Acousto-Mechanical Tuning of Photonic Crystal Nanocavity Modes for Quantum Gate Applications

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Recently we have shown that the mechanical deformation induced by radio frequency surface acoustic waves (SAWs) on a two-dimensional photonic crystal membrane (PCM) spectrally tunes the resonance frequency of nanocavities within the PCM at gigahertz frequencies [1]. Here we report the first direct experimental investigation of this tuning mechanism in the time domain. In Fig. 1 (a), we present a typical photoluminescence (PL) spectrum (dashed) of a nanocavity mode recorded under non-resonant excitation of an ensemble of quantum dots off-resonantly coupled to the mode. Turning the SAW on, leads to a clear, characteristic broadening of the spectrum (solid), with a tuning bandwidth of 100 GHz. To demonstrate that the applied SAW dynamically modulates the optical mode, we implemented a time-resolved detection scheme. The excitation laser pulses were actively phase locked to the SAW and the PL signal was detected with an avalanche photodiode with a temporal resolution of 50 ps. The transient of the unperturbed mode detected at n_0, is plotted for reference (grey line) in Fig. 1 (b). With a SAW of f_{SAW} of 850 MHz is applied, we set the laser repetition rate to $f_{\mathrm{SAW}}/11$ and detect the nanocavity emission at the blue end of the tuning range $\nu_{\mathrm{det}} = \nu_{\mathrm{blue}}$ marked in panel (a). The signal shows a clear beating, precisely given by the SAW period T_{SAW} = 1175 ps which is enveloped by the transient of unperturbed mode. For the solid black line, the phase relation between laser pulse and the SAW was set such that the system is pumped at the time when mode is tuned to the detection frequency, $\nu(t_{\mathrm{exc}} = t_0) = \nu_{\mathrm{blue}}$. Shifting the time of excitation by $T_{\mathrm{SAW}}/2$, we excite the system with the mode at $\nu(t_{\mathrm{exc}} = t_0 + T_{\mathrm{SAW}}/2) = \nu_{\mathrm{red}}$. Since the detection is performed at $\nu_{\mathrm{det}} = \nu_{\mathrm{blue}}$, the beating of the transient (dotted grey) is offset in time also by $T_{\mathrm{SAW}}/2$. To resolve the full dynamics of our tuning mechanism we keep $\nu(t_{\mathrm{exc}} = t_0 + T_{\mathrm{SAW}}/2) = \nu_{\mathrm{red}}$ and tune ν_{det}. The recorded transients are plotted in grayscale representation in Fig. 1 (c). In this data the dynamic tuning and mode decay is monitored and clearly resolved over the full spectral tuning bandwidth.

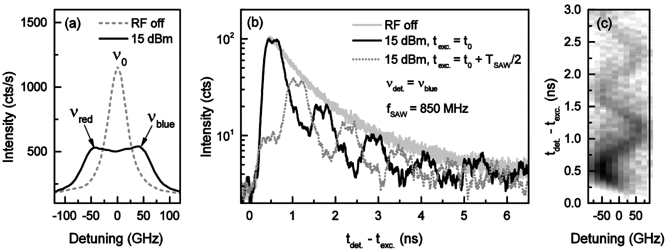

Fig. 1 (a) Time integrated spectrum of the cavity mode with no fixed phase relation between SAW and excitation laser (b) Time resolved traces of the modulated mode

Finally we elaborate strategies to extend our approach for controlled entanglement generation in this prototype solid-state cavity quantum electrodynamics system using Landau-Zener-Stückelberg transitions. For our theoretical modelling we consider a realistic dissipative system being at or above the threshold to the strong coupling. Our first calculations predict for cavity quality factors $Q \geq 60000$ a concurrence of $C \sim 0.7$ when driving the coupled quantum dot-nanocavity system at SAW frequencies up to 3 GHz.

[1] D. A. Fuhrmann *et al.*, Nature Photonics **5**, 605 (2011)