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(G*) Manipulation of phonon modes in a trapped-ion system by optical tweezers

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In recent years, multi-species trapped-ion systems have been investigated for the benefits they provide in quantum information processing experiments, such as sympathetic cooling and combining long coherence time of one species with ease of optical manipulation of the other. However, a large mass-imbalance between the ions result in decoupling of their motion in the collective vibrational (phonon) modes that are used to mediate entanglement between ion-qubits. We theoretically and numerically investigate a scheme that introduces far off-resonant optical tweezers, tightly focused laser beams on individual ions, of controllable strength in a conventional Paul (RF and DC) trap. The tweezers enable site-dependent control over the trapping strength and manipulation of the phonon mode structure (eigenfrequencies or eigenvectors) of the trapped-ion system. The tweezers provide local control over the effective mass of the ion and hence minimize the motional decoupling. We demonstrate an algorithm to program the optical tweezer array to achieve a target set of phonon modes. Our work paves the way for high efficiency sympathetic cooling and fast quantum gates in multi-species trapped-ion systems.

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