Quantum Matter in Artificial Electrostatic Crystals

Alexander Hamilton

University of NSW, Sydney

Alex.Hamilton@unsw.edu.au

The properties of solids are determined by the crystal structure and interactions between electrons, giving rise to a variety of collective phenomena including superconductivity, strange metals and correlated insulators. The mechanisms underpinning many of these collective phenomena remain unknown, driving interest in creating artificial crystals which replicate the system of interest while allowing precise control of key parameters. Here we introduce an approach that allows lattices of arbitrary geometry to be created, provides control over the band filling and inter-site tunnelling, and enables direct transport measurements of the synthetic quantum matter [1,2]. We can create and detect artificial bandstructure, change the sign of the carrier charge, and also vary the mass from zero to almost infinite, giving rise to new correlated states.

We create a low disorder lattice with ~5,000 sites by applying a periodic electrostatic potential to the high mobility 2D electron gas in an ultra-shallow GaAs quantum well. The artificial crystal is identified by the formation of a new bandstructure, different from the original cubic crystal: transport measurements show the Hall coefficient changing sign as the chemical potential sweeps through the artificial bands. Uniquely, the artificial bandstructure can be continuously tuned from parabolic free-electron bands into linear graphene-like and flat kagome-like bands in a single device. The 100nm lattice constant allows access to high magnetic fields with multiple flux quanta per unit cell (equivalent to thousands of Tesla in natural graphene), with clear evidence of many-body correlated states forming in the flat band [3].

This electrostatic gating technique is widely applicable to a multitude of semiconductors and atomically thin 2D materials, and opens up new avenues to study collective phenomena in lattices of arbitrary geometry

References

[1] D. Q. Wang, D. Reuter, A. D. Wieck, A. R. Hamilton, and O. Klochan, Appl. Phys. Lett. 117, 032102 (2020).

[2] D. Q. Wang et al, Nano Lett 23, 1705 (2023).

[3] D.Q. Wang et al, arXiv:2402.12769 to appear in Nature Physics (2026)

Figures

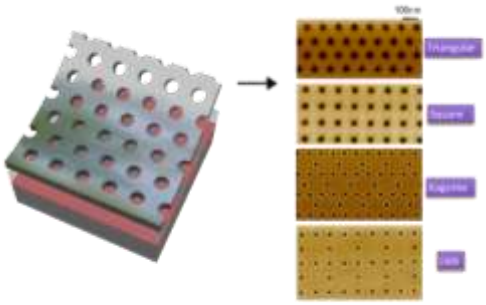

Figure 1: *Artificial lattices of arbitrary geometry can be formed by electrostatically patterning arrays of thousands of lattice sites.*

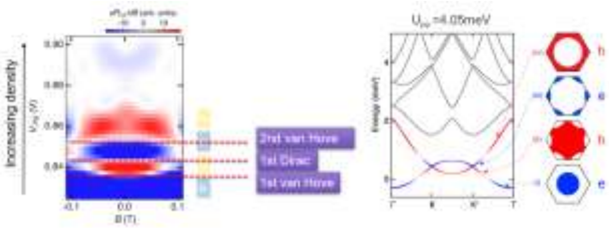

Figure 2: Transport measurements show periodic reversals in the sign of the Hall coefficient, as the carrier type switches from electrons to holes, consistent with the calculated bandstructure of the triangular lattice