A.E. BELYAEV,[1] N.I. KLYUI,[1] R.V. KONAKOVA,[1] A.M. LUK'YANOV,[1]
YU.M. SVESHNIKOV,[2] A.M. KLYUI[3]

[1] V.E. Lashkaryov Institute of Semiconductor Physics, Nat. Acad. of Sci. of Ukraine
(41, Prosp. Nauky, Kyiv 03028, Ukraine; e-mail: klyui@isp.kiev.ua)
[2] Close Corporation "Elma-Malakhit"
(Zelenograd, Russia)
[3] Taras Shevchenko National University of Kyiv
(2, Prosp. Academician Glushkov, Kyiv 03022, Ukraine)

PACS 78.66.Hf

OPTICAL PROPERTIES OF IRRADIATED EPITAXIAL GaN FILMS

The influence of a microwave treatment (MWT) on the optical properties of hexagonal GaN films has been studied. To estimate the internal mechanical strains and the degree of structural perfection in a thin near-surface layer of the film, the electroreflectance (ER) method is used. The ER spectra are measured in the interval of the first direct interband transitions. It has been shown that the MWT results in the relaxation of internal mechanical strains in the irradiated films. In addition, the structural perfection in the thin near-surface layer of the irradiated film became higher. A mechanism that includes resonance effects and the local heating of the film defect regions is proposed to explain the effects observed.

Keywords: gallium nitride, epitaxial film, electroreflectance, microwave treatment, broadening parameter, internal strain.

1. Introduction

Epitaxial films on the basis of $A^{III}B^{V}$ compounds – in particular, III-nitrides (GaN, AlN, BN) – are intensively used in modern micro-, nano-, and optoelectronics to manufacture a wide class of devices [1–3]. Gallium nitride films are applied most successfully in the production of light and laser diodes for the short-wave spectral range [1], as well as in RF and high-temperature devices [2, 3]. In all cases, an integral part of the technological process is the application of different treatments to either the films themselves or the devices in whole. It is evident that the research of the treatments effect on the film properties is an important and challenging task, because knowlenge of the mechanisms of film property modification allows the parameters of the film-based devices to be predicted.

Among the active treatments of GaN films, most widely used are the thermal annealings (short- and long-term) [4, 5], plasma, chemical, and photochemical treatments [6–8]. The influence of penetrating radiation, e.g., γ-radiation, is most often regarded not as a component of the fabrication technology, but rather as a possible factor of their degradation. On the other hand, as was shown in works [9, 10], γ-irradiation can improve the properties of epitaxial GaN films and the structures on their basis.

The microwave treatment (MWT) is successfully applied to improve the quality of GaN contacts [11] and to carry out the high-temperature activation of an acceptor impurity (e.g., Mg) in GaN, which was introduced either in the course of growing [12] or at the subsequent ion implantation [13]. In the opinion of the author of work [14], MWT is the only method that allows high-temperature treatments to be realized at extremely high rates of temperature growth and decrease. However, this way is impossible if the usual rapid thermal annealing is applied. In the latter case, MWT equipments based on powerful gyrotrons are used, which allows high densities of radiation power to be obtained [14]. At the same time, it was demonstrated earlier that the low-power MWT can also substantially affect the properties of silicon [15] and $A^{III}B^{V}$ films, as well as instrument structures on their basis [16, 17]. Therefore, this work aimed at studying the influence of the low-power MWT on the optical properties of a thin near-surface layer in epitaxial GaN films.

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2. Experimental Part

In our studies, we used GaN films with the n-type conductivity, which were doped with silicon to concentrations of about $(1 \div 3) \times 10^{17}$ cm^{-3}. The films were deposited onto the (001) surface of Al_2O_3 substrates using the metallorganic chemical vapor deposition (MOCVD) technique. The thickness of the films was 1 μm.

For MWT, we used UHF radiation with a frequency of 2.45 GHz. A magnetron with a specific output power of 1.5 W/cm^2 served as a radiation source. MWT of the films was carried out in the working chamber of a magnetron in the air environment. The MWT cycles were carried out stage-by-stage with a gradual increase of the irradiation time. The total time of MWT was equal to 5, 10, 20, and 30 s.

