Time Domain Investigation of Radio Frequency Acousto-Mechanical Tuning of Photonic Crystal Nanocavity Modes

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Surface acoustic waves (SAWs) have proven a useful tool for dynamically manipulating the optical properties of semiconductor nanostructures [1,2]. Recently we have shown that the mechanical deformation induced by a SAW on a two-dimensional photonic crystal membrane (PCM) spectrally tunes the resonance frequency of nanocavities within the PCM employing phase locked stroboscopic excitation [3].

Here we present a study of this tuning mechanism directly in the time domain. Fig. 1. (a) shows a typical photoluminescence (PL) spectrum (dashed) of a nanocavity mode recorded under non-resonant excitation of an ensemble of quantum dots coupling to the mode. Turning on the SAW leads to a clear, characteristic broadening of the spectrum (solid) [3], with a tuning bandwidth of 100 GHz at an RF power of 15 dBm. 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 ν_0 is plotted for reference (gray line) in Fig. 1 (b). With a SAW of f_{SAW} = 850 MHz applied, we set the laser repetition rate to $f_{SAW}/11$ and detect the nanocavity emission at the blue end of the tuning range $\nu_{det.} = \nu_{blue}$ 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 the unperturbed mode. For the solid black line, the phase relation between the laser pulse and the SAW was set such that the system is pumped at the time when the mode is tuned to the detection frequency, $\nu(t_{exc.} = t_0) = \nu_{blue}$. Shifting the time of excitation by $T_{SAW}/2$, we excite the system with the mode at $\nu(t_{exc.} = t_0 + T_{SAW}/2) = \nu_{red}$. Since the detection is performed at $\nu_{det.} = \nu_{blue}$, the beating of the transient (dotted gray) is offset in time also by $T_{SAW}/2$. To resolve the full dynamics of our tuning mechanism we keep $\nu(t_{exc.} = t_0 + T_{SAW}/2) = \nu_{red}$ and tune $\nu_{det.}$. 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. Our results show that acousto-mechanical tuning of the cavity mode can be achieved on time scales faster than the exciton lifetime, making this method a promising approach for the dynamical study of light-matter interaction in this prototype solid-state cavity quantum electrodynamics system.

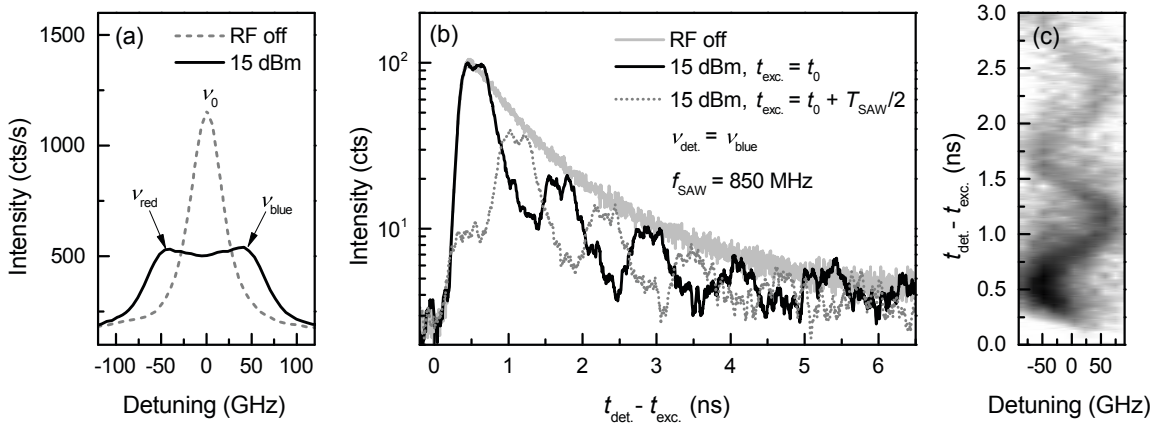

Fig. 1 (a) Time integrated spectrum of the cavity mode (ν_0 = 322 THz, Q = 7600) with no fixed phase relation between SAW and excitation laser (b) Time resolved traces of the modulated mode with detection at ν_{blue} for two different SAW phases at the time of excitation and the unperturbed mode detected at ν_0 (c) Time resolved spectrum with excitation at $t_{exc.} = t_0 + T_{SAW}/2$ corresponding to $\nu_{mode}(t_{exc.}) = \nu_{red}$

References

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