Universal measurement-based quantum computation with opto-mechanical systems

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Quantum computation over continuous variables using the measurement-based approach has recently attracted much attention [1]. This approach allows to process quantum information provided a suitable entangled state — dubbed *cluster state* — is used as a resource and additional measurements are locally performed over its constituents. Despite the limitations of finite squeezing, this model has been theoretically proven to be fault tolerant.

Much effort has been devoted towards the generation of cluster states whose nodes are constituted of light modes. On the other hand, recent experimental advances have shown that various types of massive mechanical oscillators can operate deeply in the quantum regime [2], promoting these systems to interesting candidates for quantum technologies. In this context, the aim of the present work is to introduce a scheme to generate, verify, and process information over continuous-variable cluster states of mechanical oscillators. The main advantage of these systems would be that, being hosted in stationary or solid-state based architectures, they offer a promising path towards integrated and scalable quantum technologies.

Generation and verification of the cluster state over a mechanical-oscillator network— We propose a scheme for generating cluster states whose nodes are embodied by the mechanical modes of an optomechanical system. These states are obtained by properly engineering both the linearized Hamiltonian and the dissipative dynamics of the radiation degrees of freedom. Specifically, the method we use to engineer the desired Hamiltonian is based on multitone external driving, adapting and generalizing previous approaches so that the required sidebands could be independently excited. The merit of our scheme is that one can generate arbitrary graph states only by driving the optomechanical system with a sequence of tunable pulses. The generation protocol is sketched in Fig.1 and described in full in Ref. [3]. Once the cluster state has been generated, its state can be reconstructed relying again on the linearized radiation pressure interaction, and exploiting measurements on the accessible output modes of the optical cavity. An important advantage of this scheme is that it requires minimal access to the mechanical network, in that only one light probe is sufficient to reconstruct the state of the entire network (details can be found in Ref. [4]).

Quadrature Measurements for Computation— In order to carry out a computation on the cluster state, appropriate measurements must be available. For continuous-variable clusters, an arbitrary Gaussian transformation can be achieved via measurements that can be implemented in the same set-up depicted in Fig. 1. We show that this can be achieved by monitoring the cavity field once an appropriate quantum non-demolition interaction between the desired quadrature measurement operator and the cavity field is established. When this indirect measurement is performed on a node of the cluster state, the steady state of the remaining nodes transforms as for the case of a strong projective measurement. One can show that the procedure is robust when noise in the measurement is included. This implies that any single-mode mechanical measurement can be performed by measuring the cavity field only, allowing in turn the realisation of arbitrary Gaussian dynamics over the cluster.

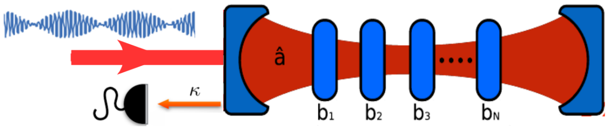

Figure 1: A driven-dissipative optomechanical system consisting of a cavity mode a — subject to dissipation at rate κ — coupled to N non-interacting mechanical oscillators $b_1, \ldots, b_N$. The steady-state of the *mechanical* oscillators can be prepared in a cluster state via properly modulating the driving field (curly line). The cluster state can then be used for continuous-variable measurement-based quantum computation by exploiting quadrature measurements of the field leaking from the cavity. Universality of the computation is ensured if an opto-mechanical coupling quadratic in the mechanical position can be achieved.

Universal gates via non-linear radiation-pressure interaction — Besides the above mentioned Gaussian operations, an essential requirement for universal quantum computation is a non-Gaussian gate. The latter can be enabled by a non-Gaussian resource state — in particular, the so-called cubic phase state. We propose a dissipative method to prepare a mechanical cubic phase state, taking advantage of the quadratic mechanical position coupling achievable both in cavity opto- and electro-mechanics settings. Furthermore, we illustrate how to incorporate such a resource into a generalised cluster state and evaluate the feasibility of these schemes within state of the art technology [6].

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