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GaN m-i-n LED grown by MOVPE

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Abstract

Undoped and Zinc-doped GaN films have been grown using TMGa, DEZn and Ammonia by MOVPE. The GaN blue-green LEDs of m-i-n structure have been fabricated. They can be operated at forward bias less than 5 volts. The EL peak wavelength was from 455 nm to 504 nm.

1. Introduction

Column III nitride, AlN, GaN, InN, and their alloys, AlGaN, GaInN, and AlGaInN, are very promising materials for fabricating blue-green light optoelectronical devices, especially light-emitting diodes (LEDs), laser diodes (LDs) and detectors, because they possess large direct band gap energy from 1.9 eV to 6.2 eV, corresponding to the spectral range from visible to ultraviolet. For lack of ideal substrate, GaN has usually been grown on sapphire, because it has good thermal stability and can be obtained with high quality and large size at low cost, although there are large mismatches of lattice constant and thermal expansion coefficient between substrate and epilayer. Therefore it is difficult to obtain a GaN film of good crystalline quality. Moreover, high background electron concentration, usually attributed to nitrogen vacancy and/or residual impurities , and the difficulty of achieving p-type material hinder the progress of GaN-related device research. By far , MOVPE has proven its suitability for the epitaxial growth of high quality GaN using a thin low-temperature-deposited AlN [1] or GaN [2] buffer layer. Recently significant advances in GaN blue LEDs and LDs technology have been made after the reducing of the background electron concentration and the achievement of the p-GaN since high-brightness blue LEDs were obtained in 1994 [3].

We have grown GaN films by MOVPE. The GaN blue-green LEDs of metal-insulating GaN-n type GaN (m-i-n) structure have been fabricated . The results of recent research are reported in this paper.

2. Experimental

GaN thin films were grown in a horizontal MOVPE reactor at atmospheric pressure [4]. Trimethylgallium (TMGa) , diethylzinc (DEZn) and NH_3 were used as sources. TMGa and DEZn were transported by H_2 bubbling through the liquid, then diluted by another flow of H_2 with flow rate 3000 sccm (standard cubic centimeter per minutes). The flow rate of NH_3 was 3000 sccm. The sources were mixed at the entrance of the reactor in order to suppress the parasitic reactions. The (0001)-oriented sapphire was degreased with organic solutions, etched in hot H_2SO_4:H_3PO_4 =3:1 mixture, rinsed with deionized water and dried naturally before loading into the reactor. Prior to growth, the substrate was heated to 1150°C in H_2 stream for 15 minutes in order to clear the surface. The low-temperature-deposited GaN buffer layer was first grown at 550°C for about 20 nm. Then temperature was raised to 1050°C and growth continued. Several analytical techniques were employed to characterize the grown layer. The surface morphology was observed by Nomarski interference contrast microscopy. The crystalline quality of GaN was measured by X-ray diffraction and double-crystal X-ray diffraction (DXRD). The electrical properties were characterized by the Van der Pauw method at room temperature (RT). The optical properties were measured by photoluminescence (PL) at 77K using a CW He-Cd laser at 325 nm.

3. Results and discussion

With a GaN buffer layer, the surface morphology and the electrical property as well as the crystalline quality of GaN have been improved considerably contrast to that of the GaN film without buffer layer [4]. The surface of epilayer was mirror-like. The full width at half-maximum (FWHM) of the DXRD rocking curve was reduced to 6 arc minutes. The unintentionally doped GaN films demonstrated n-type conduction. The electron concentration and mobility at RT were $2x10^{18}$ cm^{-3} and 114 cm^2/V.s, respectively. The n-type conduction is generally attributed to nitrogen vacancy, whose concentration is influenced by the partial pressure of active nitrogen and the growth temperature [4]. From the PL spectra at 77K, a very strong near-band-edge emission was shown. The main peak was 365 nm, the FWHM of this peak was 40 meV. The yellow emission, with peak at 550 nm, which may be due to carbon impurity and/or some intrinsic defects, was very weak. All of these results meant that the quality of the epitaxial film was already quite good.

