Multi-Qubit BEC Trap for Atomic Boson Sampling

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We discuss simple 1D and 2D models of a multi-qubit trap for atomic boson sampling in a Bose-Einstein condensed gas. Such an atomic boson sampling has been recently suggested in [1,2] as an alternative to the well-known Gaussian boson sampling in an optical interferometer [3,4] aimed at demonstrating quantum advantage of quantum simulators over classical computers [5]. The multi-qubit trap is built of the single-qubit cells separated by the inter-cell potential walls of a finite height (Fig. 1a). Every single-qubit cell has two close lower energy levels, like a double-well trap. We present the analytical and numerical results on calculating the lower energy minibands (Fig. 1c) and the spatial structure of the single-particle ground and excited states in the multi-qubit trap (Fig. 1b).

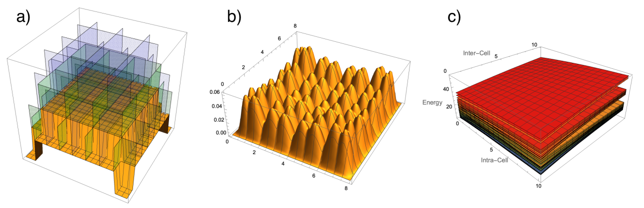

Figure 1: 2D model of the (4×4)-qubit BEC trap: (a) Trapping potential $U(x, y)$ consisting of the inter- and intra-cell walls atop the central pedestal (the infinite outer walls of the box trap are not shown); (b) Occupation probability in the single-particle ground state, $|\psi_0(x, y)|^2$; (c) Energy levels of lower minibands as the functions of heights of inter- and intra-cell potential walls.

The next steps in these studies should include solving the Gross–Pitaevskii equation for the condensate wave function and the Bogoliubov–de Gennes equations for the quasiparticle energies and wave functions that would allow one to calculate the Bogoliubov couplings and the covariance matrix for the noncondensate excitations. The latter is necessary for classical computing the joint excited-states occupation statistics (similar to computing the total noncondensate occupation statistics described in [6]) and various quantum-supremacy manifestations of it as well as for the validation of future experimental demonstrations of the ♯P-hardness of computing the atomic boson sampling [1]. Just one extra step has to be done for pioneering such experiments as compared to the recent successful experiment [7] on measuring statistics of the total noncondensate occupation. Namely, one has to split the noncondensed atoms into a few separate groups and perform simultaneous measurement of their occupations.

In conclusion, we discuss a possibility of a wide-range control of multi-qubit trap parameters, necessary for accessing a rich set of statistics required for demonstrating quantum advantage, and briefly touch upon a multi-detector imaging technique for measuring excited states occupations in atomic boson sampling.

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