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Single GaN/AlGaN Quantum Dot Spectroscopy

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Microphotoluminescence of low-density GaN/$Al_xGa_{1-x}N$ quantum dots grown by metal-organic vapor phase epitaxy using *in situ* etching of AlGaN is presented. The detailed analysis of the emission from these structures enables the observation of pairs of lines separated by the energy up to 3 meV. They behave in a different way under different excitation power that suggests that this doublet structure can be associated with the exciton and trion (or biexciton recombination). It is observed that for different quantum dots the energy of the charged exciton complex emission could be higher or lower than the neutral exciton one. It is discussed in terms of a competition between attractive e–h and repulsive e–e (h–h) Coulomb interaction that occurs because of the existence of the built-in electric field that separates electrons and holes in the dot.

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1. Introduction

Standard method of quantum dot (QD) fabrication relies on the Stranski–Krastanov growth mode [1]. This technique provides usually high-density assemblies of quantum dots, which makes experimental studies of individual quantum dots very difficult. Recent advance in the growth of a new type of quantum dots allowed detecting emission from single GaN/AlGaN QDs using standard microphotoluminescence (μPL) technique, without any artificial mesa or mask structures [2, 3].

2. Samples and experiment

The low-density GaN/$Al_xGa_{1-x}N$ ($x = 0.12$) QDs were grown by metal--organic vapor phase epitaxy (MOVPE) using modification of the proposed earlier

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method [4]. The AlGaN layer is grown on the sapphire substrate. The grown layer is treated *in situ*, at high temperature, by SiH_4 that leads to the roughening of the surface. On the substrate prepared in such a way the GaN is grown. Nucleation takes place only at distinctly separated points leading to the growth of 3D GaN crystallites with the shape of hexagonal pyramids. Then the number of crystallites is decreased during the annealing process. Afterwards the AlGaN cap layer is grown. At the beginning it nucleates mainly on crystallites widening them to relatively large hills. The continuation of the growth leads to the lateral expanding of the hills and then to the flattening of the surface. The details of the growth procedure are described elsewhere [3].

The low temperature μPL was done using He–Cd laser operating at 325 nm line. The measurements were performed using a continuous flow cryostat in a temperature range of 4.2–60 K. The laser spot was focused on the surface of the sample using reflecting microscope objective with the magnification of 25. The resulting excitation spot size is estimated to be of about a few μm in diameter.

3. Results and discussion

A typical μPL spectrum of the investigated system is presented in Fig. 1. The emission at energy of about 3.74 eV comes from the AlGaN barrier and the energy is consistent with the Al content assumed in MOVPE process. The origin of the strong emission band with the maximum in energy of 3.53 eV is not clear. Probably it can be associated with the defect related luminescence of AlGaN layer. In the low energy of the PL spectrum the sharp lines can be observed. We associate them with the emission from GaN quantum dots. It must be stressed that these lines appear in the energies lower than the energy of the GaN band gap. While the quantum confinement and stress lead to the increase in the luminescence energy of the emitted line, the lowering indicates that the observed quantum objects are relatively big (the diameter of the GaN pyramid base, known from scanning electron microscopy (SEM), is up to dozen nm) and the confining potential is significantly modified by electric field built-in GaN/AlGaN heterostructure leading

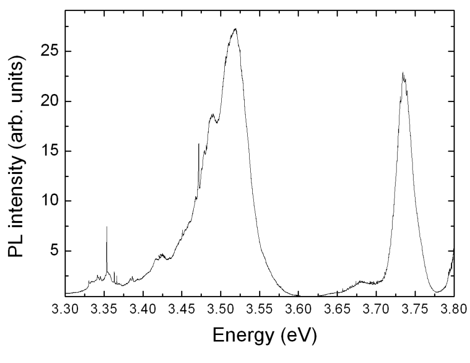

Fig. 1. Typical photoluminescence spectrum of the investigated structure measured at 4.2 K.

to the quantum confined Stark effect. According to Ref. [5], the electric field in the structure can be estimated to be about 400 eV/cm. The PL energy of quantum wells with the similar AlGaN/GaN Al fraction are investigated [5] and this allows us to estimate the height of the crystallite to be about 20 nm, that is in agreement with the atomic force microscopy (AFM) measurements.

