Reactive ion-beam etching of GaN epitaxial layers using O_2 + Ar gas mixture

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Dry etching techniques of GaN are necessary to obtain vertical and smooth sidewall profiles for optoelectronic device applications. A number of methods have been employed to solve this problem, including chemically assisted ion-beam etching, reactive ion etching and reactive ion-beam etching (RIBE). These methods usually use aggressive halogen-based gases. Etch rates from 10 to 10^3 nm/min were reported. However, there are a few studies of the etch-induced degradation of the optical properties of the etched surfaces [1,2]. A RIBE process of the GaN epitaxial layers using Ar+O_2 and the influence of the etching on luminescence of the GaN layers were investigated in this work. A uniform ion beam was extracted from an ion source with a cold hollow cathode [3]. The ion beam current density J was varied from 0,1 to 0,3 mA/cm^2, the ion beam energy E was varied from 0.1 keV to 1 keV, and the O_2 species concentration was varied from 0% to 100 %. The GaN layers used were nominally undoped 3-µm-thick epitaxial layers with good surface morphology grown in AIXTRON MOVPE reactors using TEGa/TMGa and NH_3 and a V/III-ratio of 1000 at 1180-1240°C. A GaN buffer layer was deposited at 560°C prior to growth. The substrate temperature during etching was about 50°C. Vacuum conditions of 0,4 mTorr working pressure at 5 sccm gas flow rate were employed. Photoluminescence experiments were performed at room temperature using N_2-laser radiation (hν=3.68 eV, t = 8 ns, I_{exc} = 3*10^5 W/cm^2) for excitation. The etching rate of GaN is plotted in Fig.1 as a function of working gas composition. The etching rate was varied from 1.5 nm/min to 12 nm/min depending on the E, J and oxygen concentration. The etching rate was reproducible and highly uniform across the sample surface. Fig 2 shows a scanning electron micrograph of the GaN surface etched using Ar+ 10% O_2 as working gas at the ion beam energy E=1 keV and under the beam current density of J=0,15 mA/cm^2 for 100 min. Anisotropy sidewall and good surface morphology of the etched region can be seen clearly. The surface roughness of the as grown sample decreases on the in-plane etched surface and the surface morphology does not change. A relatively large roughness on the vertical sidewalls is attributed to the mask edge profile. The photoluminescence spectra of the as grown and GaN layers etched under different conditions are shown in Fig 3. The spectral shape of the etched samples are similar to the spectral shape of the as grown samples but their PL intensity was lower after etching. The ratio of the PL intensity of the etched to the as grown samples is shown in Fig. 4 as a function of the ion beam energy for different etching duration (10 - 90 min). The PL intensity after etching decreases with an increase of the ion-beam energy owing to defect creation in the near surface layer. The PL intensity increases with an increase of the etching time. The sputtering range ion method (SRIM-99) was used for simulation of the surface damage layer formation. It was shown that the depth profile of the etch-induced defects does not exceed of 10 nm. The depth of the damaged layer decreases with the ion energy decrease independently of the working gas composition. The use of the Ar+ 5% O_2 working gas provides higher etching rates than the pure O_2. The last one should be used as a post-etching stage for PL efficiency recovery (Fig.3, curve 2). The PL spectra at cryogenic temperatures were investigated to clarify the defect nature in the near surface etched layer. The RIBE based on the Ar+O_2 gas mixture allows to avoid of organic impurities on the layer surface and to refuse the galogen-based gases. The work was partly supported by the ISTC project B-176.

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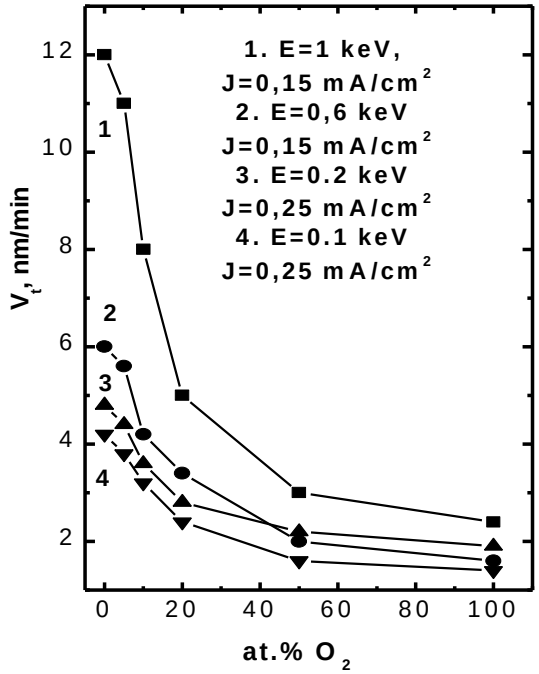

Fig. 1. Etching rate as a function of working gas composition at different ion energies and current densities.

