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EBIC and CL studies of ELOG GaN films

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ABSTRACT

Results demonstrating the ability of EBIC and CL methods for ELOG GaN films characterization are presented. It is shown that EBIC measurements allow us to estimate not only the lateral distribution of diffusion length but also the donor distribution in such films. Donor concentration is found to be different in slit and wing regions. A difference in CL and EBIC images is revealed, which is explained by band bending near the boundaries where two overgrowing fronts meet.

1. Introduction

Due to a lack of a suitable lattice matched substrate GaN epitaxial layers usually contain dislocation densities in the order of 10^9 cm^{-2} [1]. Dislocations in such high densities adversely affect the operation time of injection lasers and have to be reduced. Epitaxial lateral overgrowth (ELOG) technique [2,3] is one of approaches allowing such reduction. In this method a GaN template is grown by standard metallorganic chemical vapor deposition (MOCVD). Then a mask of SiO_2 stripes is prepared by photolithography and finally a thick GaN layer is grown by MOCVD over the masked surface. The material above the mask grows predominantly in the lateral direction and has the dislocation density from two to three orders of magnitude lower than that in the material grown in the windows of SiO_2 mask, for which the dislocation density is the same as for standard MOCVD layers. Densities of extended and point defects in the regions above the mask and above the slit differ

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significantly, therefore the difference in the electrical properties of these regions could be expected. The scanning electron microscopy in the Cathodoluminescence (CL) and/or Electron Beam Induced Current (EBIC) modes is one of a few methods suitable for the characterization of such structures with a spatial variation of electrical properties in the micron range. It was shown [4–6] that indeed the inhomogeneous distribution of extended defects leads to inhomogeneous distribution of excess carrier recombination rate and of donor concentration. Moreover, it was observed [5] that after neutron irradiation, the radiation defect distribution was strongly inhomogeneous with a reduced defect concentration near coalescence boundaries.

In this paper the results of CL and EBIC investigations of such inhomogeneous objects are analyzed. The difference in the CL and EBIC images of ELOG structures is revealed and discussed.

2. Experimental

The samples studied in this paper were grown on basal plane sapphire substrates. First, 2 μm-thick n-GaN templates were grown by standard MOCVD. Then a mask consisting of SiO_2 stripes with a 12 μm width and a 4 μm slits between the stripes was prepared by photolithography. Finally, (6–12 μm)-thick n-GaN layers were deposited by ELOG MOCVD. The ELOG layers studied were either undoped or Si doped. Si doping was achieved via adding SiH_4 to the reagents flowing into the reactor and was varied from 10^{15} to 10^{17} cm^{-3}. The same silane flows were used for growth of MOCVD GaN templates and the ELOG layers. The direction of the SiO_2 stripes was $[1\bar{1}00]$ so that the lateral growth from the two opposite ends of the stripe occurred in the directions $[11\bar{2}0]$ and $[\bar{1}\bar{1}20]$. The grown films were characterized by the EBIC and CL. The EBIC and CL studies were carried out in the JSM-840 and JSM-6490 scanning electron microscopes, respectively. For the EBIC measurements rectangular Au Schottky diodes with an area 0.75×0.75 mm^2 were prepared by vacuum evaporation through a shadow mask, ohmic contacts were made by indium.

The diffusion length and doping concentration (depletion region width W) was obtained by fitting the collected current I_c dependence on beam energy E_b [7,8]. The EBIC images inside the slit and wing regions were inhomogeneous. Therefore to obtain the reliable $I_c(E_b)$ dependence for any region the EBIC images of the same regions were obtained at different E_b. Then the signal profiles in the direction perpendicular to slits in the mask averaged over the band with a thickness of about 20 μm were obtained for any energy used. Then the collection efficiency dependencies $\eta(E_b)$ in the corresponding regions were calculated from these profiles as $\eta(E_b) = \frac{I_c(E_b)E_i}{I_b E_b \chi}$, where I_b is the e-beam current, χ is the beam energy absorption coefficient, E_i is the average energy necessary for electron–hole pair creation (for GaN χ/E_i is equal to 8×10^{-2} [9]).

To fit the experimental dependencies, the collection efficiency was calculated as

$$\eta(E_b) = e\int_{t_m}^{\infty} h(z, E_b)\psi(z)\mathrm{d}z \tag{1}$$

where t_m is the metal thickness, $h(z, E_b)$ is the normalized depth-dose dependence and $\psi(z)$ is the collection probability [10], which was obtained by a solution of homogeneous diffusion equation outside the depletion region and of homogeneous drift-diffusion equation inside it. As shown in [9] $h(z)$ for GaN could be approximated as

$$h(z) = \frac{3.207}{R_{\mathrm{Beth}}} \exp\left[-A\left(\frac{z}{R_{\mathrm{Beth}}} - 0.11\right)^2\right] \tag{2}$$

where $R_{\mathrm{Beth}}(\mu\mathrm{m}) = 0.0132 \cdot E_b(\mathrm{keV})^{1.75}$ and $A = \begin{cases} 42.8, z < 0.11 \cdot R_{\mathrm{Beth}} \\ 16.5, z \geq 0.11 \cdot R_{\mathrm{Beth}} \end{cases}$.

3. Results and discussion

Typical CL and EBIC images of ELOG structure are presented in Fig. 1. It is seen that in both images a decrease of signals in the regions above the slit and at the boundaries where two overgrowing fronts