Abstract

In this work, rare earth doped III-V nitride semiconductors are investigated with spectroscopic methods. Especially thin films of *GaN* and *InGaN* are studied. Another set of specimens are quantum structures of *GaN/AlN* and *GaN* thin films double doped with Er^{3+} and Yb^{3+}. The *GaN* thin layers grown by a unique MOCVD method which allows for doping rare earth ions during the growth process. The samples were doped with high concentration of *Er* ions in the range from 2×10^{20} cm^{-3} up to 10^{21} cm^{-3}. In the case of doubly doped *GaN* thin films, the implantation dosage was 10^{15} *at./cm²* of Er^{3+} and 2×10^{15} *at./cm²* of *Yb*.

GaN:Er thin films were investigated with temperature dependent photoluminescence (TPL), temperature dependent excitation photoluminescence (TPLE) and time-resolved photoluminescence (TRPL) in order to verify the energy level schemes of the ground $^4I_{15/2}$ and first three excited ($^4I_{13/2}$, $^4I_{11/2}$ and $^4I_{9/2}$) states of Er^{3+} proposed for hexagonal *GaN* by other investigators. A complete set of identified and ascribed energy levels in each energy state was a reference for theoretical calculations based on Exchange Charge Model of Crystal Field Analysis. The results allowed to ascribe the local symmetry of *Er* ions position (C_{3v}) and confirm the correctness of energy levels identification. The TPL gave information about characteristic temperature quenching energies E_A of luminescence (depending on excitation mechanism up to 198 *meV*) and TRPL analysis reveals efficient radiative de-excitation channels. The results have shown that there are some differences between previously presented data and the data obtained in this work and the reasons of it are discussed.

Having well-elaborated energy level schemes for *Er* in *GaN* an attempt of using *Er* ions as an alloy disorder probe in *InGaN* was undertaken. The samples of *InGaN:Er* were obtained with the same growth procedure as the *GaN:Er*. Depending on the content of *In*, energy levels were broadened in comparison to *GaN:Er*. In the case of $In_{0.05}Ga_{0.95}N:Er$ the broadening is well visible in PL spectra as well in the PLE. The largest broadening is visible in the case of 9% of *In* in *GaN*, where the energy levels are overlapping and thus *Er* emission behaves quite similar to like Er-related PL in glasses. The spectral line narrowing effect is well pronounced but the broadening is much lesser than in glasses. Analysis of the PL and PLE allowed stating that in *InGaN:Er* with 9% of *In* two families of *Er* emitting centres are developed. The first family is similar to that in *GaN*, but disturbed by alloy disorder, and the other family seems to reflect the presence of *In* atom in the second coordination sphere around *Er* ions. It shows that *Er* ions are very good probes of local disorder.

Effective enhancement of the *Er* 1.54 *μm* emission is very important for further application of *Er* doped materials. Two approaches to emission enhancement were checked. First one is emission sensitized with *Yb* ions as the best candidate for *Er* due to the close energetic proximity of the $^2F_{5/2}$ of *Yb* excited state to the $^4I_{11/2}$ second excited state of *Er*. This approach appeared to be ineffective at low temperatures because of bidirectional energy transfer from *Yb* to *Er* and simultaneously from *Er* to *Yb*. The second reason for this ineffectiveness is strong thermal quenching of luminescence at higher temperatures. The second approach was incorporating of *Er* ions into the quantum structure, especially into *GaN* quantum wells in

GaN/AlN superlattice. In this way much better results were achieved. The twelvefold increase of the emission intensity near 1.54 *μm* in comparison to *GaN:Er* thin films was realised. A proper choice of the quantum well and barrier widths appeared to be crucial for the emission efficiency enhancement. A model explaining the mechanism of enhancement is proposed.

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