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Influence of treatment in weak magnetic fields on photoluminescence of GaN:Si

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Abstract. The long-term transformations of photoluminescence of GaN:Si treated with pulsed weak magnetic fields have been studied. The defect structure transformations have been inferred from the radiative recombination spectra within the range 350…650 nm at 300 K. A possible mechanism of observed modifications related with the magnetic field induced destruction of metastable complexes has been discussed.

Keywords: photoluminescence, weak magnetic field, gallium nitride.

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1. Introduction

Processes related with the influence of weak magnetic field (WMF) on the impurity-defect composition of semiconductor compounds $A^{III}B^{V}$ were studied in [1-3]. It was found that magnetic field treatment leads to long-term non-monotonic transformation of the defect composition in the near-surface region in the spectral characteristics of GaAs, InP, GaP, GaN. However, the processes responsible for this realignment, in particular for changing the photoluminescence (PL) spectra of semiconductors, remains uncertain. Therefore, researches aimed at studying this kind of interactions in promising semiconductor device structures are required to determine all the features associated with magnetic-induced transformations.

2. Experimental

The object under study was the samples of GaN:Si of *n*-type conductivity (the concentration of charge carriers was ~$1.6\cdot10^{19}$ cm^{-3}) with the thickness ~2.2 μm, which were grown using MOCVD on sapphire substrates. PL measurements were carried out at room temperature within the 350–650-nm wavelength range using a Perkin-Elmer LS55 PL spectrometer with an error below 0.5 nm. A source of excitation was light with the wavelength λ = 315 nm. WMF treatment (B = 60 mT) was chosen for our experiments, with duration of processing 1 (sample 1), 3 (sample 2) and 8 min (sample 3). The initial sample (i.e., not subjected to WMF treatment) served as the reference one.

3. Results and discussions

Fig. 1 shows evolution of PL spectra of these structures after treatment in WMF for 1, 3 and 8 min, respectively. It can be seen that the initial spectra of semiconductor material contain the narrow band in the short-wave region at 363.6 nm, which is associated with interband transitions of free charge carriers (~3.417 eV), and the wide, so-called yellow impurity band in the long-wave region near 550 nm. With regard to the nature of the latter band, the data in the literature differ. Some authors attribute the nature of this wide band to interference [4] associated with purely geometric effect of spreading the beams in a studied structure. However, in our view, it is advisable to relate with certain radiative transitions involving impurity centers to the energy levels located closely to each other in the forbidden band, as in the work [5].

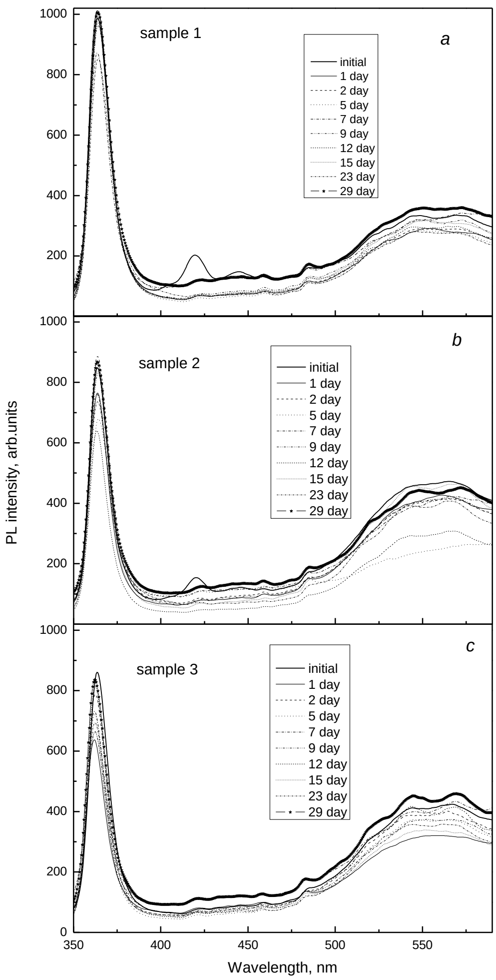

Fig. 1. Evolution of PL spectra of GaN:Si caused by WMF treatment for 1 (*a*), 3 (*b*) and 8 min (*c*), respectively.

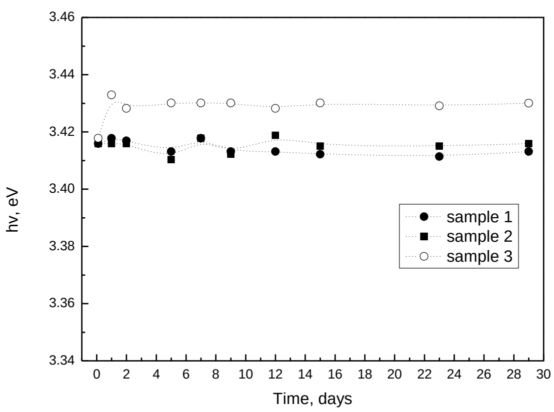

Fig. 2. Frequency positions of the edge peak as a function of time passing after the WMF treatment.

