Density-dependent dynamics and effective temperature of nonradiative exciton reservoir in quantum wells

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Optically dark or nonradiative excitons with large wave vector exceeding the wave vector of light play important role in the dynamics of excitons and polaritons in semiconductor heterostructures. The interaction of bright and dark excitons plays particularly important role in formation of polaritons and their dynamics in structures with microcavities [1]. In high quality structures, the reservoir excitons can persist for a long time (tens of nanoseconds [2]) and they can be accumulated up to large densities.

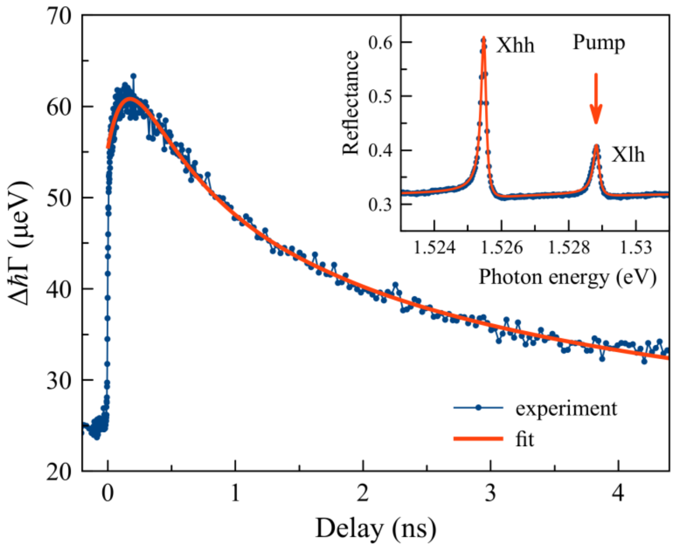

Figure 1. Dynamics of the photoinduced nonradiative broadening of the Xhh resonance under excitation into the Xlh resonance. Experimental data are shown by the blue dots, simulation by the red curve. The inset shows the reflectance spectrum with no pumping.

We report here on density-dependent dynamics of excitons in the nonradiative reservoir. The method of the study is based on detection of the photo-induced broadening of exciton resonances in a reflectance spectrum [2]. An example of the broadening dynamics measured by the pump-probe technique for the heavy-hole exciton resonance (Xhh) in a GaAs/AlGaAs quantum well (QW) is shown in Fig. 1.

The areal density and the dynamics of quasi-particles in the reservoir are controlled by several processes. The reservoir is populated via scattering of the photocreated excitons into the states with large in-plane wave vector. The exciton density in the reservoir depends on the depleting processes. In high-quality heterostructures, the main mechanism of depletion of the reservoir at low temperatures is the scattering of excitons into the light cone, where they quickly recombine with the emission of photons. We found that the exciton-carrier scattering dominates over other depleting processes [2].

Strong optical excitation leads to heating of the exciton reservoir and activation of other processes. The heating is accompanied by a shift in the dynamic equilibrium of excitons ↔ free charge carriers towards the latter. This leads to an acceleration of the scattering of excitons from the

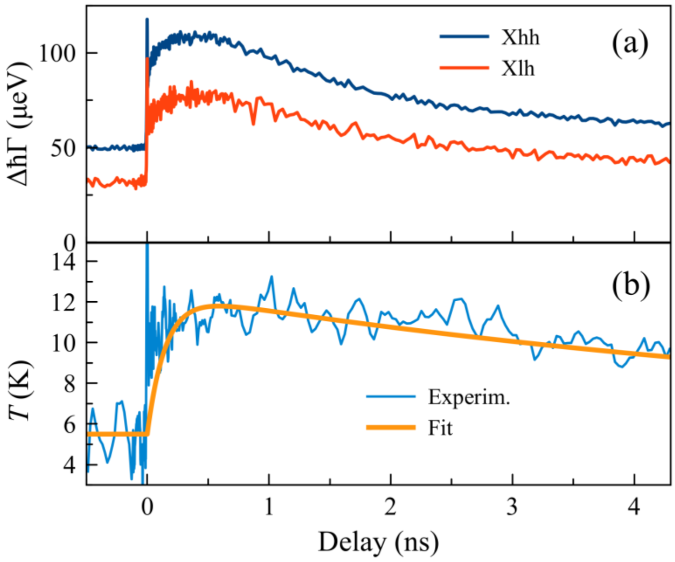

Figure 2. (a) Dynamics of the nonradiative broadening of the Xhh and Xlh excitons measured at the excitation power P = 1.6 mW. (b) Dynamics of reservoir temperature extracted from the experiment (noisy curve). Smooth curve is the fit by a two-exponential function with parameters: T_0 = 5.5 K, ΔT = 7 K, t_{decay} = 7 ns, and t_{rise} = 0.15 ns. Sample temperature T = 4.5 K.

light cone and a reduction in their lifetime in the reservoir. In addition, the states of the light-hole excitons (Xlh), which are higher in energy than the Xhh exciton states, are populated in the reservoir. Experiments show that, at low temperatures, the Xlh resonance broadening is approximately twice smaller than that of the Xhh resonance [2]. This is due to peculiarities of the exciton-exciton exchange interaction [3]. When the reservoir temperature increases the interaction strength of excitons in the reservoir with the Xlh and Xhh bright excitons levels out. In the experiment, this is observed as equalization of the photo-induced non-radiative broadening of the Xlh and Xhh exciton resonances. The ratio of the broadenings can serve as a kind of thermometer for the reservoir. We found that, at the excitation power density of about 10 W/cm^2, the reservoir temperature increases by about 7 K and then it slowly relaxes down with characteristic time 9 ns, see Fig. 2. We developed a model of dynamic processes in the exciton system, which quantitatively describes the observed dynamics.

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