On the basis of above research, we fabricated GaN LED of m-i-n structure. The epitaxial growth was successively 20 nm GaN buffer layer, 4 µm undoped n-type GaN and 1 µm i-GaN. All of these thickness were estimated form the average growth rate. The i-GaN (insulating GaN) was obtained by doping with Zinc. Metal Aluminium was used for the electrodes to both the i-GaN and the n-GaN layer. The electrode to i-GaN was a circular pad with 500 µm in diameter. After deposition, thermal annealing was performed at 500°C for 5 minutes. Because the device of m-i-n structure emits light only underneath the electrode to i-GaN [5], the emission area was approximately equal to the electrode area. Electroluminecscence was detected from the sapphire side. The emission spectra at different injection current under forward bias (i layer biased positive) at RT of m-i-n GaN LED were similar (See Figure 1). A broad blue emission with peak wavelength about 455 nm was observed. The FWHM of the peak at 90 mA injection was 82 nm. We observed very little peak shift when injection current were changed from 5 mA to 90 mA. The emission light could readily be seen in a well-lit room. The brightness increased almost linearly with the current, but the absolute brightness intensity was not measured.

We increased the molar flow rate of DEZn in order to increase the dose of Zn-dopant. When the molar flow rate of DEZn varied from 24 to 54 µmol/min and kept TMGa 24 µmol/min as a constant, the EL emission shifted from blue to green. Jacob also noticed the similar phenomenon [6]. Usually Zn forms a single acceptor on the Ga site, but at higher concentration, a triple acceptor on the N site. At low doping, blue is observed. The green emission is attributed to the electron transition from the conduction band to the shallowest level of the Zn(N) acceptor. The emission peak of green light LED was at 504 nm at 60 mA with 4.3 V bias. The FWHM of the peak was 112 nm (See Figure 2).

LED of m-i-n structure is more suitable for manufacturing plane and multicolour display devices [5], much easier to be obtained than that of p-n junction structure since it is unnecessary to grow p-type GaN for the former. But it usually needs high voltage. The operational voltage is usually more than 9 V [7], even 10~60 V [8]. Figure 3 showed the typical I-V characteristic of the blue light LED from figure 1 under forward bias. Substantial conduction began at about 3 V. The current reached 100 mA at 5 V. Maruska believed that the electroluminescence processes consist of field emission of electrons from deep centers (Zn) with a subsequent radioactive transition of a conduction band electrons, which tunnel from the n-GaN conduction band through a triangular potential barrier at the i-n junction into the conduction band of the i-GaN, to the empty center [9]. According to this theory, the width and the height of the potential barrier determines the relation of the electric current and bias. A sharp i-n junction may narrow the potential barrier. This, in turn, can result in an enhancement of the electric field in the i-n junction so that the electron can easily tunnel the barrier. In our well-designed, circulation-free reactor, sharp interface can easily be obtained. We have ever grown 10-angstrom-thickness GaAs/AlGaAs quantum well at atmospheric pressure. The sh arp i-n interface is maybe one of the reasons of the low operational voltage. Moreover, the barrier height was estimated, according to the method proposed by Maruska [9]and our I-V data, to be 0.7 eV, much lower than 1. 7 eV, which was estimated by Maruska. This is maybe the second reason of the low operational voltage. More investigation is needed to understand the reason.

4. Conclusion

The quality of GaN film grown by MOVPE using home made sources in a home made reactor with GaN buffer layer have been improved. The substrate is (0001)-oriented sapphire. The i-GaN was grown by doping with Zn. The m-i-n GaN LED was obtained. In the EL spectrum of the m-i-n GaN LED, a broad blue to green emission with peak wavelength from 455 to 504 nm was observed at RT. The growth conditions and the diode structure have not been optimized.

