亮点报道：双 q-BIC 协同增强：钙钛矿超表面实现深低温激光制冷新方案

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激光制冷是一种利用光与材料相互作用实现降温的技术，可在无需机械压缩部件的情况下实现冷却，因而具有低振动和便于集成等特点，在高灵敏探测、精密测量以及低噪声光电器件等领域受到关注。

针对固态激光制冷中“泵浦吸收不足、辐射效率受限”的关键难点，暨南大学李向平教授、秦飞教授团队基于卤化物钙钛矿超表面提出“双 q-BIC 共振协同增强”的激光冷却新策略。研究通过精确设计 $MAPbBr_3$ 钙钛矿纳米盘阵列的非对称位移，在单一超表面结构中同时激发了两个独立调控的 q-BIC 共振模式。热力学模拟仿真显示，这种双共振协同带来的增益可使钙钛矿超表面在室温起始条件下实现净制冷，最低预测温度达到 −201°C(低于液氮温区)。

该成果的突出意义在于，它证明了通过精细的共振与光谱匹配设计，可以在不改变材料体系的前提下更充分释放钙钛矿的光学制冷潜力，为无机械、低振动干扰的深低温固态制冷提供了可集成的实现路径。同时，双 q-BIC 的设计思路为纳米光子学与热管理的交叉研究提供了可迁移的结构化原则，并有望推广至其他高折射率介质体系。

Highlights: Dual quasi-BIC resonances synergized laser cooling in halide perovskite metasurface

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Laser refrigeration offers a low-vibration, integration-friendly alternative to mechanical cooling, but achieving net cooling is difficult. Halide perovskites are a promising platform due to their high luminescence efficiency, tunable bandgaps, and compatibility with micro/nanostructuring. However, enhancing both pump absorption and the anti-Stokes radiative channel at the micro/nanoscale while suppressing losses remains a central challenge.

Prof. Xiangping Li and Prof. Fei Qin from Jinan University, along with Associate Prof. Tianyue Zhang, proposed a halide-perovskite metasurface strategy based on dual quasi-bound states in the continuum (q-BICs). By engineering an asymmetric displacement in a $MAPbBr_3$ perovskite nanodisk array, they realized two independently tunable q-BIC resonances. The long-wavelength mode (625 nm) matches the absorption edge to enhance pump absorption, while the short-wavelength mode (540 nm) aligns with the photoluminescence peak for Purcell-enhanced radiative recombination. This dual resonance optimizes the absorption–emission cycle. Simulations predict 98.8% external quantum efficiency and net cooling down to −201 °C, providing a transferable strategy for integrated solid-state cooling.

Potential applications include miniaturized temperature control for vibration-sensitive systems such as densely integrated photonic circuits, quantum photonic devices, and space instrumentation.

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