A three-dimensional array of quantum dots

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Quantum dot-based spin qubits have made rapid developments in device complexity. Approaches towards scaling up spin qubits are primarily based on one- or two-dimensional planar arrays. In the case of Ge/SiGe heterostructures, by introducing an additional quantum well, vertically coupled quantum dots can be formed.
The formation of quantum dots in different quantum wells spaced by few nm was first demonstrated using transport measurements across a single hole transistor (SHT) [1]. Control over a vertical double quantum dots at the single-hole occupancy using rf-sensors was achieved in [2]. Novel approaches to qubit operation, as well as readout schemes can be engineered by controlling and stacking vertically double quantum dots.

Here we demonstrate the feasibility of creating three-dimensional quantum dots lattice, which we call the Qube (Figure 1). Independent control of the occupation of the vertically aligned quantum dots is achieved only using top plunger and barrier gates, thanks to the different gate-to-dot capacitances due to the separation of the quantum wells in the vertical z-direction. This results in differences in electrostatic confinement. When strongly confined, only the upper quantum well is occupied, and in this regime, we can define lateral singlet-triplet qubits and electrically driving single spins (EDSR). The expansion of quantum dot devices to the third spatial dimension presents an exciting opportunity to extend the framework of gate-defined semiconductor quantum dots beyond planar implementations, for quantum computation and simulation in three dimensions.

References

[1] H. Tidjani, et al., Physical Review Applied 20.5 (2023).
[2] Ivlev, Alexander S., et al., Applied Physics Letters 125.2 (2024)

Figures

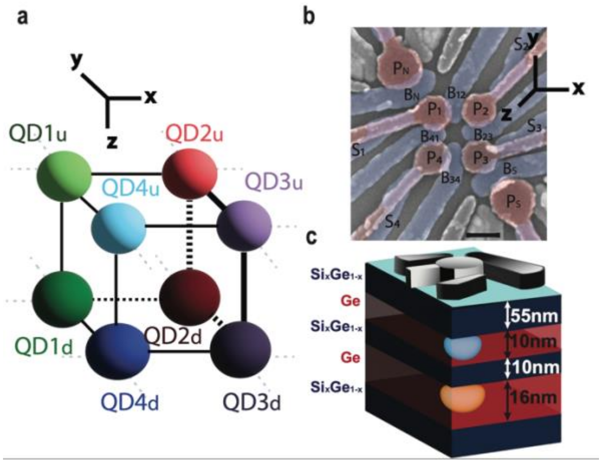

Figure 1: a) Schematic of the quantum dot interconnectivity. b) SEM image of the gate structure used to control the Qube. c) Illustration of the double-layer heterostructure used in the work.

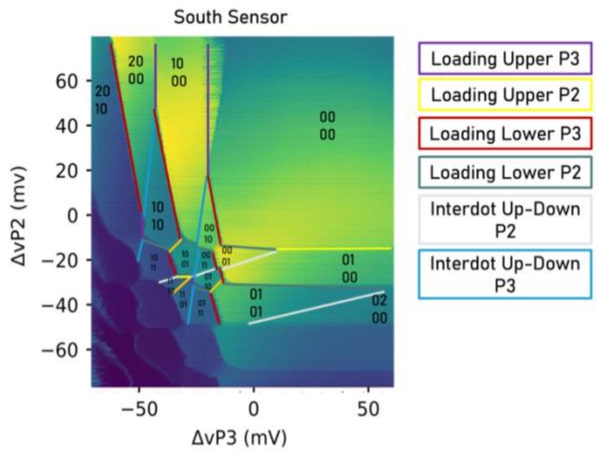

Figure 2: Charge stability diagram of a vertical two-by-two quantum dots array under P2 and P3