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COMMENT

# Bose-Einstein condensation of exciton polariton in perovskites semiconductors

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Polariton-hybridization of light-matter oscillations can emerge from various quasiparticles, such as phonon, plasmon, exciton and magnon. Particularly, exciton polaritons are bosonic quasiparticles with half-light, half-matter nature, which are originated from strong coupling between excitons and microcavity photons. The half-light nature results in extremely small effective mass, making it feasible to achieve high temperature even room-temperature Bose-Einstein condensation (BEC). Meanwhile, the half-matter nature leads to strong nonlinear interaction, which is missing between photons and can promote the polaritons relaxation to ground state and give rise to low threshold polariton lasing, compared to photonic lasing. The exciton polaritons are of great importance in applications of quantum simulation, topological quantum optics, ultrafast optical switch and low threshold lasers.

Usually, exciton polaritons are realized by coupling the semiconductor to an optical cavity to achieve strong light-matter interaction. The excitonic fraction of polaritons can be tuned by changing the detuning, namely, the energy difference between exciton and cavity resonance at $k_{||} = 0$. The coupling strength is reflected by the Rabi splitting energy. Cavity exciton polariton was firstly demonstrated in GaAs quantum wells (QWs) sandwiched by two distributed Bragg reflectors (DBRs) in 1992 [1]. Later on, the polariton condensation was observed in CdTe QWs at 5 K in 2006 [2]. The Wannier-Mott exciton in GaAs or CdTe has small exciton binding energy, which renders that polariton condensation must operate at cryogenic temperature. In contrast, the large exciton binding energy in ZnO [3] or GaN [4] can sustain room temperature polariton. However, for the inorganic materials, it demands sophisticated epitaxial techniques such as metal organic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE) to grow both the planar cavity and semiconductor film, which is constrained by the defects, strain and the lattice mismatch problems. On the other hand, the binding energy of Frankel exciton in organic materials is large enough to support room temperature polariton. The organic materials also hold the advantages of facile synthesis and large range of species. Nonetheless, the Frankel exiciton nature renders it suffers from small Coulomb interaction and thus weak polariton-polariton interaction, leading to much smaller nonlinearity and higher polariton lasing threshold compared with inorganic materials. To this end, it is desired to have materials with robust synthesis, large exciton binding energy and significant polariton-polariton interaction for room temperature polariton applications.

Recently, halide perovskites are emerging as excellent semiconductor materials in the applications of optics and optoelectronics. Perovskites semiconductors possess the advantages of high optical gain, robust exciton at room temperature, tunable bandgap in visible-near infrared range, facile fabrication and ease to couple to various optical microcavities, which makes it an ideal candidate for the polariton applications. The first perovskite based polariton can be traced back to 1998, in which the $(C_6H_5C_2H_4NH_3)_2PbI_4$ was coupled to a grating and characterized by angle resolved transmission [5]. Subsequently, various organic-inorganic perovskites were utilized to obtain room temperature exciton polariton [6,7]. However, it was still challenging to achieve room temperature polariton condensation in perovskite system probably due to the insufficient quality of perovskite crystal. The first room temperature perovskite based

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polariton condensation was realized in $CsPbCl_3$ planar microcavity grown by chemical vapor deposition (CVD) method with high crystalline quality. The polariton lasing was also demonstrated with the threshold of 12 μJ/cm$^2$ [8]. Later on, the strong exciton-photon coupling and lasing was achieved in $CsPbBr_3$ micro/nanowires which serve as gain materials and Fabry-Pérot cavity simultaneously [9,10]. The success of realization of room temperature polariton condensation in perovskite provides the access to manipulate the BEC for quantum applications. For instance, long-range coherent exciton polariton condensate flow was realized in 1D $CsPbBr_3$ microcavity with propagation distance of 60 μm and group velocity of 10 μm/ps [11]. Furthermore, 1D polariton condensation lattice was experimentally realized at room temperature by utilizing the periodic potentials, which opens the route for the topological polaritonic devices and polaritonic quantum simulation [12]. This work opens up an exciting revenue towards quantum control of exciton polariton condensate at room temperature and their practical polaritonic device applications. On the other hand, there are still a number of exciting fundamental questions, for instance, the strength of nonlinear polariton-polariton interactions, both in all inorganic perovskites and hybrid 2D perovskites with naturally-occurring quantum well structures [13–16].

In conclusion, perovskites semiconductors are ideal materials for room temperature polaritonic devices and significant progresses have been achieved up to now. Apart from the all-inorganic perovskites, the 2D layered hybrid perovskites with high quantum and dielectric confinement could be explored for polariton devices in the future. Furthermore, more complex 1D/2D polariton lattices can be realized for some novel functionalities and some fundamental issues such as the nonlinear polariton-polariton interaction also need to be addressed.

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