

The growth of highly doped p-GaN on sapphire by RF plasma-assisted molecular beam epitaxy

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Abstract

In this paper, we present the study of the electrical, structural and optical properties of p-type GaN grown on sapphire by RF plasma-assisted molecular beam epitaxy (RF-MBE). Hall effect measurement shows that the film was highly doped with carrier concentration of $6.58 \times 10^{18} \text{cm}^{-3}$. X-ray diffraction (XRD) measurement reveals that the GaN was epitaxially grown on sapphire substrate. For the photoluminescence (PL) measurement, a sharp and intense peak at 363.8 nm indicates that the sample is of high optical quality. The presence of the peak at 658.4 cm^{-1} in Raman measurement confirmed that our p-type GaN sample was highly doped with Mg.

1. Introduction

III-V nitride semiconductors have received much attention for use in optoelectronic devices such as light emitting diodes (LEDs). Most of the research groups working on GaN based material have concentrated on the metalorganic chemical vapor deposition (MOCVD) growth technique. However, the turn on voltage of MOCVD grown laser diode is 28V due to high contact resistance of p-GaN layer [1]. The main advantages of molecular beam epitaxy (MBE) over MOCVD for GaN growth are precise control thickness and composition, low temperature growth and high p-type doping concentration [2]. However, slow growth rate of MBE is the main disadvantage compared with other growth techniques.

The case of p-type doping is much more complicated than that of n-type doping. Achieving a high hole concentration with Mg as the dopant is still not an easy task. Neugebauer and Van de Walle [3] commented that the determining factor is the solubility of Mg in GaN, which is limited by competition between incorporation of Mg atoms and formation of Mg_3N_2 . However, it is possible to obtain a high quality GaN with a specular surface, a low residual carrier concentration and a high carrier mobility if the nucleation layers are used to overcome the large mismatch between GaN and sapphire [4].

In this work, a study of the structural, electrical and optical characteristics of these epitaxial p-type GaN thin films were carried out using Hall effect measurement, high resolution X-ray diffraction (XRD), photoluminescence (PL) and Raman spectroscopy.

2. Experimental Method

The growth was carried out in a RF plasma-assisted molecular beam epitaxy (RF-MBE) system. The active nitrogen was supplied by RF plasma source while conventional effusion cells were used for Ga and Mg. The nitrogen flux was adjusted by varying the RF power input to the plasma. The substrate temperature was measured with a pyrometer. The c plane sapphire wafer was used as substrate. The sapphire wafer was metallized on the back surface in the interest of radiative heating and reliable temperature measurement. Prior to the growth, sapphire substrate was subjected to temperature at 930°C in the growth chamber for outgassing followed by nitridation by using nitrogen plasma source for 45 min at 200°C . This process results in the formation of a relaxed AlN thin buffer layer [5]. The thin AlN buffer layer may act as a substrate fixing the polarity of the subsequent deposition of GaN layers [6]. Before p-type GaN deposition, a thin AlN buffer layer is grown at substrate temperature of 743°C . Subsequently, GaN layer was grown at substrate temperature of 761°C , followed by *in situ* doping using Mg. The growth was monitored by RHEED which displayed a streaky pattern characteristic of two-dimensional surface.

Scanning electron microscopy (SEM) was used to observe the cross section of the sample. The Van der Pauw method was used for room temperature Hall effect measurements. Indium ball was used to fabricate ohmic contacts for electrical measurements. The structural and optical properties of the grown layers were examined by using high-resolution X-ray diffraction, photoluminescence (PL) and Raman scattering. PL measurements were performed at room temperature by using Jobin Yvon HR800UV system with He-Cd laser 325nm as excitation source while Raman scattering experiments were carried out at room temperature by using Jobin Yvon LabRam HR system with air-cooled Argon laser 514.5nm source operating at 10mW.

3. Results and Discussion

Fig. 1 shows the SEM cross section of the p-type GaN. As seen in the figure, the AlN buffer layer and p-type GaN layer are clearly seen. Result from Hall effect measurement shows that we obtained a p-type carrier concentration of GaN as high as $6.59 \times 10^{18} \text{cm}^{-3}$. This is about two orders of magnitude higher than the typical reported values. From the literature, the common

hole carrier concentrations are mostly found in the range of $1 \times 10^{16} \text{ cm}^{-3}$ - $2 \times 10^{17} \text{ cm}^{-3}$ [7].

