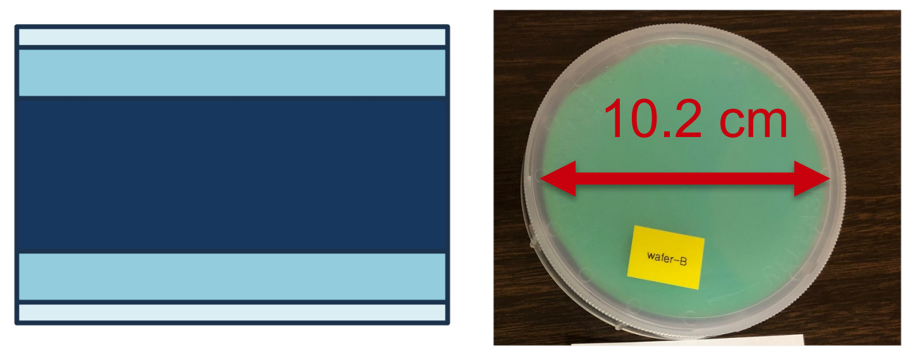
Fabrication of solid-state silicon nitride membranes for nanopore devices

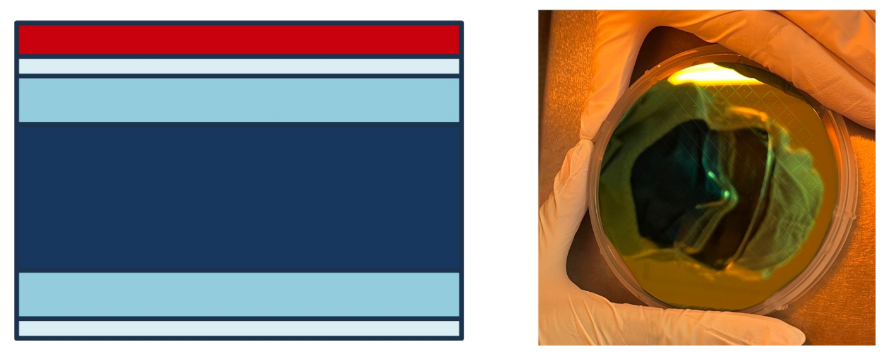
Ngaatendwe M. Manyika[1], Pia Bhatia[2], Kyril Kavetsky[3], Rachael Keneipp[2], Alexandra Uy-Tioco[2,3], Trey Shin[2,3], Marija Drndić[2]

[1]Department of Mechanical Engineering & Applied Mechanics, Philadelphia, Pennsylvania 19104, United States
[2]Department of Physics & Astronomy, University of Pennsylvania, Philadelphia, Pennsylvania 19104, United States
[3]Department of Materials Science & Engineering, University of Pennsylvania, Philadelphia, Pennsylvania 19104, United States

