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Rapid Research Note

Radiative Recombination in Type II GaSb/GaAs Quantum Dots

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The type II band alignment of GaSb quantum dots (QDs) in a GaAs matrix leads to peculiar optical and electronic properties [1–4]. Such type II QDs provide an about twice as large hole confinement as comparable type I InAs/GaAs QDs, whereas the electrons are delocalized in the surrounding barrier. However, the Coulomb interaction provides for bound exciton states. The spatial separation of the electron and the hole reduces the overlap of the wavefunctions reducing the oscillator strength compared to type I structures. The disparate electron and hole localization is reflected in many-particle effects being dominated by hole–hole interaction. [4]

In this paper we report time-resolved photoluminescence (TRPL) measurements of self-organized GaSb/GaAs QDs. Previous investigations [1, 5] have been performed on samples with additional AlGaAs barriers, which artificially enhance the electron–hole overlap. Here we report on the intrinsic radiative lifetime of isolated type II QDs, which will be much longer than the previously reported 5 ns.

The investigated sample was grown by metal organic vapor phase deposition (MOCVD) using the Stranski-Krastanov mode. The island density is $\sim 3 \times 10^{10}$ cm^{-2} and atomic force microscopy (AFM) measurements of a comparable uncapped sample suggest a lateral width of ≈25 nm and a height of 2–4 nm. More details of the growth are reported elsewhere [6].

The sample was cooled to 2 K in a He-immersion cryostat and excited at 2.18 eV by a pulsed dye laser with a repetition rate of 3.8 MHz. The emission was dispersed by a 0.35 m subtractive double monochromator and detected with a multi-channel-plate photomultiplier with a S1 cathode. Using single photon counting a time resolution of 30 ps

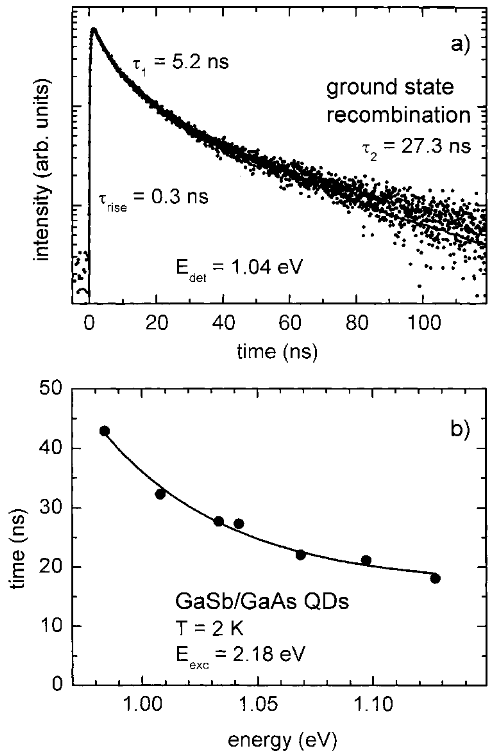

Fig. 1. a) A typical transient (dots) with corresponding 3-exponential fit (line). b) The slow decay time decreases with increasing transition energy. The slow decay time gives a lower limit for the radiative recombination

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was achieved. The transients were analyzed taking into account the system response by convolution techniques. The large number of excitons generated by each laser pulse leads to initially highly occupied QDs and the photoluminescence (PL) spectrum (not shown here) is comparable to previously reported ones for high-density continuous wave excitation [4] showing a broad peak between 0.95 and 1.12 eV.

Figure 1a shows the transient (dots) recorded at 1.04 eV. As demonstrated by the solid line the transient is well fitted by three exponentials covering the rise ($\tau_{\rm rise}$ = 0.3 ns) as well as the fast (τ_1 = 5.2 ns) and slow (τ_2 = 27.3 ns) decay components. With increasing detection energy the two decay times become faster and the relative amplitude of the fast component increases.

The rise time characterizes the initial capture of holes into the QD potential and the thermalization of electrons in the long-range Coulomb potential, leading to many-exciton states. The initial decay is attributed to the decay of the multi-exciton states, in which a host of possible recombination channels contribute [7]. Finally the decay converges against the slow component describing the recombination of the final exciton, i.e. the slow component is attributed to the ground state lifetime. As shown in Fig. 1b the ground state lifetime (τ_2) decreases with increasing transition energy, i.e. with decreasing QD size. Based on the giant oscillator strength model [8] the opposite trend would be expected. However, the type II confinement in the GaSb/GaAs QDs spatially separates electrons and holes rendering the electron–hole overlap the decisive factor. Indeed, an overlap of 10^{-2} is required to explain the decay being about two orders of magnitude slower than in type I InAs/GaAs QDs [7]. The increasing recombination probability for smaller QDs is attributed to an increasing electron–hole overlap. The hole wavefunction penetrates deeper into the barrier and the exciton (i.e. electron) binding energy increases with decreasing QD size.

In conclusion our experiments provide insight into the dynamics of type II excitons in GaSb/GaAs QDs. The oscillator strength of the ground state exciton scales inversely with the QD size, due to a decreasing overlap of the confined hole and the delocalized electron.

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