Cooperativity and entanglement pave way for ground-state cooling using nitrogen vacancy centers

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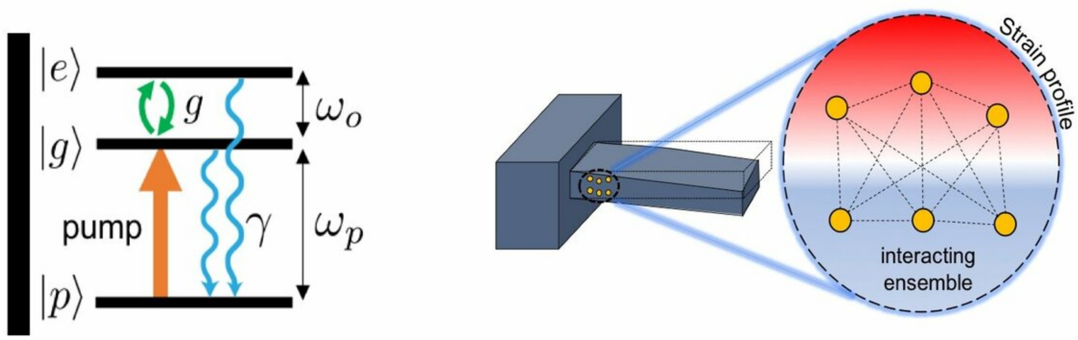

(left) Model of cooling cycle: an external laser pumps atoms into a two-level subspace coupled directly to a mechanical resonator; phonon absorption results in cooling of the mechanical system. (right) Schematic of a mechanical resonator interacting with an atomic ensemble. The engineered strain profile couples to dark entangled states of the ensemble resulting in optimal cooling. Credit: Argonne National Laboratory

Center for Nanoscale Materials researchers present a quantum model for achieving ground-state cooling in low frequency mechanical resonators and show how cooperativity and entanglement are key factors to enhance the cooling figure of merit.

A resonator with near-zero thermal noise has better performance characteristics in nanoscale sensing, quantum memories, and quantum information processing applications. Passive cryogenic cooling techniques, such as dilution refrigerators, have successfully cooled high-frequency resonators but are not sufficient for lower frequency systems. The optomechanical effect has been applied successfully to cool low-frequency systems after an initial cooling stage. This method parametrically couples a mechanical resonator to a driven optical cavity, and, through careful tuning of the drive frequency, achieves the desired cooling effect. The optomechanical effect is expanded to an alternative approach for ground-state cooling based on embedded solid-state defects. Engineering the atom-resonator coupling parameters is proposed, using the strain profile of the mechanical resonator allowing cooling to proceed through the dark entangled states of the two-level system ensemble. This approach enables ground-state cooling despite weak interaction strengths commonly seen in experimental settings. Entanglement and cooperative effects are key factors to enhance the cooling figure of merit.

The results apply to a variety of systems such as silicon and nitrogen vacancy centers in diamond and quantum dots, and advance the potential for miniaturization and room-temperature operation required for long-term technological applications. This work paves the way for ground-state cooling experiments using solid-state defects. The approach, accessible for experimental demonstrations and universal to a variety of systems, overcomes the main obstacles that have blocked realization of ground-state cooling using embedded solid-state defects.

Rigorous quantum simulations of interacting 2-level systems (atoms, NV centers, etc.) embedded within a mechanical resonator (e.g., microscale cantilever) were performed. Engineering the local phase of the coupling strengths using the strain profile in mechanical resonators enables efficient cooling mediated by cooperativity and entanglement.

More information: Cristian L. Cortes et al. Ground-state cooling enabled by critical coupling and dark entangled states, *Physical Review B* (2019). DOI: 10.1103/PhysRevB.99.014107

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