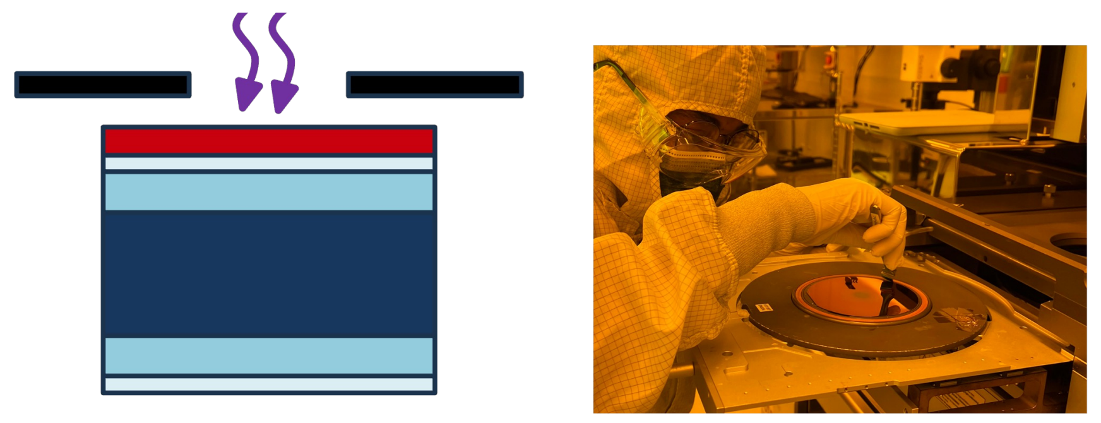
① Blank Silicon Wafer



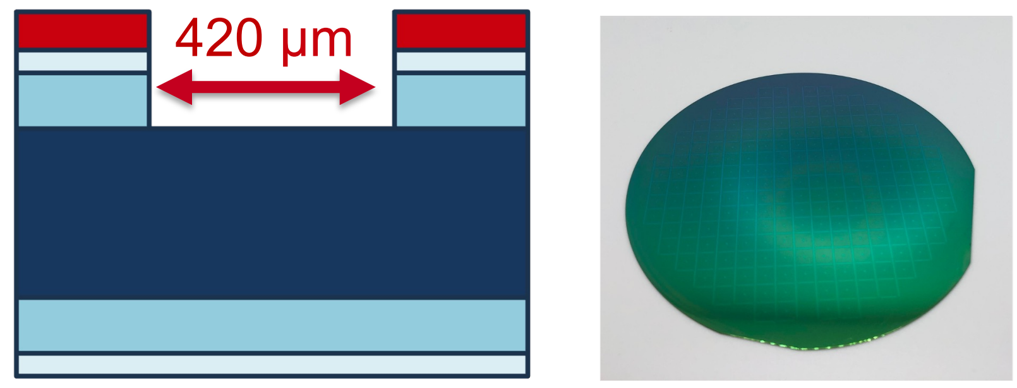
② Spincoating Resist



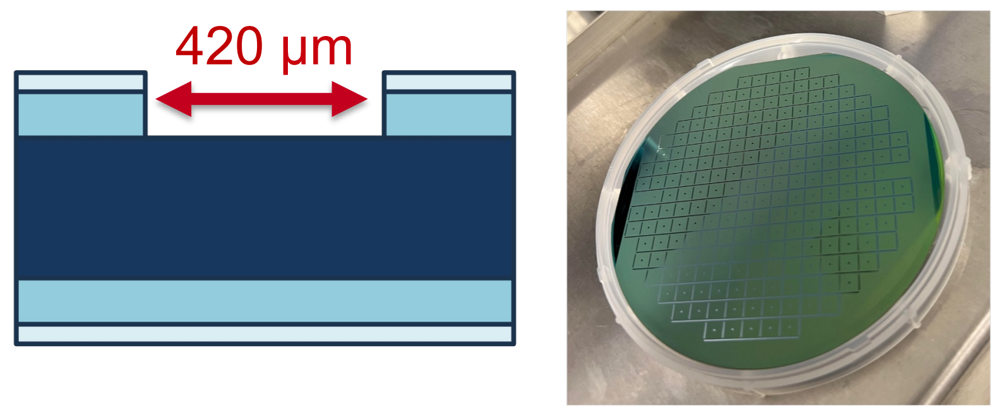
③ Lithography



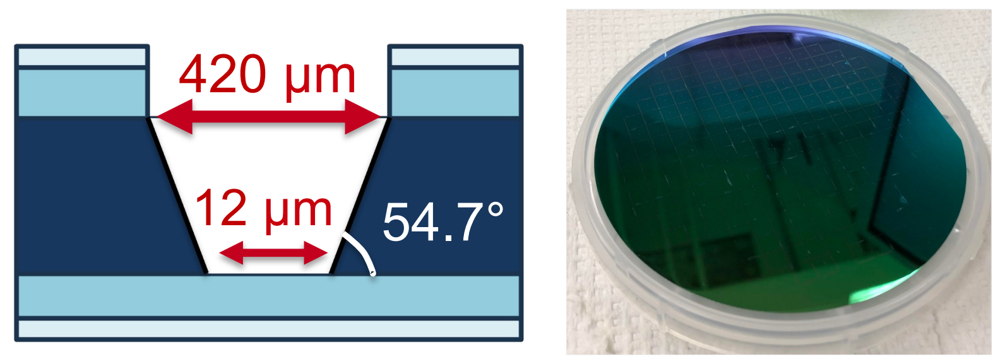
④ Reactive Ion Etching



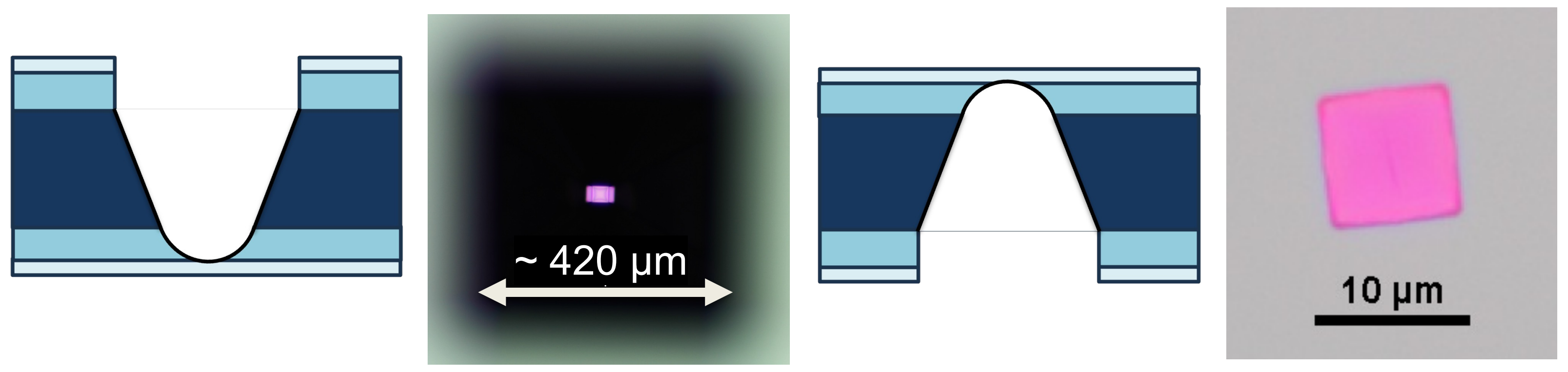
⑤ Acetone and IPA Rinse



⑥ KOH Etching



⑦ Buffered Oxide Etch



Cross Section Key

SiN_x ~ 55 nm	⬜
SiO_2 ~ 485 nm	🟦
Si ~ 300 µm	⬛
Photoresist	🟥
Photomask	⬛

Abstract

Solid-state nanopore technology applications span various fields, including DNA sequencing, filtration in desalination plants, and protein sequencing [1]. In the case of DNA sequencing, atomically thin nanopores are needed to improve spatial resolution. To create such devices, we first fabricate substrates with 12 x 12 µm^2 suspended silicon nitride (SiN_x) windows using micro- and nanoscale fabrication techniques. These techniques include optical lithography, reactive ion etching (RIE), and wet chemical etching. Next, ~300 nm diameter holes are milled in SiN_x windows with a focused ion beam (FIB). Finally, 2D materials are suspended over FIB holes and drilled via transmission electron microscopy (TEM). This results in atomically thin nanopores with diameters of only a few nanometers.

Background

- Silicon nitride is a "fan favorite" material because it is electron-transparent, making devices compatible with TEM [2].
- Standardizing nanopore fabrication and improving yield are critical to advancing the field.

Substrate Fabrication

① Verify the SiO_2 and SiN_x film thicknesses on Si wafer with Filmetrics F40 optical profilometer.

② Spincoat wafer with Shipley S1813 positive resist resulting in ~1.5 µm thick film [3]. Bake for 60 s at 115°C.

