Noise effects on the resonance fluorescence from acoustically modulated quantum dots

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In the field of quantum information processing, one of the current goals is the high scale integration of miniaturized devices. Photons are not always an ideal carrier of information, hence hybrid quantum acousto-optic systems have been proposed, which use surface phonons as the information carrier within the device [1]. A quantum dot (QD) can be used as a transducer between the acoustic and optical signals on the quantum level.

In this work we theoretically study the spectrum of the low-excitation resonance fluorescence (RF) for a single two-level QD, whose transition energy depends on time due to two simultaneous factors: First, the QD is modulated by a surface acoustic wave (SAW). Second, it is affected by environmental noise.

We iteratively solve the equations of motion for the density matrix of a two-level system driven by a weak, monochromatic, classical laser light. Then, the two-time correlation function is found using the quantum regression theorem. The time-integrated RF spectrum is obtained in the standard way as its Fourier transform, including a finite instrumental resolution. Thus, we extend our previous analysis of the noise effects in RF [2] to acoustically modulated systems [3,4].

The noise-free RF spectrum shows a series of unbroadened peaks from elastic scattering, shifted by a multiple of acoustic frequencies from the laser frequency [3,4]. White-noise environmental fluctuations leads to the appearance of additional peaks from inelastic scattering. They are located relative to the transition frequency and their width depends on the exciton decay rate and phase diffusion coefficient. We show that the environmental noise modifes the relative intensities of the spectral lines in the spectrum of a periodically modulated system. We study also the acoustic frequency mixing effect [4] and show that noise affects the quantum interference between various contributions to the scattering process, decreasing the contrast of spectral oscillations as a function of the relative phase of the two acoustic waves of different frequencies.

We consider also the case of telegraph noise environmental fluctuations, which differs from the white-noise case by the structure of spectral lines.

Our study presents a comprehensive characterization of noise effects on the resonance fluorescence spectra of acoustically modulated systems and may be useful both for interpreting experiments as well as for determining the limits of quantum acousto-optic transduction.

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[2] Bogaczewicz R. A., Machnikowski P., arXiv:2303.01531v1 (2023).

[3] Wigger D. *et al.*, *Phys. Rev. Res.* **3**, 033197 (2021).

[4] Weiß M. *et al.*, *Optica* **8**, 291 (2021).