

# Reliable Prepatterned STM Fabrication and Real-Space Imaging of Quantum Hall Quasiparticles

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**Principal Investigator(s): Xiaomeng Liu**

**User(s): Yiming Sun, Jinghao Deng**

*Affiliation(s): Laboratory of Atomic and Solid-State Physics, Cornell University*

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*Contact: xl956@cornell.edu, ys2289@cornell.edu, jd2353@cornell.edu*

*Research Group Website: <https://www.xiaomengliu.com>*

*Primary CNF Tools Used: Heidelberg DWL 2000 Mask Writer , GCA AS200 i-line Stepper, Oxford Plasmalab 81/82 RIE, SC4500 Odd-Hour Evaporator, DISCO Dicing Saw*

## Abstract:

This report details a novel fabrication methodology that enables the reliable production of scanning tunneling microscopy (STM) prepatterned chips, which subsequently facilitated the direct real-space imaging of individual quantum Hall quasiparticles. By integrating precision photomask design, optimized interfacial metal stacks, and defect-minimized processing, we achieved greater than 95 percent yield in devices capable of targeting sub-5-micron flakes. Leveraging this platform, we utilized scanning tunneling spectroscopy to observe the spatial and spectroscopic fingerprints of quasiparticles in graphene. We successfully resolved the localized electrostatic potentials around charged defects and observed the sequential addition of fractionally charged anyons in the fractional quantum Hall regime.

## Summary of Research:

Scanning tunneling microscopy achieves atomic resolution but suffers from an intrinsically small field of view, rendering navigation to specific micron-scale 2D materials slow and prone to tip crashes. Because external localization aids are impractical in extreme cryogenic environments [1, 2], we developed recipes in the Cornell NanoScale Facility for prepatterned chips with integrated registration markers. This resolved the navigation challenge and enabled our subsequent quantum Hall measurements on graphene devices [3].

Critical to this process was precision photomask engineering. Using the Heidelberg DWL 2000, we created quartz photomasks with alignment markers resolvable at 199 nm scales. During lithography, we optimized a bilayer resist system (LOR3A/SPR700) to create STM-specific undercut profiles, producing 800 nm apertures with tapered sidewalls via the GCA i-line

stepper. For the flake-electrode interfaces, we utilized an ultrathin Chromium and Palladium bilayer (3.5 nm Cr / 15 nm Pd) for edge contacts, providing an oxidation-resistant and atomically flat surface essential for tip stability. Finally, a damage-mitigated device release using inverted solvent immersion and predefined dicing minimized edge fractures, yielding chips with greater than 90 percent electrode integrity (Fig. 1-2).

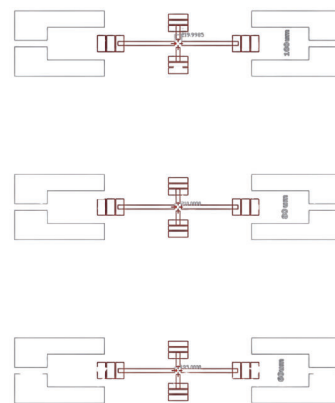


Figure 1: STM\_v3 mask design showing 3-micron alignment markers used to eliminate coordinate drift and target microscale 2D materials.

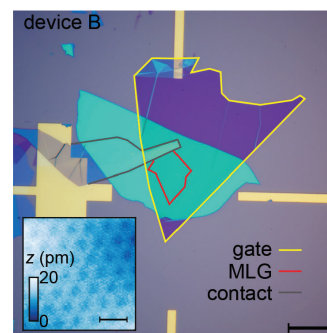


Figure 2: Optical micrograph of a complete graphene-based 2D device fabricated on an STM prepattern chip.

These highly reliable platforms allowed us to perform scanning tunneling spectroscopy on pristine graphene and hexagonal boron nitride heterostructures under high magnetic fields. While quantum Hall quasiparticles have traditionally been studied via macroscopic transport measurements, identifying and imaging them in real space has been a persistent challenge. Our prepatterned chips allowed the STM tip to accurately target the active device region and probe incompressible quantum Hall states.