③ Using the SUSS MicroTec MA6 Mask Aligner, align the photomask and expose the resist to UV light (λ = 405 nm, 115 mJ/cm^2 dose). After exposure, develop resist with the base AZ300MIF and rinse in DI water.

④ With Oxford 80 Plus Reactive Ion Etch (RIE) tool, remove exposed SiO_2 and SiN_x.

⑤ Strip the resist by rinsing with acetone and IPA.

⑥ Use 40% (w/w) potassium hydroxide (KOH) to etch the exposed Si anisotropically. KOH preferentially etches the <100> crystal plane at a 54.7 ° angle relative to the <111> crystal plane [4].

⑦ Perform isotropic buffered oxide etch (BOE) to remove any remaining SiO_2.

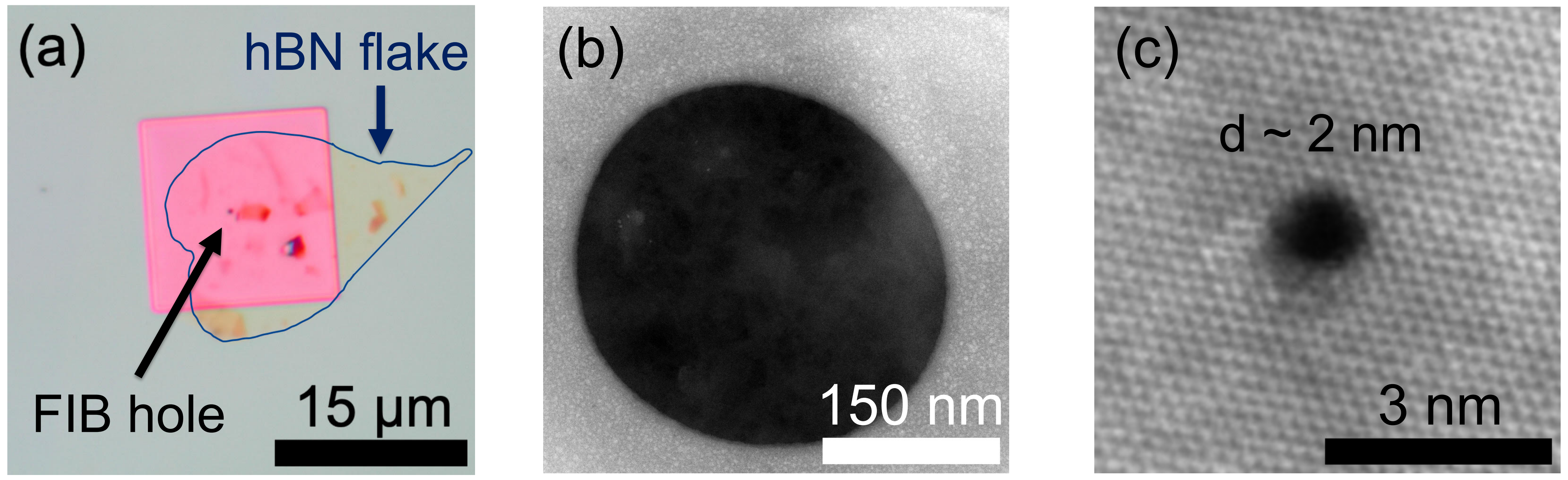


Fig (a) Optical micrograph of hBN flake (dark blue) transferred on top of a window with a FIB hole. **Fig (b)** TEM image of FIB hole with suspended hBN. **Fig (c)** TEM of a ~2 nm pore drilled in the suspended hBN. Note, a Gaussian blur filter (r = 2 px) was applied to this image.

Future Directions

Once fabricated, solid-state nanopore devices can be used for many kinds of research:

- Ionic transport measurements across nanoporous membranes to probe osmotic power generation and fundamental nanofluidics.
- Gas sensing and separation experiments across nanoporous membranes.
- Explore the relationship between nanopore (defect) density and electronic transport in various 2D materials and their heterostructures [5].

Acknowledgments

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Reference

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