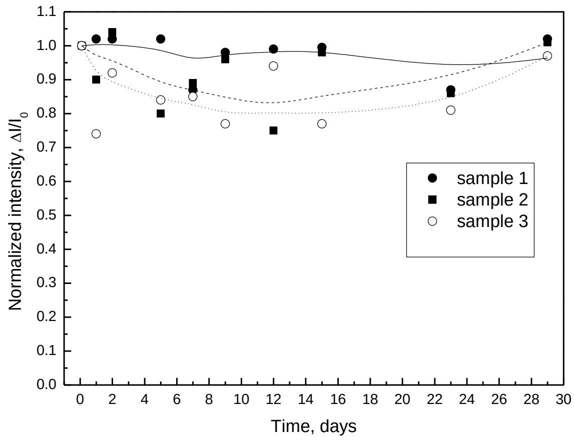

Fig. 3. Variations of edge peak intensity as a function of time passing after the WMF treatment.

Since the nature of the wide long-wave band is not completely clear, we analyzed only the peak of edge PL. WMF treatment of the samples has led to the PL spectra transformation manifested in the change of intensity of the bands, which was observed in the experiment, and in the case of the longest treatment, in addition, the frequency shift of the edge peak to the short-wave region. Figs. 2 and 3 show the dependences of frequency position and normalized intensity of the peak at 363.6 nm on the time elapsed after the WMF treatment. It is seen that the nonmonotonic change in the peak intensity for all the modes of treatment lasts for about 30 days and eventually becomes close to the reference value. In this case, the “amplitudes” of deviations from the original intensity as a whole increase with increasing duration of treatment and suggest a temporary weakening of radiative recombination. That is, the maximum mean-square deviations of the edge PL intensity from the initial value are ~5%, ~15%, ~22% for the WMF-treated samples for 1, 3 and 8 min (Fig. 3), respectively. Regarding the frequency position of edge PL peaks, the following feature was revealed. For samples subjected to the treatment for 1 and 3 min, the frequency change of the studied peak did not exceed the experimental error. However, for the sample after the longest treatment (8 min), irreversible shift of the band-to-band peak by ~12.5 meV was found.

It should be noted that the magneto-induced shift of the spectral curves related with interband transitions were previously observed when studying the optical transmission spectra for $Hg_{1-x}Cd_xTe$ [6], the reflectance spectra of epitaxial structures based on GaAs [7]. The physical nature of this phenomenon is not fully clarified. The authors of [6] associate this effect with the appearance of additional force of pressure on the film from the side of substrate, resulting in a change in the lattice parameter, which in turn leads to the transformation of the spectral curves. However, in [8] it was recorded the magneto-induced change of interatomic distance in classical semiconductors without substrates, however it had the temporary character. One can assume that the presence of the substrate leads to a significant prolongation of duration of magneto-induced change in the lattice parameter. The authors of the work [8] associated the temporary (600…700 s) change of inter-atomic distance with the magnetic stimulated generation of clusters of the Frenkel defects with an abnormally low energy of formation. It is probable that in our experi-ments a similar effect takes place. Although, it is re-corded without using the spectra of optical transmission or reflection, as in [6, 7], but with the photolumi-nescence technique. It is known that the peak position of edge radiation of semiconductors essentially depends on the availability of internal mechanical stresses in the studied system [9, 10]. Therefore, it is evident that WMF treatment changed the state of mechanical stresses in the inves-tigated near-surface layer of GaN. Effects related to phenomena of this type are known [11].

Possible physical mechanisms of interaction of WMF with solids that were analyzed in [12-15], they is quite reasonable to interpret the experimental results, in particular the model of spin-selective nanoreactor [15] is the most attractive in this case, since changes in the values of internal mechanical stresses have obviously to reflect on changing the microhardness of material under study. One can assume that WMF induced decomposition of metastable impurity-defect complexes leads to rapidly diffusing point defects. The latter move to the natural drains (for example, surface of semiconductor) and may take place in modification of the impurity-defect state, changing the state of internal mechanical stresses, which are reflected in the PL spectra.

4. Conclusions

Thus, it has been investigated transformation of PL spectra of the structures GaN:Si with time as a consequence of WMF treatment. Evolution processes of migration of decomposition products of metastable defect complexes existing at the interface film-substrate leads to restructuring in the near-surface region of gallium nitride. The latter, in its turn, reflect on trans-formation of the PL spectra. Realignment of the impurity “yellow” band of radiative recombination due to the influence of WMF as well as ascertainment of the detailed and sequential picture of the energy interaction of WMF with semiconductor material require further studying the phenomena of this type.

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