EXCITONIC GAIN IN CDSE/ZNSE QUANTUM DOT STRUCTURES

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We studied gain and absorption in CdSe quantum dots (QDs) in a ZnSe matrix. It was demonstrated that, caused by a strong excitonic absorption, excitonic waveguiding occurs in edge geometry. No significant change of the gain maximum energy over a range of two magnitudes above the threshold was detected. Magneto-optical investigations demonstrate the strong lateral localisation of excitons at CdSe QDs in agreement with lack of exciton screening in QDs revealed in gain studies.

1. Introduction

Submonolayer (SML) depositions of lattice mismatched materials are proven to form a dense array of quantum dots (QDs) in several II-VI and III-V materials. Laser structures with an active region consisting of a CdSe SML superlattice (SL) in a (Zn,Mg) (S,Se) matrix exhibit an ultrahigh material gain due to the excitonic waveguiding effect [1]. To use this waveguiding effect a strong localisation of the excitons is required. The confinement of the exciton wavefunction due to localisation at QDs can be clarified by magneto-optical investigations, as it was shown e.g. for InAs QDs [2]. To investigate the nature of the intensive stimulated emission, gain spectroscopy in such structures was performed.

2. Experimental Details

The investigated structures were grown by molecular beam epitaxy (MBE) [3]. The most remarkable differences to common laser structures are the 360 nm thin ZnSSe

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buffer layer and a 60 nm thick active region consisting of a CdSe/ZnSe SML SL. ZnSe barriers separate the sheets of CdSe SML insertions and have thicknesses of 15 Å, 30 Å, and 80 Å, respectively.

To reveal the distribution of the strained cadmium selenide insertions, cross-section high-resolution transmission electron microscopy (HRTEM) is performed along the <110> direction using a PHILIPS CM 200 FEG/ST electron microscope with a Scherzer resolution of 0.24 nm, and the DALI evaluation program [4] was applied.

Additionally, the II-VI SML SLs were characterized using photoluminescence (PL), calorimetric reflection (CR), and magneto-optical spectroscopy. Gain studies have been performed in the edge geometry. The gain spectra are evaluated using the variable-stripe-length method.

3. Experimental Results and Discussion

To investigate the structural properties of the samples we performed HTREM measurements. In Fig. 1 we show a colour-coded map of the local lattice parameter (LLP) in growth direction ($a_\perp$) for the structures with 15 Å (a) and 30 Å (b) spacer layer thickness. The reference lattice parameter for Fig. 1b was chosen to be the ZnSSe lattice constant resulting in LLPs between 1 and 1.07. An averaged lattice parameter was determined from the whole image Fig. 1a. Therefore, normalised LLPs smaller than 1 are observed in the ZnSe spacers. The shift in the colour from blue to red corresponds to an increase of the lattice parameter in the vertical direction $a_\perp$ due to the larger bulk lattice parameter of CdSe (6.081 Å) with respect to that of ZnSe (5.6697 Å). One can see that the CdSe insertions demonstrate different behaviour for different spacer layer thicknesses. The most pronounced result is the remarkable change in the lateral arrangement of islands with decrease of the spacer layer thickness. A close inspection of Fig. 1b reveals that the islands in the upper sheets which are separated by 30 Å spacers tend to nucleate at positions between the islands of the previous sheet (anticorrelated growth), while a vertical correlation of islands is *locally* observed for the structure with the 15 Å spacers (Fig. 1a). This is in very good agreement with theoretical predictions [5].

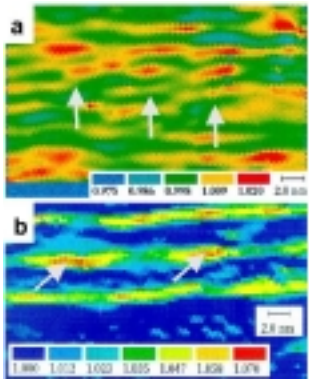

Figure 1. Local lattice parameter for stacked CdSe SML structures with 15 Å (a) and 30 Å (b) spacer.

