Wafer-Scale Fabrication of Silicon Nitride Membrane Chips on Sapphire with Noninvasive Resonant Optical Cavity-Based Colorimetric Thickness Monitoring

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Suspended thin membranes have shown broad applications in MEMS and optoelectronics for pressure sensing, IR detection, biosensing, etc. Solid-state nanopores have also been created in such membranes as single-molecule biosensors. We have developed a sapphire-supported nanopore platform using micrometre-sized membranes, such as silicon nitride (Si_3N_4), achieving greatly reduced device noise suitable for high-speed sensing[1,2]. Precise control over membrane thickness is required for high-sensitivity and reproducible nanopore sensor applications. However, thickness measurement of micrometer-sized transparent membranes is challenging for conventional reflectometry and ellipsometry techniques and often requires individual chip dicing and advanced imaging, such as TEM, which are not compatible with scalable production. Novel non-destructive thickness monitoring techniques are thus strongly desired for scalable manufacturing and functional device integration.

Our lab has previously established a wafer-scale fabrication process for sapphire-supported Si_3N_4 (SaS) membranes[2]. In this study, we expanded on this work by integrating an on-wafer membrane thickness characterization method into our process flow. We fabricated SaS membranes using a novel monolithic integration approach (Figure 1), achieving flat membranes over a 2-inch wafer scale. Further, silver (Ag) thin films were evaporated across the membrane, creating a suspended metal-insulator-metal (MIM) structure as a Fabry-Pérot-like resonator. The reflectance spectra were measured and analysed to determine membrane thicknesses (Figure 2). Our results demonstrated visual and spectral differentiation of ~10nm thickness variations by simulation using the Transfer Matrix Method[3] (TMM) (Figure 3a-c) or Finite-difference Time Domain analysis (FDTD). The membrane integrity was preserved after Ag removal, providing a reliable wafer-scale pathway for verifying thin films prior to nanopore drilling. Additionally, the performance of the fabricated chips in analyzing nanostructured biomolecules, such as DNA, are ongoing, for different SaS membrane thicknesses, and will be presented at the conference. Together, these results in our study will prove the concept of reproducibly fabricating novel membranes and nanopore chips suitable for detecting biomolecules at a high signal to noise ratio.

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[1] P. Xia *et al.*, Biosensors and Bioelectronics **174**, 112829 (2021).

[2] P. Xia, M. A. R. Laskar, and C. Wang, ACS Applied Materials and Interfaces **15**, 2656 (2023).

[3] K. J. Pascoe, Air Force Institute of Technology Report No. ADA389099, 2001 (unpublished)

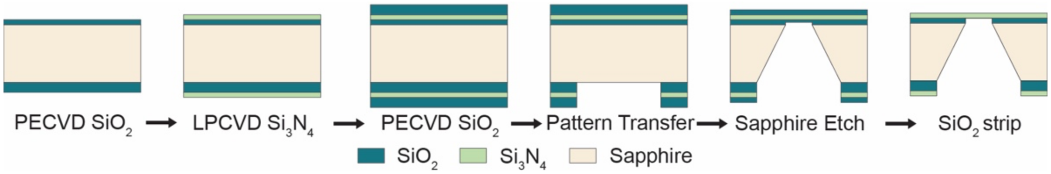


Figure 1: Wafer-Scale fabrication process used for suspended SaS membranes: Monolithic integration was achieved through Si_3N_4 deposition prior to the sapphire substrate etch in contrast to our labs previously established method[2] where the Si_3N_4 is deposited post substrate-etch. This has resulted in reduced wafer handling times and increased membrane yield.

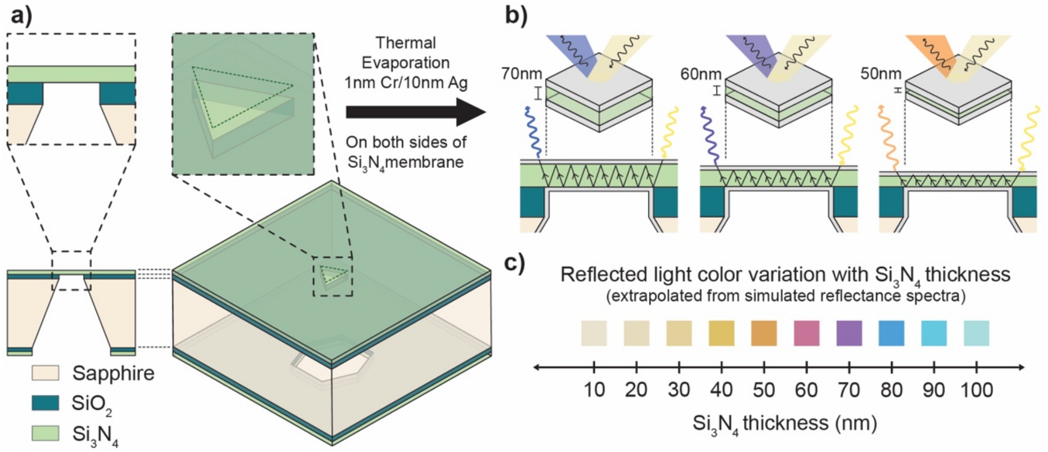
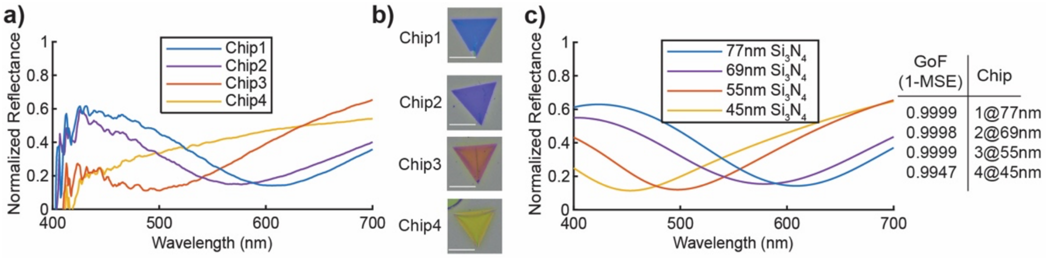


Figure 2: Overview of proposed characterization method. a) Illustrative cross section and isometric representations of SaS membrane chip. b) 10nm of Ag with a 1nm Chromium (Cr) adhesion layer is thermally evaporated on either side of the suspended Si_3N_4 membrane. The resulting structure forms a partially resonant optical cavity with reflectance spectra highly sensitive to the Si_3N_4 thickness. c) Expected membrane colors obtained from FDTD simulations of the suspended MIM structure for different Si_3N_4 thicknesses.



GoF (1-MSE)	Chip
0.9999	1@77nm
0.9998	2@69nm
0.9999	3@55nm
0.9947	4@45nm

Figure 3: Visual and Spectral differentiation of distinct SaS membrane thicknesses: a) Reflectance spectra of chips fabricated by our monolithic integration approach etched in hot phosphoric acid (etch rate ~3nm/min) in 4min intervals. b) Optical images of chips in (a). c) Simulated spectra of Si_3N_4 thickness best fit to spectra of chips. Goodness of fit (GoF) is calculated as 1 – mean squared error (MSE) of the fit in the 500-700nm range. *Scale bar – 20um*