A Scalable 2D Planar Penning Trap Architecture for Trapped-Electron Quantum Computing

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Synopsis Planar Penning traps offer a route to quantum computing based on trapped electrons, combining long-lived spin states with microwave control and the absence of radio-frequency trapping fields [1, 2]. The main challenge is to move from a single micro-sized trap to a compact and scalable array while retaining a sufficiently harmonic potential and reliable detection of individual electrons.

We are developing a 2D array of micro-sized planar Penning traps for quantum computing with trapped electrons. The proposed trap consists of concentric planar electrodes with dimensions in the tens of micrometres and an inter-trap spacing of about 100 μm. The electrode geometry is being optimized to reduce anharmonicity of the axial potential, since amplitude-dependent frequency shifts can affect coherent control. Recent calculations of sub-millimetre planar traps show that finite electrode gaps have to be included at this scale and that a three-gap geometry is a suitable building block for a 2D array [1]. For the optimized micro-trap, axial frequencies in the few-GHz range are obtained with modest electrode voltages.

In the proposed quantum processor, the two spin states of each trapped electron form the logical qubit [2]. Microwave radiation is used to drive the electron-spin transition and implement single-qubit operations. The axial vibrational motion provides a common motional degree of freedom through which the Coulomb interaction between electrons can be used to generate two-qubit coupling [2]. Carrier and red- and blue-sideband transitions therefore provide a direct route to entangling operations, including a CNOT-type sequence. This approach avoids the laser systems normally required for trapped-ion quantum computing.

The experimental system will operate in a dilution refrigerator under a strong magnetic field. Electron motion will be detected through image currents using a high-Q resonant circuit, while spin states will be read out using the continuous Stern–Gerlach technique [2, 3]. A superconducting resonator and cryogenic HEMT amplifier provide low-noise detection. This work combines micro-trap design, cryogenic integration and microwave control towards a scalable 2D trapped-electron quantum processor.

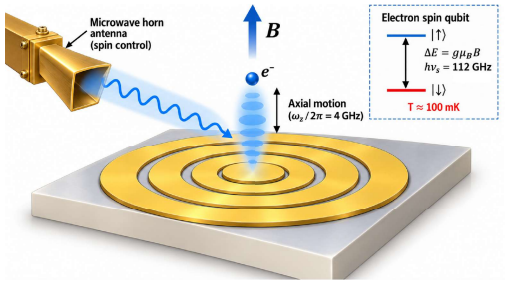

Figure 1. Schematic of a micro-sized planar Penning trap for trapped-electron quantum computing. A single electron is confined above the planar electrode array in a strong magnetic field. Microwave radiation from a horn antenna is used to control the electron spin, while the axial motional frequency is approximately 4GHz.

References

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