The stacking of the CdSe insertions results in a smaller optical transition energy for vertically coupled states, as it is shown in Fig. 2. The PL for the structure with 30 Å spacers is displayed. Two emission lines occur. The luminescence at 2.703 eV

corresponds to radiative transitions of heavy-hole like excitons localised at vertically anticorrelated QDs. The PL intensity of the luminescence at 2.644 eV originated from heavy-hole like exciton transitions localised at vertically correlated QDs is dominant. From high excitation [3] and reflection spectroscopy a larger density of states for the anticorrelated QDs was obtained. This is attributed to efficient transfer mechanisms between correlated and anticorrelated QDs.

To proof the excitonic nature of the emission and to reveal the lateral electronical confinement, magneto-optical measurements in Voigt configuration were performed. Both emission lines exhibit a splitting into σ^+ and σ^- polarised luminescence light and a shift of their weighted line center (first moment) for increasing magnetic field (**B**). The transition energies depend quadratically on **B**. The **g**-factor and the lateral diameter **d** of the exciton wavefunction [2] were obtained from the linear and quadratic term of the dependence on **B**, respectively. For the emission of the anticorrelated (vertically uncoupled) QDs follows **g** = 1.4 and **d** = 60 Å, while for the emission localised at correlated QDs with **g** = 1.9 only a upper limit of **d** could derived (**d** ≤ 30 Å). These results are in accordance to the observed island size (see Fig. 1) and thus, demonstrate a good localisation of the exciton wavefunction at the CdSe QDs. We note that latral confinement is much more pronounced for vertically coupled states in agreement with their larger localisation energy and smaller lateral size.

The gain spectrum of the structure with 80 Å spacer at high excitation density is depicted in Fig. 3. The absorption peak which appears in the region of excitonic waveguiding remains stable even at excitation densities as high as two orders of magnitude above the threshold (see insert). Thus, there still exists a spectral range of

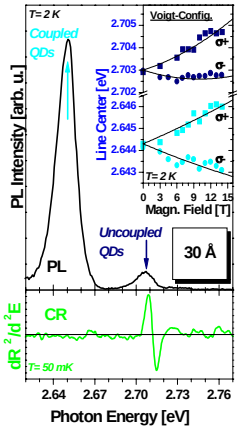

Figure 2. Photoluminescence (PL) and calorimetric reflection (CR) spectra for the structure with 30 Å spacers. The insert shows the weighted line center as a function of the magnetic field in Voigt- configuration.

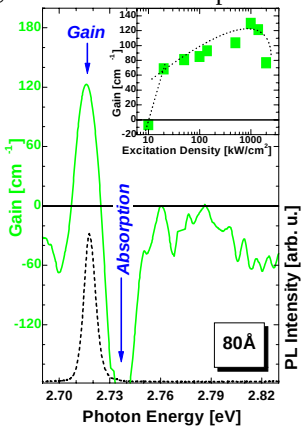

Figure 3. Gain (line) and stimulated emission (dash line) spectrum for the structure with 80 Å spacers. The spectra were recorded at 7 K with an excitation energy of 2.88 eV at a density of 1 MW/cm^2. The insert shows the maximum gain as a function of the excitation density.

strong excitonic absorption providing an increased refractive index on its low energy side, and, consequently, an efficient exciton-induced waveguiding. At highest excitation densities, however, the gain saturates and starts to decrease. The origin of this behaviour is the finite number of QDs having a proper transition energy, and after the filling of these QDs the gain saturates. At very high excitation levels when all the QDs are filled there is no excitonic absorption and, consequently, also no exciton-induced waveguiding on the low energy side of the excitonic resonance. This results in a decrease of the gain. For the other structures a similar behaviour was observed.

4. Conclusion

In conclusion, we studied gain in structures with vertically correlated and anticorrelated CdSe QDs in a ZnSe matrix. The localisation of excitons at islands comparable to the exciton radii proven by magneto-optical spectroscopy leads to the lack of exciton screening up to highest excitation densities.

5. Acknowledgements

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