Cathodoluminescence studies of individual CdSe/ZnSe quantum dots

W. Zaleszczyk, V. Kolkovsky, M. Wiater, K. Fronc, S. Chusnutdinow, M. Aleszkiewicz, M. Szymura, Ł. Kłopotowski, G. Karczewski, and T. Wojtowicz

Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland

Spatially and spectrally resolved cathodoluminescence (CL) in the scanning electron microscope (SEM) is a very powerful technique for studying the optical properties of semiconductor low-dimensional structures including self-assembled quantum dots (QDs). Monochromatic CL maps allow detecting the position of individual QD with spatial resolution higher than resolution limit of micro-photoluminescence (μ-PL) [1]. Therefore CL is a very promising tool for finding positions of optically active QDs or pair of QDs on surface of the sample for further processing (e.g. fabrication of pillars containing single QD in its center [2]) and successive measurements (e.g. μ-PL).

The studied sample with CdSe QDs embedded in ZnSe matrix was grown by molecular beam epitaxy on a (001) GaAs substrate at the temperature of 370 °C. CL characterization was performed at the temperature of 5 K using an acceleration voltage in the range 1-15 kV and an excitation beam current in the range from 0.03 to 6 nA.

Monochromatic mapping of the CL-signal at fixed wavelengths corresponding to QDs emission allows to investigate diffusion length of carriers and to estimate experimental CL spatial resolution. The CL intensity profiles for individual QDs were analyzed and the fitting curves give the statistical mean value of the minimal carriers diffusion length about of 20 nm. Hence experimental CL spatial resolution was estimated in the range 80-100 nm. Relatively short mean diffusion length suggests the presence of structural defects in ZnSe matrix.

The CL spectra collected in the spot mode show three lines: small peak at 2.81 eV originated from ZnSe matrix, another small peak at 2.61 eV related to structural defects in ZnSe, and strong inhomogeneously broadened emission of the CdSe QDs centered at 2.3 eV. This means that in spite of spatial resolution that is sufficient to see individual QDs on monochromatic maps, high density of QDs prevents observation of separate lines from single QDs in a spot mode. In order to measure spectra of individual QDs the number of excited QDs must be reduced below the number of dots in the primary electron interaction area. For this purpose the mesa structures produced by means electron beam lithography and wet etching were measured. The fields with various nominal diameters d of mesas (0.25, 0.5, 1, 2, 3, 4, 5 μm) and with mesa's heights in the range of 100 to 180 nm were fabricated.

When measuring mesas with decreasing diameter d it was observed that at the nominal value of d = 250 nm the broad multiple QDs emission band became separated into individual lines of single QDs. The jittering of luminescence excitonic lines related to quantum confined Stark effect [3] was then observed. This effect is attributed to the random neutralization of the defects in the vicinity of QD leading to random fluctuations of the electric field, which act on the QD. Such fields modify the carrier confinement in the QD leading to a shift of the luminescence lines.

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