Quantum simulators in hybrid nanocircuits

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Digital quantum simulators are among the most appealing applications of a quantum computer [1]. In principle, any model that can be mapped onto a spin-type Hamiltonian can be encoded in a digital quantum simulator. Then, its time evolution can be solved exactly, thus overcoming the unavoidable exponential scaling of computational resources that is inherent to quantum manybody physics.
Here I will review our recent theoretical proposal for a universal, scalable, and integrated quantum computing platform based on tunable nonlinear electromechanical nano-oscillators. In particular, I will describe a minimal architecture where qubits could be encoded in the anharmonic vibrational modes of nanomechanical resonators coupled to a superconducting nanocircuitry [2], see Fig. 1.
Practical realizations of such qubits will be discussed, based on engineered nano-electromechanical systems such as suspended nanotubes, 2D nanomembranes (such as, e.g., graphene sheets), or cantilevers.
An effective scheme to induce large single-phonon nonlinearities in nano-electromechanical devices will be explicitly discussed, and the quantum simulation of a few targeted models will be shown by solving the dynamical evolution in this ideal quantum hardware [2].

Finally, I will show how we challenged our proposed simulator with an actually existing one, i.e. the IBM-Q quantum computer freely available for cloud quantum computation [3].
Such a state-of-art implementation of an actual quantum computer, which employs purely superconducting qubits (the 'transmons') in a microwave nanocircuit (schematically represented in Fig. 2), is actually able to perform a digital quantum simulation of a few targeted models of interest in condensed matter physics. Nevertheless, encoding the qubits in mechanical degrees of freedom would allow to outperform the current implementations both in terms of fidelity as well as scalability of the quantum simulation.

References

[1] Lloyd, Science **273**, 1073 (1996)
[2] F. Tacchino *et al.*, arxiv1711.00051v2, to appear in Phys. Rev. B
[3] https://www.research.ibm.com/ibm-q/

Figures

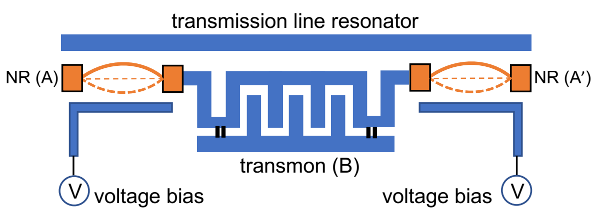

Figure 1. Schematic building block of an electromechanical quantum simulator within a superconducting nanocircuit: qubits are encoded in A, A' anharmonic oscillators, while B is used as a mediator of their effective interaction. Tunability is ensured by electrical control through external voltage pulses.

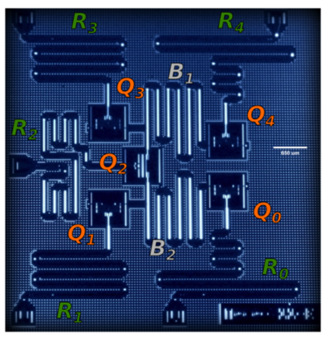

Figure 2. Picture of the ibmqx4 hardware with 5 qubits, which we employed for quantum simulation testing.