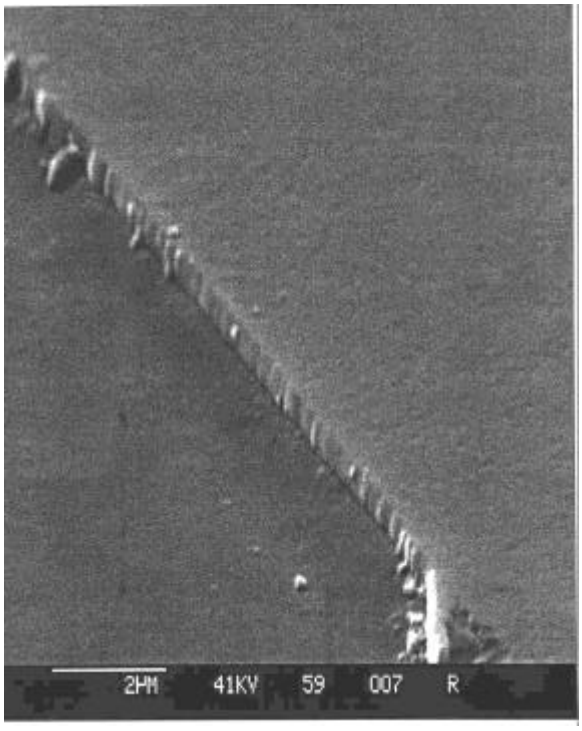

Fig. 2. Scanning electron micrograph of GaN as grown (right) and 100 min etched (left) surface using Ar+10% O_2 as working gas at E=1 keV and J=0.15 mA/cm^2.

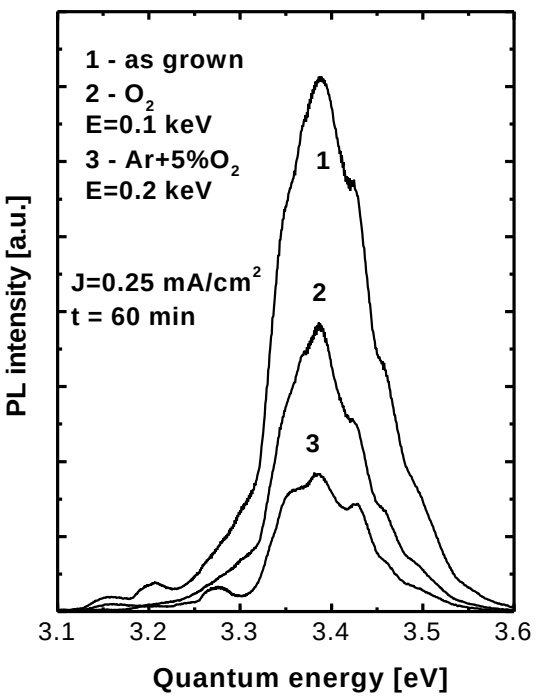

Fig. 3. Photoluminescence spectra of as grown (1) and etched at different conditions (2,3) GaN.

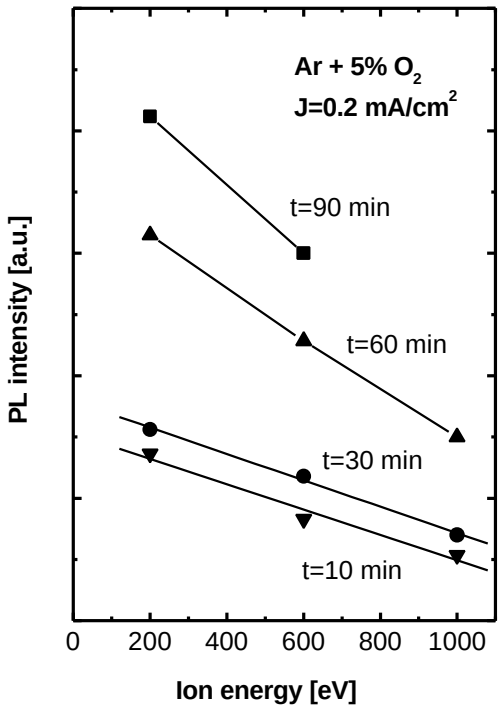

Fig. 4. Ratio of the PL intensity of the etched to the as grown samples as a function of ion beam energy for different etching time.