The electroreflection (ER) spectra were measured after every radiation cycle. The measurements were carried out in the wavelength range 350–380 nm (3.3–3.45 eV) and with a resolution of ±0.001 eV. The ER spectra were measured on an automated setup based on a diffraction spectrometer MDR-23. An ohmic contact with the GaN film was provided by sputtering a titanium film 100 nm in thickness followed by its annealing at a temperature of 700 °C and, then, sputtering a gold film with thickness 100 nm. As a front contact, the KCl solution in distilled water was used. An electric field was applied to the specimen in the electrolytic cell with a platinum reference electrode. In hexagonal GaN, there is the spin-orbit splitting of the valence band near the absorption edge at point Γ of the Brillouin zone [9, 18, 19]. Therefore, the ER signal is formed by three main interband transitions usually designated as A, B, and C. For the interpretation of spectra, we used the model of ER with three direct transitions. The parameters of ER spectra were determined by fitting the theoretical results to the experimental data. This is a usual practice for the interpretation of experimental results obtained by the modulation spectroscopy method [9, 18, 19].

3. Results and Their Discussion

It should be noted that, according to the results presented in work [20] and taking the conductivity of studied films into account, the penetration depth of the microwave electromagnetic field exceeds the film thickness by several orders of magnitude. Therefore, the power distribution across the film can be regarded as uniform. A low temperature of a specimen during MWT can also be taken as an important factor associated with the chosen MWT regimes.

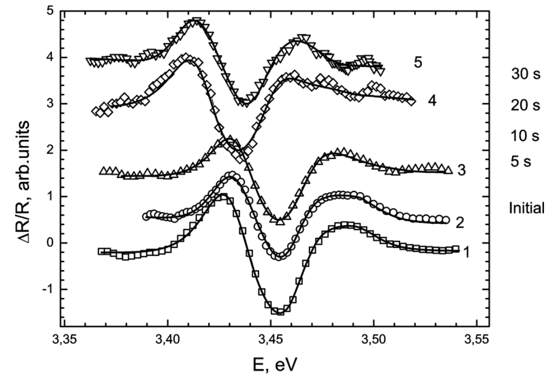

Fig. 1. ER spectra of GaN films before and after the microwave treatment. Symbols denote experimental data, and the curve exhibit the results of theoretical fitting: initial specimen (*1*) and after microwave irradiation for 5 (*2*), 10 (*3*), 20 (*4*), and 30 s (*5*)

The ER spectra of a GaN film before and after MWT are depicted in Fig. 1. The symbols correspond to experimental data, and the solid curves to the results of theoretical simulation (fitting). From Fig. 1, one can see that no substantial changes are observed in the ER spectra at short MWT times; only insignificant shifts of the peaks toward the short-wave region of the spectrum take place (spectra *2* and *3*). At the same time, the increase of the treatment time to 20 and 30 s results in appreciable shifts of the ER spectrum toward lower energies (spectra *4* and *5*).

These conclusions are directly confirmed by the energy dependences of excitonic transitions A, B, and C obtained while fitting the theoretical spectra to experimental ones (Fig. 2). One can see that, for MWT times of 5 and 10 s, the transition energies insignificantly grow, whereas the further increase of the MWT time brings about a reduction of the transition energies to values that are considerably lower than the initial ones. As was shown in work [9] on the basis of results obtained for a freestanding GaN film [18], there are the squeezing stresses in the initial films. Hence, at the first MWT stages, those stresses increase a little and, then, relax. A certain growth of the internal mechanical stresses at short MWT times may be associated with the generation of additional structural defects owing to the resonance interaction between the UHF electromagnetic field and the de-

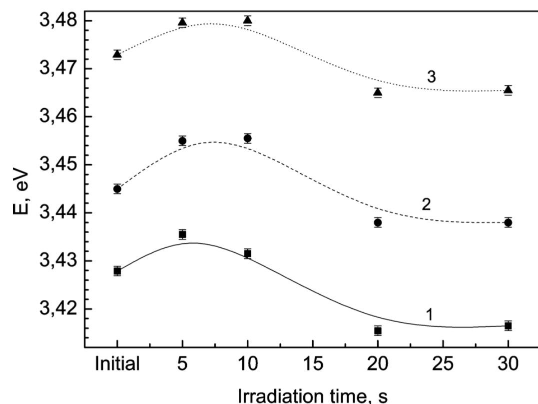

Fig. 2. Dependences of the direct transition energies on the microwave treatment time. Curves *1* to *3* correspond to interband transitions A, B, and C, respectively