Fig. 2 shows the 2θ XRD spectra of the sample. The XRD measurement shows that the heterostructure of III-nitrides were epitaxially grown on sapphire. It can be seen from the presence of the peak at 34.521° which is identified as wurtzite GaN (002) diffraction, and three peaks at 35.998° , 72.844° and 76.351° , which correspond to AlN (002), GaN (006) and AlN (004) respectively. The peak at 41.670° is from the sapphire substrate (006). The position and relative intensity of the peaks are clearly compiled in Table 1. The XRD spectra indicate that no sign of cubic phase GaN are found within the detection limit of the XRD, so it is confirmed that our samples possessed hexagonal structure.

Fig. 3 shows a PL spectrum measured for the p-GaN sample. As reported by F.A. Ponce [8], the intensity of the near band-edge PL emission of GaN is indicative of its high optical quality. From this figure, the sample exhibits the intense and sharp peak at 362.2 nm, which is attributed to the band edge emission of GaN, indicating that the grown p-GaN thin films are of high optical quality. There are also two weak broad bands at 369.5, 391.4 nm, which could be related to the shallow donor-acceptor pair (DAP) transitions. The increase of the Mg atomic concentration will lead to

deepening of the donor-acceptor pair (DAP) transitions (3.17eV) [6].

Raman spectroscopy has been used to investigate the low-wavelength phonons in GaN in order to obtain information on the crystalline quality of the layers. The crystalline structure of wurtzite-type GaN is described by the space group C_{6v}^4 , with two formula units per primitive cell. The broad band micro-Raman spectra of the p-GaN are shown in Fig. 4. The sample show a peak at 147.1 cm^{-1} , which corresponds to $E_2(\text{low})$ mode of GaN. Peaks at 568.4 cm^{-1} and 736.5 cm^{-1} are probably due to $E_2(\text{high})$ and $A_1(\text{LO})$ modes respectively. The presence of a LO mode in the spectrum indicates a high crystalline quality of the sample [10]. Furthermore, the result confirmed that our sample has a high carrier concentration. This can be seen from the presence of the peak at 658.4 cm^{-1} . The $\sim 657 \text{ cm}^{-1}$ peak is assigned to the local vibrational mode (LVM) for the Mg-N bond because the mode intensity is almost proportional to the hole density and the frequency agrees with an estimate from the optical mode frequency of GaN ($\sim 560 \text{ cm}^{-1}$), obtained by considering the difference in reduced mass between the Mg-N and Ga-N pairs [11]. It is found that our sample have native p-type character [12] so it is not surprising that the $\sim 657 \text{ cm}^{-1}$ peak was observed in our sample.

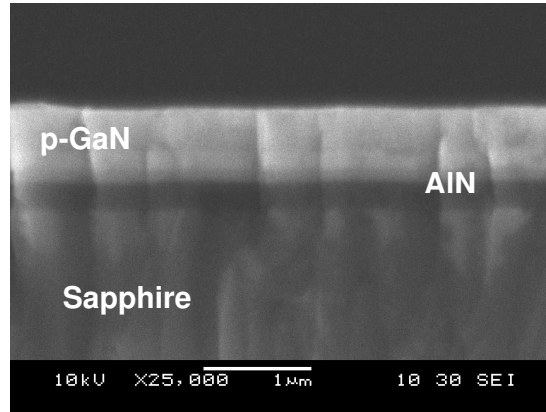


Fig.1 SEM cross section of p-type GaN.

Table 1. The 2θ XRD spectra of different crystal planes and their relative intensity

2θ peak position ($^\circ$)	Crystal Plane	Rel. Intensity (%)
34.521	GaN (002)	100.00
35.998	AlN (002)	7.09
41.670	Sapphire (006)	23.12
72.844	GaN (004)	3.13
76.351	AlN (004)	0.16