By mapping the local density of states, we focused on localized electrostatic potentials created by charged defects in the hexagonal boron nitride substrate. These defects acted as quantum dots, splitting the energy levels of the Landau orbitals (Fig. 3). We were able to spatially image the discrete wavefunctions of these orbitals.

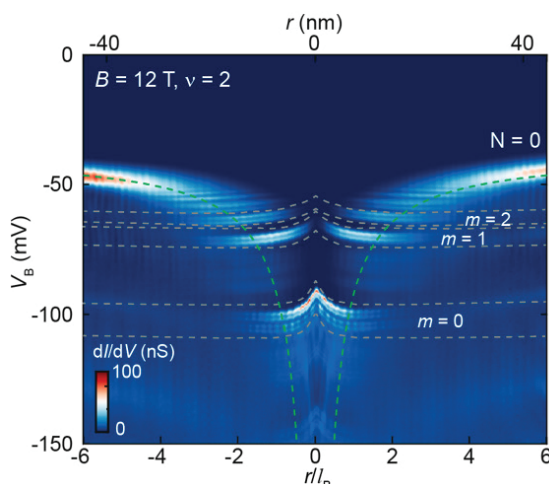


Figure 3: Scanning tunneling spectroscopy maps revealing the discrete energy splitting of Landau orbitals near a localized defect.

Furthermore, by applying this technique to the fractional quantum Hall regime, specifically at one-third filling, we observed unique spectroscopic fingerprints (Fig. 4). Our spectroscopic mapping demonstrated the spatial and energetic signatures of fractionally charged quasiparticles (anyons) becoming trapped by the defect potentials. The experimental data matched theoretical predictions for a three-anyon bound state, providing the first real-space visualization of fractional quasiparticle addition.

### Conclusions and Future Steps:

The established CNF fabrication process directly enabled our breakthroughs in resolving the spectroscopic fingerprints of individual quantum Hall quasiparticles in real space. Future work will extend this fabrication methodology to highly air-sensitive quantum materials

via glovebox-compatible integration. Scientifically, we plan to utilize these platforms to explore other exotic fractional quantum Hall states and develop methodologies for the direct real-space manipulation of anyons.

### References:

- [1] Li, G., Luican, A. & Andrei, E. Y. Self-navigation of a scanning tunneling microscope tip toward a micron-sized graphene sample. *Rev. Sci. Instrum.* 82, 073701 (2011).
- [2] Liu, X. et al. Visualizing broken symmetry and topological defects in a quantum Hall ferromagnet. *Science* 375, 321–326 (2022).
- [3] Deng, J. et al. Real-space imaging of quantum Hall quasiparticles. Preprint at <https://arxiv.org/abs/2606.25036> (2026).

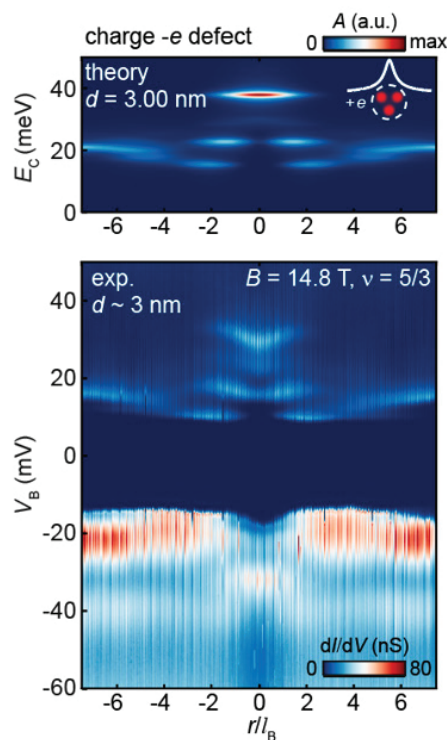


Figure 4: Spectroscopic data at one-third filling of holes demonstrating the sequential addition of three fractional anyons into a bound state.