It is observed that in the luminescence spectrum not only single sharp lines can be observed but also the pairs with the separation up to 3 meV between the components can be found. These groups have been examined in detail under changing excitation power.

Typical results are shown in Fig. 2 and exemplary objects are marked by circles and squares. A different behavior of the observed lines upon variable excitation power (P) was found. The dependence between the emission intensity (I) and the excitation power was fitted using $I \propto P^{\alpha}$ formula. A typical ratio of the α coefficients observed for the pair constituents is close to the value of 1.5. This suggests that the observed doublet structure can be associated with the neutral exciton and trion (or biexciton) recombination from the same single quantum dot. It is observed that for different QDs the energy of the trion (or biexciton) emission could be higher or lower than that of the neutral exciton. It was also found that both lines described above disappear from the PL spectra above 40–50 K. This suggests that the observed complexes are weakly bound.

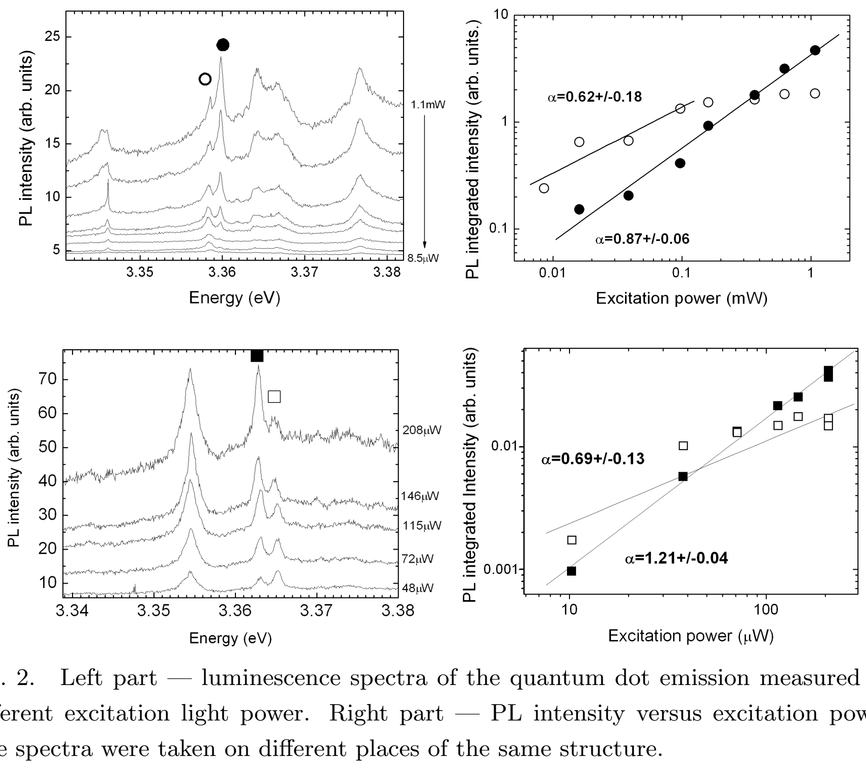

Fig. 2. Left part — luminescence spectra of the quantum dot emission measured for different excitation light power. Right part — PL intensity versus excitation power. The spectra were taken on different places of the same structure.

4. Discussion

The above observations can be explained taking into account specific properties of nitride low dimensional systems. The energy position of the emission from observed quantum dots is well below the GaN band-gap energy. It indicates the existence of the built-in electric field in the structure and suggests that the investigated objects are relatively big. Since the built-in electric field separates electrons (e) and holes (h) in the dot, one could expect a competition between attractive e–h and repulsive e–e (h–h) Coulomb interaction. Effectively it can result in different energy arrangements of the emission due to neutral exciton and exciton complexes.

5. Conclusions

It was shown that for GaN/AlGaN quantum dots the system obtained by MOVPE sharp lines assigned with a single dot emission are observed. Characteristic doublets with lines showing a different behavior with excitation power were found and they can be assigned to the recombination of different exciton complexes localized in the same single quantum dot. The presented results show that in the discussed system there is a possibility of more sophisticated investigations of individual quantum dots.

Acknowledgments

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