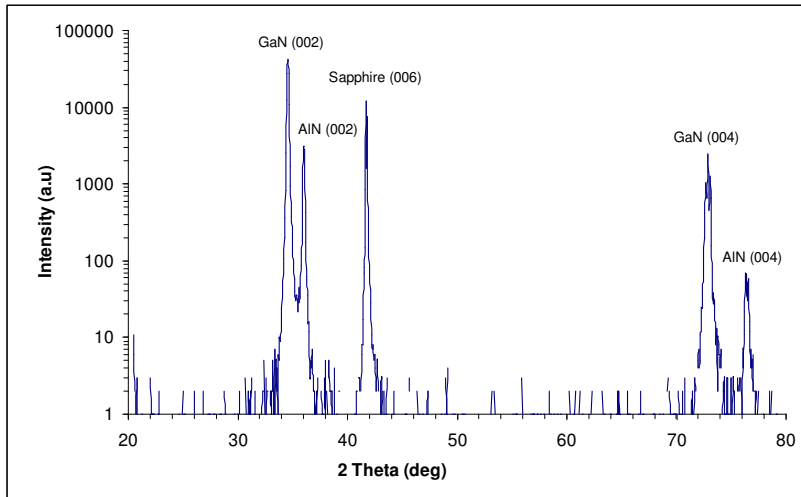


Fig. 2. XRD spectra of the p-GaN

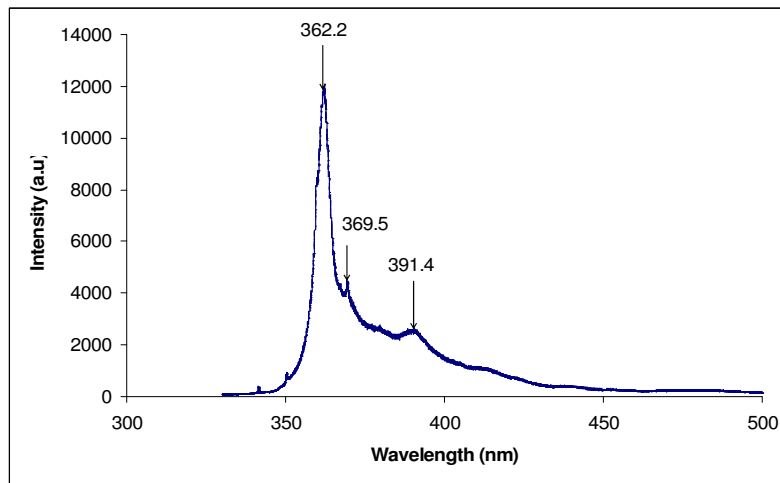


Fig. 3. PL spectra of the p-GaN

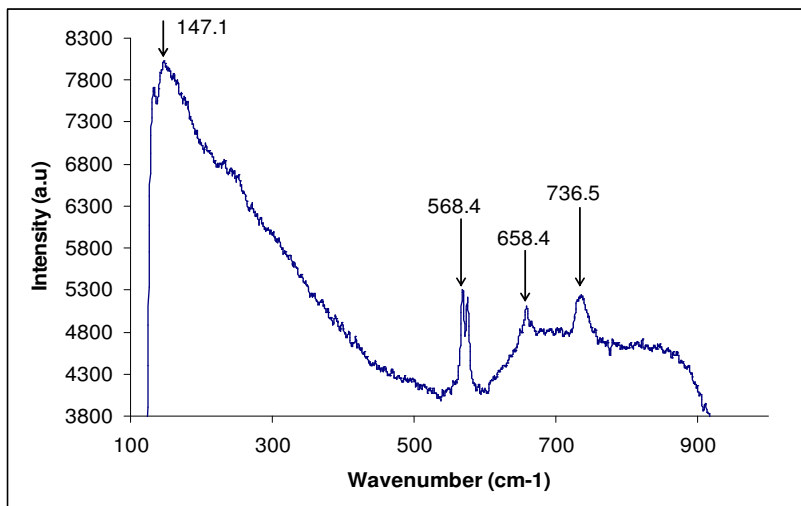


Fig. 4. Room temperature micro-Raman spectra of p-GaN

4. Conclusion

In conclusion, the growth of high carrier concentration p-GaN thin film on sapphire has been obtained by plasma-assisted molecular beam epitaxy. Results of Hall effect measurement revealed that our sample has a high carrier concentration of $6.58 \times 10^{18} \text{ cm}^{-3}$. The sharp and intense peak at 362.2 nm in PL measurement indicates that the sample is of high optical quality. In addition, the presence of a peak at 658 cm^{-1} in Raman results confirmed that our sample was highly doped.

Acknowledgement

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