PCSI
Room Keahou I - Session PCSI-MoE
STM Controlled Surface "Lego" and Panel Discussion

Moderator: Paul M. Koenraad, Eindhoven University of Technology, Netherlands

7:45pm **PCSI-MoE-1 Engineering Qubits in Silicon with Atomic Precision***, **Michelle Simmons**,* UNSW, Australia **INVITED**

The realisation of a large-scale error corrected quantum computer relies on our ability to reproducibly manufacture qubits that are fast, highly coherent, controllable and stable. The promise of achieving this in a highly manufacturable platform such as silicon requires a deep understanding of the materials issues that impact device operation. In this talk I will demonstrate our progress to engineer every aspect of device behaviour in atomic qubits in silicon for fast, controllable exchange coupling [1], fast, high fidelity qubit initialisation and read-out [2]; low noise all epitaxial gates allowing for highly stable qubits [3]; and qubit control [4,5] that provide a deep understanding of the impact of the solid-state environment [6] on qubit designs and operation. I will also discuss our latest results in quantum machine learning [7], analogue simulation [8,9] and demonstration of the highest efficiency Grover's algorithm to date [10].

[1]Y. He, et al., "A fast (ns) two-qubit gate between phosphorus donor electrons in silicon", Nature 571, 371 (2019).

[2]D. Keith et al., "Microsecond Spin Qubit Readout with a Strong-Response Single Electron Transistor", Physical Review X 9, 041003 (2019); D. Keith, et al., "Benchmarking high fidelity single-shot readout of semiconductor qubits", New Journal of Physics 21, 063011 (2019).

[3]L. Kranz, et al., "Exploiting a Single-Crystal Environment to Minimize the Charge Noise on Qubits in Silicon", Advanced Materials 32, 2003361 (2020).

[4]L. Fricke, et al., "Coherent spin control of a precision placed donor bound electron qubit in silicon", Nature Communications 12, 3323 (2021).

[5]J. Reiner, et al., "Control of multiple nuclear spin quantum registers", Nature Nanotechnology 19, 584 (2024).

[6]M. Koch, et al., "Spin read-out in atomic qubits in an all-epitaxial three-dimensional transistor", Nature Nanotechnology 14, 137 (2019).

[7]S.A. Sutherland, et al., "*Experimental quantum enhanced machine learning using quantum many body systems",* paper in review (2024).

[8]M. Kiczynski, et al., "*Engineering topological states in atom-based semiconductor quantum dots*", Nature 606, 694-699 (2022).

[9]M.B. Donnelly, et al., "*Large-scale analogue quantum simulation using precision atom-based quantum dot arrays*", paper in review (2024).

[10]I. Thorvaldson, et al., "*Grover's algorithm in a four-qubit silicon processor above the fault-tolerant threshold*", arXiv:2404.08741v1 (2024).

8:25pm **PCSI-MoE-9 Local Probe Investigations of Topological States of Matter***, **Ingmar Swart**,* University of Utrecht, Netherlands **INVITED**

Topological insulators are renowned for their robust edge modes, which offer the prospect of dissipationless transport of electrons. The boundary state manifests in one dimension lower than the material itself, e.g., 0D end states for 1D chains. However, boundary modes do not necessarily have a topological origin. For example, the well-known surface state of crystals of noble metals with (111) termination is topologically trivial. To establish the nature of a boundary mode, topological invariants such as the Chern number, the winding number, or the Zak phase can be computed directly from

the phase of the wavefunction. For solid-state materials, the phase of the electronic wave function is not experimentally accessible. Instead, topological invariants can be extracted from transport experiments via the quantization of conductance at values proportional to the Chern number. However, transport measurements do not provide local information, essential to study the influence of defects. In addition, it can be difficult to contact the edge (end) mode of 2D materials.

In my talk, I will present recent results of our investigations of various topological insulators using scanning tunneling microscopy and spectroscopy. In particular, using artificial lattices assembled atom-by-atom, I will introduce Wannier center spectroscopy, a tool to distinguish the phases of boundary-obstructed topological insulators beyond 'just' the observation of an edge mode. Furthermore, I will discuss experiments and simulations on finite-sized Bi_2Se_3 crystals, where we studied the transition from a 3D to a 2D topological insulator, as well as the influence of various types of defects on the electronic structure.

9:05pm **PCSI-MoE-17 Panel Discussion***,*

Bold page numbers indicate presenter