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Coupled dynamics of photons, excitons, and biexcitons analyzed by a fully-quantized approach to the light-matter interaction in semiconductor nanostructures

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Abstract

The coupled coherent dynamics of quantum light and material excitations are analyzed by a fully-quantized microscopic approach for semiconductor nanostructures which includes many-body Coulomb correlations. We investigate a one-dimensional two-band electronic system interacting with a single-mode, two-photon quantum state using the Tavis–Cummings framework. By employing an exact coherent factorization scheme, the computational complexity is significantly reduced. We also derive and analyze a simplified model that includes only the bound 1s-exciton and biexciton states for comparison. Our simulations reveal a complex quantum dynamics which depends sensitively on the frequency of the cavity mode and the strength of the light-matter interaction. We find single- and two-photon Rabi oscillations due to excitations of excitons and exciton-biexciton transitions, respectively. In addition, our results reveal that biexciton continuum states, which simplified reduced-state models fail to capture, significantly affect the dynamics, e.g., lead to shifts of the resonances. Thus, our findings clearly demonstrate the importance of a microscopic modeling in order to accurately describe the interaction between quantum light and semiconductor nanostructures.