Structural, optical and electrical properties of ZnO single crystals and epitaxial films implanted with Er and Yb

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Rare Earth (RE) doped semiconductor materials have been widely investigated because of their optical properties and possible application as fiber lasers and amplifiers, plasma displays, phosphors in fluorescence lamps and solar cells. The *RE4f* electron shell is highly localized, so the intra-shell transitions of *4f* electrons are only slightly affected by the host material, therefore the radiative efficiencies are almost temperature independent. Wide bandgap semiconductors are especially interesting as host materials, because they are expected to overcome the temperature quenching observed in other materials (e.g. in Si) and to promote effective resonant pumping of the *f* shell [1]. GaN and ZnO have been the most investigated semiconductors in this field. Both materials have a similar bandgap (about 3.4 eV at RT) and nowadays they compete with each other as the most promising new materials for optoelectronics. ZnO, in contrary to GaN, still experiences a problem with reliable and stable p-type doping, but has such important advantages over GaN as much higher exciton binding energy (60 meV vs. 24 meV) and possibility to grow a high quality films by commercial and inexpensive deposition methods.

In the present work we report on Yb- and Er-ion implantation on epitaxial ZnO films grown by the Atomic Layer Deposition (ALD) method on a commercial GaN/Al_2O_3 substrate. The samples of about 1 µm thick have been grown at temperature of 300^oC using diethylzinc and deionized water precursors. The full width at half maximum (FWHM) of the rocking curve of the (006) diffraction peak was established as 0.05^o. The collected channeling Rutherford Backscattering (RBS/c) spectra reveal χ_{min} = 3% which is comparable with that for commercial single ZnO crystal (MaTecK).

The ZnO films have been implanted with Er or Yb ions to fluence of $1x10^{15}$, $5x10^{15}$ and $1x10^{16}$ at./cm^2. Photoluminescence measured at helium temperature for ZnO:Yb films shows a weak the *Yb4f* related emission between 970 and 1020 nm. Post-growth annealing performed at 800^oC in an ambient atmosphere (30 and 60 min.) enhances the *Yb4f* emission by more than one order of magnitude. The structural effects of ion implantation has been studied by the RBS/c technique. It allows direct measurements of defect depth distributions and to perform lattice location of implanted species. It has been demonstrated that above 50% of implanted Yb ions occupy substitutional lattice positions. Subsequent thermal annealing of implanted samples leads to partial recovery of the crystal lattice but also reduces substitutional fraction of Yb atoms. The Hall effect measurements show a significant decrease of electron mobility after implantation (about one order of magnitude, from 50 to 6 cm^2/Vs), while electron concentration stays at the same level (~10^{18} cm^{-3}). The 30 min. annealing results in the increase of both electron concentration and mobility and the resultant resistivity drops to about 10^{-2} Ωcm.

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