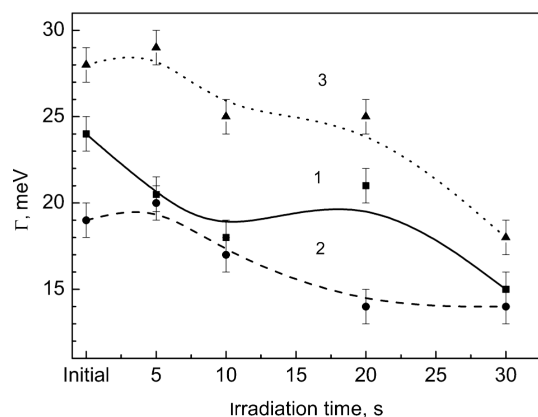

Fig. 3. The same as in Fig. 2, but for the band-broadening parameter

fect subsystem of the film, analogously to what was observed in works [16, 17].

The increase of the MWT time gives rise to the warming up and the resonance activation of local defect regions, when the MWT frequency coincides with the characteristic frequencies of defect vibrations [16, 17]. Owing to a considerable mismatch between the lattice constants in the film and the substrate [21], there exists a gradient of mechanical stresses in the system. As a result, the gettering of structural defects can take place at the film–substrate interface. At a substantial stress relaxation degree, this effect should disappear, which is also observed in the experiment. The described mechanism is confirmed by the dependences of the band-broadening parameter Γ for the corresponding bands in the ER spectrum (Fig. 3). Note that the parameter Γ is directly related to the degree of structural perfection in the film. The energy relaxation time for light-excited charge carriers, τ, (and, hence, their mobility) is related to the band-broadening parameter as follows: $\tau \sim h/\Gamma$, where h is Planck's constant [9]. Therefore, the reduction of the transition band-broadening, which is observed at long MWT times, confirms the mechanism proposed above. The effects observed cannot be explained by purely thermal processes. As was already mentioned above, the selected parameters of MWT prevent the specimens from a considerable warming up, whereas rather high temperatures are required for a rapid thermal annealing of defects in GaN films to take place [5].

4. Conclusions

To summarize, a conclusion can be drawn that MWT, even the low-power one, is a promising method for the improvement of the properties of epitaxial GaN films, in particular, for a reduction of the mechanical stresses in them and an enhancement of the structural perfection in the near-surface layer of a film. The latter factor is especially important for the technology of device production on the basis of III-nitrides. It is so because the GaN film is often used as a substrate for the following epitaxial deposition of other films, so that the properties of the surface and the near-surface region in GaN substantially govern the characteristics of the instrument structure in general [1–3, 21].

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Received 14.03.13.
Translated from Ukrainian by O.I. Voitenko

А.Є. Беляєв, М.І. Клюй, Р.В. Конакова,
А.М. Лук'янов, Ю.М. Свешніков, А.М. Клюй

ОПТИЧНІ ВЛАСТИВОСТІ ЕПІТАКСІЙНИХ ПЛІВОК GaN, ЩО ПЕРЕБУВАЛИ ПІД ДІЄЮ МІКРОХВИЛЬОВОГО ОПРОМІНЕННЯ

Р е з ю м е

Досліджено вплив мікрохвильових обробок (МХО) на оптичні властивості епітаксійних плівок GaN гексагональної модифікації. Для діагностики рівня внутрішніх механічних напружень і структурної досконалості тонкого приповерхневого шару плівки використовувався метод електровідбивання (ЕВ). Спектри ЕВ вимірювалися в області локалізації перших прямих зона-зонних переходів. Показано, що внаслідок МХО в опромінених плівках спостерігається релаксація внутрішніх механічних напружень і поліпшення структурної досконалості приповерхневого шару. Запропоновано механізм виявлених ефектів, що враховує резонансні ефекти і локальний розігрів дефектних областей плівки.