Time-resolved second-order correlations of photons emitted by a quantum dot in microcavity

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We present a theoretical study of the correlations between the photons, emitted by a incoherently-pumped quantum dot strongly coupled to a microcavity optical mode. At small pumping the time-dependent correlation function demonstrates Rabi oscillations, while at larger pumping it shows monoexponential decay. The decay time of the correlations nonmonotonously depends on the pumping value and has a sharp maximum corresponding to the self-quenching transition.

Semiconductor quantum dots form a promising platform for quantum optics devices, including single photon emitters and emitters of entangled photon pairs [1, 2]. The quantum dot-based light sources can be characterized by means of photon-photon correlation spectroscopy, i.e. by measuring the second-order correlation function $g^{(2)}(t)$ between two photons with the delay t [3]. We consider zero-dimensional microcavity where the single photon mode is strongly coupled to the single excitonic state of the quantum dot. The coupling strength g is supposed to be larger than the photons escape rate through the cavity mirrors $\Gamma_{\rm C}$. The exciton in the quantum dot is incoherently continuous pumped with the rate W.

The time dependence of two-photon correlator is shown in Fig. 1. Depending on the strength of the pumping W, several qualitatively different regimes can be distinguished [4]. At low pumping, $W \ll \Gamma_{\rm C}$, the correlation function $g^{(2)}(t)$ is less than unity at $t = 0$ (antibunching) and demonstrates Rabi oscillations with the frequency $2g$. The decay rate of the oscillations is equal to the average of the exciton and photon decay rates. The growth of the pumping intensity ($\Gamma_{\rm C} \lesssim W \ll g^2/\Gamma_{\rm C}$) leads to the decrease of both the period and the lifetime of the oscillations. In a wide range of higher pumping intensities $\Gamma_{\rm C} \ll W \ll g^2/\Gamma_{\rm C}$ the emission statistics is Gaussian and the correlation function is close to unity and almost time-independent. This can be understood as a lasing regime for the dot, strongly coupled to the cavity mode. The pumping value $W^* = 4g^2/\Gamma_{\rm C}$ corresponds to the transition from the lasing regime to the so-called self-quenching regime. When the pumping rate reaches the critical point W^* the stationary correlator $g^{(2)}(0)$ exhibits an abrupt growth. The time-dependent correlator decays exponentially with the time $\tau^{(2)}$. The correlation lifetime $\tau^{(2)}$ demonstrates a non-monotonous behavior when pumping rate crosses the critical value W^*, see inset in Fig. 1. It rises as $\tau^{(2)} \propto 1/|W - W^*|$ reaching the value of the order of $g/\Gamma_{\rm C}^2$, that strongly exceeds the lifetime of the empty cavity mode. At larger pumping $W \gg W^*$ the strong coupling regime is destroyed, the emission statistics is thermal $[g^{(2)}(0) = 2]$ and the decay time of the correlations equals to the empty cavity mode lifetime $1/\Gamma_{\rm C}$.

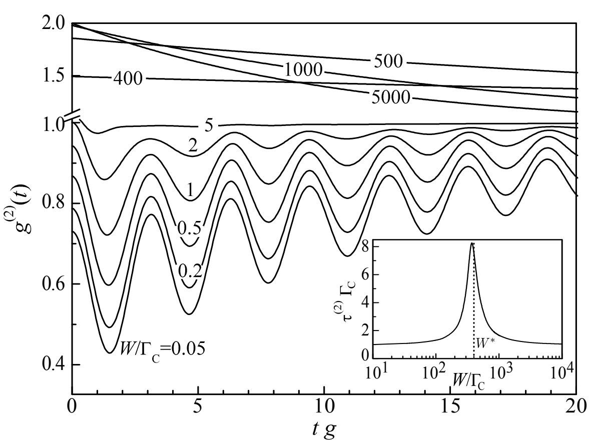

FIG. 1. Time dependence of the correlation function $g^{(2)}(t)$. Curves are plotted for $g/\Gamma_{\rm C} = 10$ and various pumping rates $W/\Gamma_{\rm C}$ shown in graph. Inset shows the dependence of lifetime of photon correlations $\tau^{(2)}$ on the pumping rate in the vicinity of the critical point $W^* = 4g^2/\Gamma_{\rm C}$, corresponding to transition from lasing regime to the self-quenching regime.

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