Photoluminescence studies of PbSe/CdSe heterostructures

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PbSe is a narrow band gap IV-VI semiconductor known for applications in mid-infrared detectors and lasers but also from investigations of epitaxial PbSe quantum dots [1] and colloidal core/shell dots, like PbSe/CdX (X = S, Se, Te) [2]. The recent discovery of topological insulators gave new impulse for studies of PbSe-based heterostructures as this semiconductor with proper addition of Sn constitutes new class of topological materials, namely topological crystalline insulators [3]. In this paper we concentrate on optical investigations of quantum wells of rock-salt PbSe with wide gap barriers of sphalerite CdSe grown on GaAs (001) substrate. The preparation of PbSe/CdSe heterostructure in the form of quantum well shifts the region of optical activity of PbSe ($E_g \approx 150$ meV at 4K) to the higher energies due to the quantum size effect. It can be crucial in the case of future photoluminescence measurements of topological $Pb_{1-x}Sn_xSe$ material as the increase of tin content decreases the energy gap to the region in which the non-radiative recombination processes dominate.

The samples were grown by molecular beam epitaxy technique with use of separate effusion cells for Pb, Se, and Cd. The growth temperatures were 365 °C for CdSe and 263 °C for PbSe material. First, samples containing thin CdSe buffer and 300 nm thick PbSe layer were prepared for different Se/Pb flux ratio η varying from 1 to 2.2. The best photoluminescence efficiency was obtained for samples with $\eta \approx 1.6$. For such samples we observe band-to-band transitions with maximum shifting from 165 meV at 15 K up to 275 meV at room temperature. The 15 meV shift observed at low temperatures as compared to bulk PbSe is due to stress resulting from difference in temperature expansion coefficient for PbSe and GaAs substrate and CdSe buffer. It is also worth to notice, that the 30 min annealing (in nitrogen atmosphere) of the samples grown for η significantly different from 1.6 can considerably increase their photoluminescence activity. Such behavior is a result of improved crystal quality by reduced number of intrinsic defects (like Pb vacancies and Se interstitials) during annealing process.

Further, three samples containing single CdSe/PbSe/CdSe quantum well with thicknesses of 100 nm, 80 nm and 50 nm respectively were grown. For 100 nm PbSe QW samples we observe the blue-shifted photoluminescence emission up to 225 meV at 50 K due to quantum size effect. Increase of temperature in the case of this sample causes further shift of the luminescence peak to 275 meV at 230 K. Surprisingly, for samples with thinner PbSe QWs the photoluminescence signal is observed only at higher temperatures starting from 130 K and 150 K for 80 nm and 50 nm QW respectively, and is much weaker as compared to the 100 nm sample. This unexpected temperature behavior of photoluminescence will be discussed within the model taking into account quasi-type II band alignment expected in the case of PbSe/CdSe heterostructures [2]. In this localization regime the electrons are delocalized while the holes remain localized within the region of PbSe material. It makes the investigated structures very sensitive to the temperature induced change of the conduction band offset.

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