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Growth and characteristics of GaN_xP_{1-x} alloys by magnetron reactive sputtering on GaN

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Abstract

The growth and characteristics of GaN_xP_{1-x} alloys produced using magnetron reactive sputtering on GaN were studied. These GaNP alloys exhibit a mirror-like surface morphology and a flat interface without inclusions. An emission peak in the photoluminescence (PL) was observed in each GaNP alloy spectrum at temperatures between 20 and 120 K. The emission peak for the 20 K PL spectrum was at 714 nm (1.737 eV) with a full-width at half-maximum (FWHM) 28.1 meV. The peak shifted to 719 nm (1.725 eV) as the temperature moved toward 120 K.

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1. Introduction

Recently, GaN_xP_{1-x} alloy systems, with their large miscibility gaps from a two-crystal structure (GaP:zincblende, GaN:wurtzite), have been extensively investigated. Most of these alloys were grown using molecular beam epitaxy (MBE), [1] gas source MBE (GSMBE), [2–4] metalorganic chemical vapor deposition (MOCVD), [5] and laser-assisted metalorganic chemical vapor deposition (LA-MOCVD), [6] because these epitaxial growth techniques yield GaN_xP_{1-x} alloys with high nitrogen concentrations. In this study, a uniform GaNP alloy was fabricated with high nitrogen content on a GaN buffer layer or C-face (0 0 0 1) sapphire substrate.

The photoluminescence (PL) spectrum dependence of GaN_xP_{1-x} alloys on the nitrogen content

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was examined. The luminescence peak becomes broader and shifts to lower energies as the nitrogen content is increased. Many authors have revealed the same results experimentally and theoretically [1,7,8]. These results are considered to originate from the isoelectronic traps associated with the nitrogen atom isotation in GaP [9]. This article reports on the characteristics of GaNP films grown using magnetron reactive sputtering deposition using a GaP target.

2. Experiments

All samples used in this work were deposited using RF magnetron sputtering and a 2-in GaP target, in 99.995% pure mixture of nitrogen and argon. The sapphire substrates and GaP targets were cleaned with HCl and $HCl:HNO_3 = 3:1$ for 10 and 1 min, respectively. Both the substrate and target were then rinsed in deionized water. The GaN buffer layer was prepared on sapphire substrates using MOCVD before the GaNP alloys were deposited. High-purity Ar gas was introduced into the chamber after the chamber was evacuated to below 5×10^{-6} Torr. The GaP target was then pre-sputtered for 5 min with the shutter closed. The nitrogen gas was introduced into the chamber and the reactive sputtering was initiated. Table 1 presents the typical deposition conditions. During deposition, only the nitrogen flow rate was monitored; all the other parameters were kept constant.

A JEOL JSM-5600 scanning electron microscope (SEM) and a transmission electron microscope (TEM) were used to study the surface morphology and obtain a cross-sectional micrograph of the GaN_xP_{1-x} alloys. The X-ray $\theta-2\theta$ diffraction pattern was obtained using a Rigacu X-ray diffractometer with CuKα radiation, to determine the nitrogen content, assuming Vegard's law. Furthermore, all samples were characterized using a JEOL JXA-8800 M electron probe X-ray microanalyzer (EPMA) to accurately determine the nitrogen and phosphorous GaN_xP_{1-x} alloy content. PL was measured at temperatures from 20 to 120 K. A He–Cd laser (325 nm) was used as the excitation source for taking the PL measurements.

Table 1
Deposition conditions

Substrate	GaN buffer/(0 0 0 1) sapphire
Substrate temperature	500 °C
Substrate-to-target distance	8 cm
RF power	60 W
Targets	GaP
Gas ($Ar + N_2$ mixtures)	20–80% N_2
Residual pressure	$< 5 \times 10^{-6}$ Torr
Sputtering pressure	5 m Torr
Deposition time	60 min

3. Results and discussion

Fig. 1 shows the surface morphology and cross section of the GaN_xP_{1-x} alloys deposited with various nitrogen flow rates between 10 and 40 sccm, at a constant substrate temperature of 500 °C and an RF power of 60 W. As shown in Fig. 1(a), the mirror-like surface morphology was obtained under all deposition conditions. Additionally, a flat interface without any inclusion was observed between GaN_xP_{1-x} and the GaN buffer layers, as shown in Fig. 1(b). Fig. 2 shows the $\theta-2\theta$ patterns for a wide range of diffraction angles. This pattern was obtained from the GaN-rich side of GaNP under the deposition conditions depicted above. No peaks associated with cubic GaP were observed, indicating that no phase separation occurred in the GaNP alloy formation. Fig. 3 shows the XRD rocking curve at the GaN (0 0 0 2) angle from the GaNP layer. Two peaks are observed at the 2θ angles of 34.56° and 33.35°. The former peak is considered associated with the GaN buffer layer and the latter from the GaNP alloy layer. The XRD and EPMA analysis results indicate that the nitrogen content, x, in the GaN_xP_{1-x} was 68.75% and 65.59%, respectively. This is the highest nitrogen content ever reported in a GaN_xP_{1-x} alloy [1–6,10,11]. However, the nitrogen content was almost the same in all samples deposited under varying nitrogen flow rates between 10 and 40 sccm. The nitrogen flow rate played no significant role in the growth of GaN_xP_{1-x} in this study. The peak intensity increased with the nitrogen content. The improved