Influence of doping on "exciton gas – electron-hole liquid" phase transition in SiGe quantum wells

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It is well known that for moderately doped Si and Ge crystals impurities serve as centers of nucleation for electron-hole liquid (EHL) and significantly lower the threshold for condensation. The influence of impurities on the formation of the quasi-2D condensed phase in semiconductor quantum well (QW) has not been studied yet. At the same time the unique features of quasi-2D EHL and the related "gas-liquid" phase transition have been observed recently for the systems based on SiGe/Si QW: condensation occurs at much lower excitation densities as compared with bulk Si, the phase transition is accompanied by the formation of unusual excitonic complexes, the barrier for electrons in SiGe layer results in a significant increase of EHL critical temperature [1,2]. In this work, we investigated the influence of boron impurity placed in the center of SiGe layer (or in close proximity to QW) on the many-body effects occurring in photoexcited SiGe/Si QW.

SiGe/Si samples with a single SiGe layer with a thickness of 5 nm and Ge content of 3-14.5% were grown by MBE on high-resistivity Si-substrates. In some samples boron δ-layer with a density of ~ 10^{10} cm^{-2} was placed at different distances from QW or in the centre of SiGe layer. Steady-state and time-resolved photoluminescence (PL) measurement have been used to study many-particle states and the related phase transitions in the QW.

In the time-resolved PL spectra of "pure" samples (without δ-layer) with Ge content of 3-6.9% quasi-2D EHL emission has been detected at low (5K) temperatures. For a wide range of times (< 1 mks) the EHL line shape as well as the decay time constant remained unchanged. For delay time > 2 mks after an excitation pulse the QW no-phonon emission line as well as its phonon replicas shifted to shorter wavelengths. A comparison of the spectra recorded at different temperatures revealed at least two recombination channels in addition to the EHL: free excitons (FE) and many-particle states (MPS). The exact nature of the MPS is the subject of debate. In particular, a sequential analysis of PL spectra in IR and visible regions indicates that MPS should include more than 4 particles (two electron and two holes). Decrease of the excitation power density in the steady-state experiments from 240 to 70 mW/cm^2 at T = 5 K leads to "pure" sample spectra transformation from EHL to MPS PL. At higher temperature (10 K) the collective states dissociate and FE role increases.

The dopant δ-layer incorporation in the QW center hardly affects on the sample spectrum at low temperature and high excitation level. The EHL emission lineshapes in the both doped and "pure" structures are matched together with high precision. This confirms a high structural quality of the samples and their characteristics identity. Decrease of excitation power up to 70 mW/cm^2 results in significant QW PL line narrowing without distinguishable line shift. This narrow line is observed at higher temperature contrary to EHL but is absent in "pure" sample spectra. So we can to attribute this line to the luminescence of the boron-bound excitons. The binding energy of bound exciton complex (BEC) is 6 meV for QW with 5% Ge content.

It has been shown that the QW doping leads to the BEC line appearance in the PL spectra. Also, the dopant δ-layer suppresses EHL formation at low excitation power density.

[1] V. S. Bagaev, V. S. Krivobok, S. N. Nikolaev et al., Phys.Rev.B **82**, 115313 (2010)
[2] V. S. Bagaev, V. S. Krivobok, S. N. Nikolaev et al., JETP Letters, **94**(1), 63-67 (2011)