal-mask design. (a) Optical image of a sapphire wafer after sapphire being etched through. (b) A photo of a real 5mm by 5mm sapphire chip with intact membrane formed. (c) Device cross-sectional schematic showing the membrane ($L_2$), the window ($L_1$) and the etching angle θ. (d) Linear relation between $L_2$ and $L_1$. Empirical analysis (green) is modelled based on the etching angle (θ) of 36.5°. The experiment (black solid curve) is consistent with the empirical model. (e) Small membranes formation on the wafer in figure a. Scale bar: 5μm.

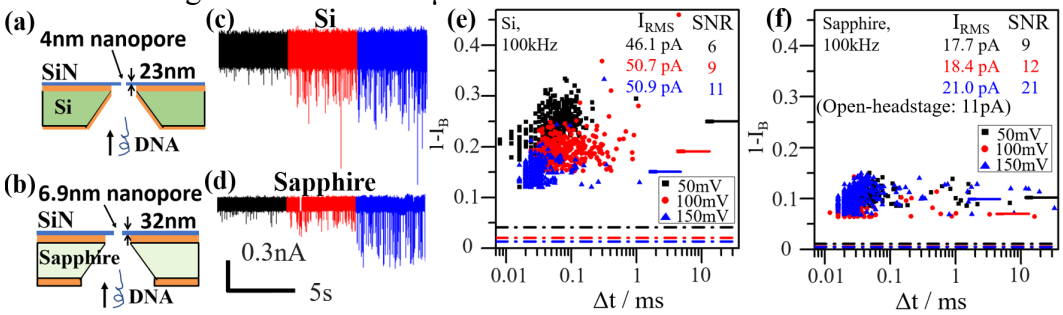


*Figure 3*: DNA sensing using the SaS nanopore. (a-b) Schematic showing structures of SiS nanopore (a) and SaS nanopore (b). (c-d) DNA signals measured with SaS nanopore under 50mV (black), 100mV (red) and 150mV (blue). (e-f) Scatter plot of the fractional blockade current $I_B$ ($=i_b/i_0$) versus the dwelling time Δt for the SiS nanopore (e) and SaS nanopore (f). The RMS of SaS nanopore (17.7pA @50mV) is just slightly higher than the system RMS (11pA).