Systematic study of quantum dot laser emission controlled by coherent phonon wave packets

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Light emission from semiconductor nanostructures can be greatly modified by coherent phonons be- cause the strain associated with the phonons shifts the electronic transitions of a laser medium with respect to the cavity mode. This can lead to significant enhancement and attenuation of the emission intensity, making phonons attractive for the control of light-matter interaction on the picosecond time scale. We consider an ensemble of quantum dots (QDs) as active medium for which such a control of the light emission has recently been demonstrated experimentally [1]. The same method has already been successfully extended to other nanostructures [2,3]. Two basic mechanisms have been identi- fied, which affect the laser intensity: (i) The *shaking effect*, which dynamically brings highly occupied excitons into resonance with the cavity mode and therefore increases the output. (ii) The *adiabatic shift* of the ensemble, which varies the absolute number of QDs in resonance with the laser mode. We develop a semiclassical laser model that is schematically shown in Fig.1(a) to analyze these mechanisms in detail. The model combines the three nonlinearly coupled subsystems: excitons, photons and phonons. By choosing special ensemble distributions and intuitive strain dynamics it is possible to distinguish between the two effects [4]. In the experiment, which is schematically shown in Fig. 1 (b), the phonons are injected into the system by intense laser pulses hitting an aluminum surface on the back side of the sample. Due to nonlinear propagation and multi-scattering processes when passing through the distributed Bragg reflector (DBR), the shape of the acoustic field hitting the QDs [given in Fig.1(c)] is quite involved. Using these strain dynamics as input in the simulations we can directly compare the laser emission properties of experiment and theory [5]. By choosing differ- ent initial detunings between the QD ensemble and the cavity mode and excitation powers close to the lasing threshold we extend the original experiment [1]. We find an excellent agreement between experiment and theory, as is exemplarily shown in Fig.1(d) and (e). Our combined approach helps to distinguish between the shaking effect and the adiabatic shift that both simultaneously affect the laser output in the experiment. This also allows us to propose new system designs to further tailor the interplay between phonons, excitons and photons.

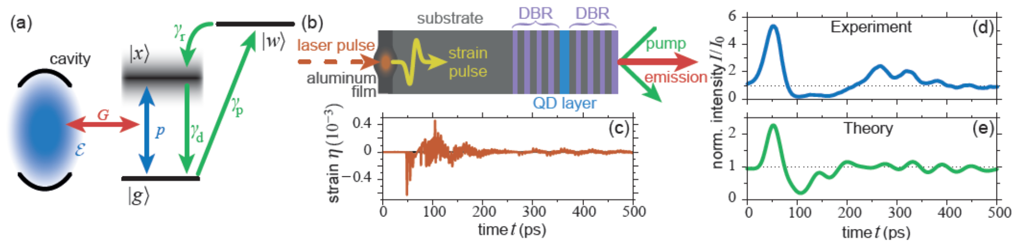

Figure 1: (a) Sketch of the theoretical model. (b) Scheme of the experiment. (c) Strain in the experiment. (d,e) Measured and calculated laser intensity.

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