Anomalous dispersion and dissipative coupling in AlGaAs exciton-polariton structure

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Strong light-matter coupling in semiconductor microcavities leads to the formation of quasiparticles called exciton polaritons, in which the energy is coherently exchanged between quantum-well (QW) excitons and bound photons. However, continuous photon loss due to the mirror imperfections, together with the exciton decay via radiative and nonradiative channels, makes it a highly lossy, dissipative system. It has been shown that dissipative light-matter coupling can be a result of various forms of decay channels [1], for instance when both resonances decay to the shared photonic environment [2]. Dissipative terms in Hamiltonian can greatly affect polariton dispersions, particularly when dissipative coupling is strong enough in comparison to the inherent coherent coupling. Then it may lead to an anomalous shape of the dispersion, with inverted lower state branch. Such energy-wavevector dependence has only recently been observed, and solely in microcavities containing transition metal dichalcogenides (TMDCs) [1,3]. With a negative particle mass, linked to its group velocity, such states have a great potential in dispersion engineering and in studies of non-Hermitian phases of quantum matter in a solid state.

In this work, we observe anomalous inverted dispersion of exciton polaritons in AlGaAs-based microcavity at low temperature. This material system is superior to microcavities with TMDCs in quality factors, linewidths, reproducibility, stability and ease of design, hence it has a large potential in reliable structure production and engineering. Our sample hosts both standard Γ-excitons in the QWs, coherently coupled to photons, but also lower-energy spatially and momentum indirect X-excitons, prone to dissipation. We show how the X-exciton resonance couples to the photonic mode in a wide range of exciton-photon detunings, leading to the inverted-mass eigenstates, observed in photoluminescence (PL) measurements. We present the evolution of polaritonic level attraction strength with the detuning, clearly showing a transition between monotonic (with a single maximum at $k=0$) and nonmonotonic (with maxima at finite wavevectors) $|k|$-dependence in lower branch dispersion. By implementing the non-Hermitian dissipative-coupling model, we characterize decay channels and interactions between resonances. Moreover, we present the temporal evolution of such states, as well as the dispersion of eigenstate lifetimes, showing a difference in branches' PL decay. Our work is the first realization of anomalous polariton states in a non-organic III-V semiconductor-based microcavity with wide detuning availability and with such a detailed characterization, which is crucial in understanding the unique nature of dissipative coupling in semiconductor microcavities and in future design of new non-Hermitian quantum phases.

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