New Prospects for Manufacture of Identical Q Dots, Qubits, Q Memories, Q Simulators, Color Centers and more.

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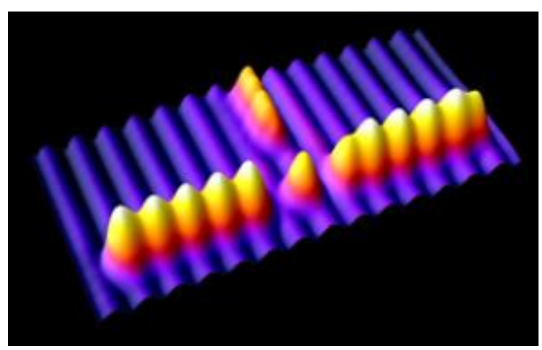
A series of advancements have brought us to a point where we can begin to manufacture error free, indistinguishable atom-defined entities with scanned probes [1]. Perfect multi-hundred atom ensembles have been made. A robust atom-defined tip (the scannable probe), a new "perfect" scanner (creep-free, 1 pm uncertainty) and multiple AI enabled procedures have overcome our long-standing expectation that probe-based manufacture would not be feasible. We are near a 1 million/year production capacity now – admittedly of low complexity devices.

On a silicon surface the elemental building block is an atomistic quantum dot, such as a Si dangling bond. Si DBs have many remarkable properties. Their energetic position in the bulk band gap makes them highly isolated. The +. 0, and – charge states enable diverse functions. The neutral species is paramagnetic. Arbitrarily complex 2D patterns of spin centres can be made of DBs, dopants or other entities.

Small groupings of DBs are strongly tunnel coupled. Whereas paired conventional Si QDs are limited to ~100 micro eV symmetric/antisymmetric splitting, the interaction among atomic QDs exceeds 100 meV, enabling improved noise immunity and higher temperature applications. Electrostatic bias-induced collapse to a "right" or "left" classical state creates a most compact (and arguably most beautiful) bit. Groupings of such double wells and interconnecting atom-defined wires embody a cryo-to-ambient capable binary atomic silicon logic (BASiL) [2]. Binary atomic wires transmit state among inputs, gates and outputs and do so ultra-fast and without Joule heating (A Google TPU would be 1000x more efficient [3]). BASiL circuitry could support quantum circuitry on the same chip. An atom-defined single electron transistor, SET, transduces information encoded as charge position to a CMOS readable current. We plan to add a spin filter to the SET.

By extending the above methods we are now prepared to make various quantum entities. The coherence properties of dopant type qubits can be compared to those of Si DB spin centres. A quadrupolar that will exhibit improved noise immunity is planned [4]. Independent of spin, exactingly placed DBs will allow much improved Fermi-Hubbard simulators to be made. The far greater complexity of simulators made possible by our methods allows more realistic treatment of many-body problems such as superconductivity. An ongoing collaboration with NIST will be outlined.

The deterministic making of color centers in Si and diamond will be advanced. By enabling the placement of color centers much closer to the surface of a substrate, enhanced quantum magnetic sensing capabilities will result. When entangled with the e-spin of a color center the nuclear spin of a randomly placed ^{13}C has been shown to serve as a coherence extending quantum memory. Our ability to exactingly place nuclear spins with respect to a paramagnetic center will create improved and reproducible magnetic sensing capabilities. An atom-defined SET is shown.



[1] Atomically Precise Manufacturing of Silicon Electronics, Jason Pitters et al, ACS Nano 2024 18, 6766-6816.
[2] T. Huff, et al., "Binary atomic silicon logic," Nature Electronics, vol. 1, pp. 636-643, 2018.
[3] S. S. H. Ng, H. N. Chiu, J. Retallick, and K. Walus, "A Blueprint for Machine Learning Accelerators Using Silicon Dangling Bonds," 2023 IEEE 23rd Int. Conf. on Nanotech., 2023, pp. 1-6.
[4] A decoherence-free subspace in a charge quadrupole qubit, M.Friesen, et al, Nat.Comm., 8, 15923 (2017)