Hyperbolic Quantum Processor.

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Achieving strong coherent interaction between qubits separated by large distances holds the key to many important developments in quantum technology, including new designs of quantum computers, new platforms for quantum simulations and implementation of large-scale quantum optical networks. However, the inherent mismatch between the spatial dimensions of a quantum emitter and the photon wavelength fundamentally limits the transmission of quantum entanglement over long distances.

In our work [1] we demonstrate that long-range qubit entanglement can be readily achieved when qubit interactions are mediated by optical polariton waves in a hyperbolic material, due to the phenomenon of the Hyperbolic Super-Resonance. We show that in this regime the resulting quantum gate fidelity that exceeds 99%, can be achieved with the use of qubits based on well-known deep donors in silicon when their interactions are mediated by polariton fields in the substrate formed by a hyperbolic material (such as e.g., hexagonal boron nitride (*h*BN)).

At the physical level (see Fig. 1) the proposed system is essentially a silicon-based optoelectronic chip, and it's readily accessible to the existing methods of semiconductor nanofabrication, leading to the integration densities of well over 10^8 qubits/cm^2, and therefore opening the way to scalable and fault-tolerant error correction in quantum computation.

Furthermore, we demonstrate that, due to the optical time scales that define the duration of the gate operation in the proposed system, and sub-nanosecond time of the decoherence in deep donors in silicon at the liquid nitrogen temperatures,[16] the proposed Hyperbolic Quantum Processor does not require dilution refrigeration and therefore offers a pathway to bring quantum computation to the realm of conventional engineering.

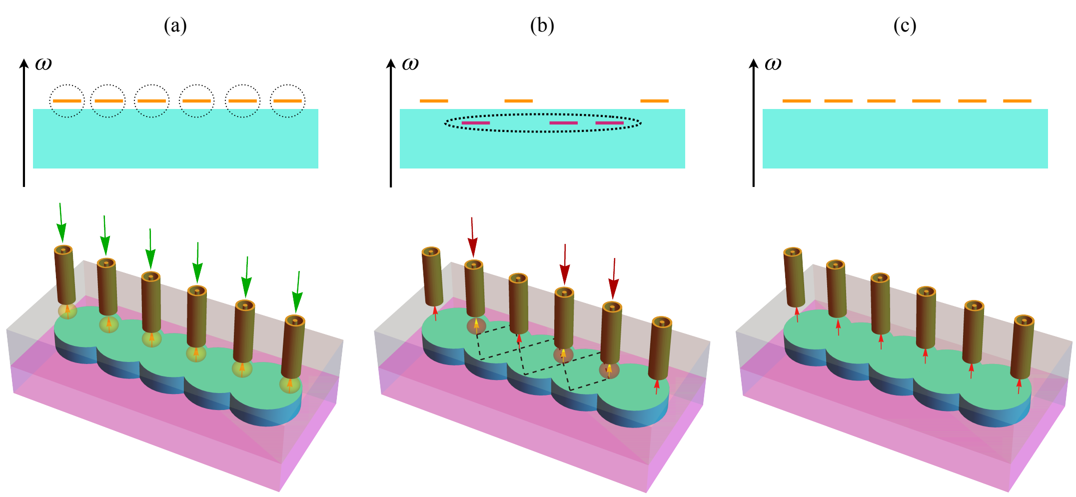

FIG. 1. Hyperbolic Quantum Processor operation. Panel (a): the quantum transition frequencies ω_0 for all cubits are beyond the hyperbolic frequency band of the *h*BN. Control fields at ω_0 in the nano-waveguides coupled to selected qubits (green "clouds"), force the desired single qubit operations. Panel (b): off-resonance control fields (red clouds) applied to selected qubits, down-shift the qubit transition frequencies to the hyperbolic band, which leads to strong dipole-dipole interactions and the resulting entanglement. Panel (c): the off-resonant control fields are released, and the entangled system is ready for the next quantum gate operation.

1. E. E. Narimanov and E.A. Demler, Hyperbolic Quantum Processor. https://arxiv.org/abs/2412.14098 .