Acknowledgments

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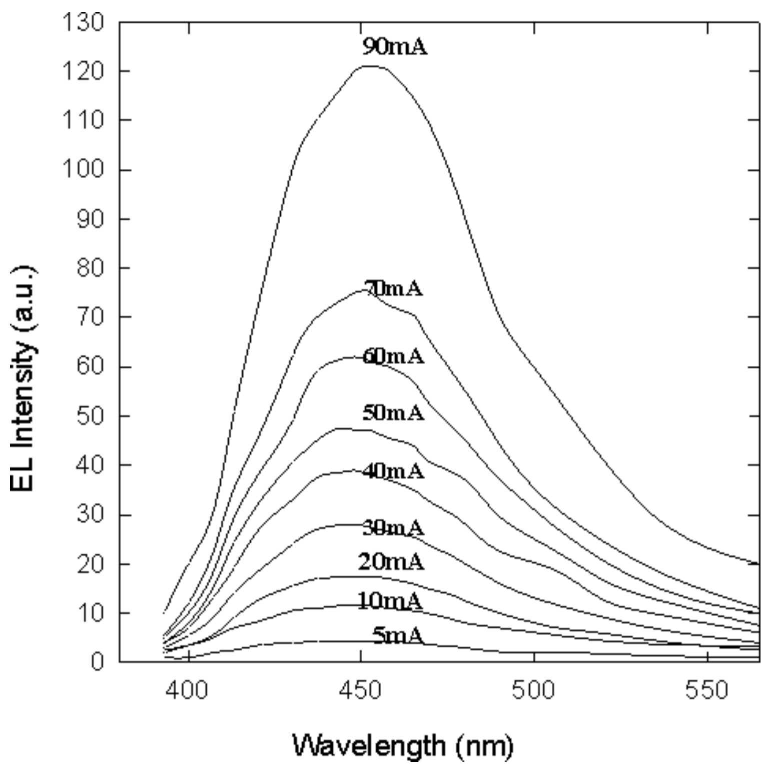

Figure 1. Electroluminescence spectrum of blue GaN m-i-n LED. The emission peak was about 455 nm with FWHM 82 nm at 90 mA injection.

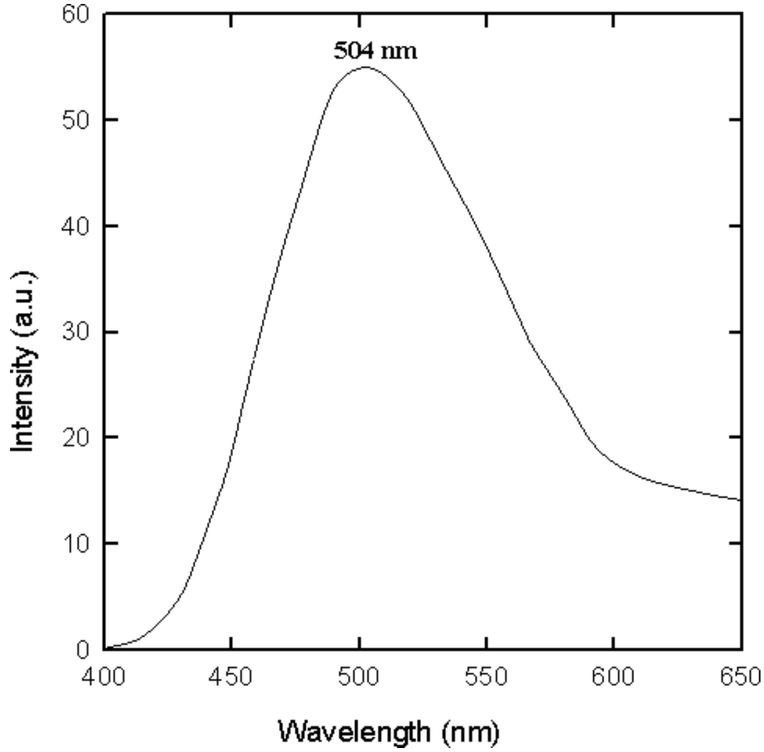

Figure 2. Electroluminescence spectrum of green GaN m-i-n LED. The emission peak was at 504 nm with FWHM 112 nm at 60 mA and 4.3 V bias.

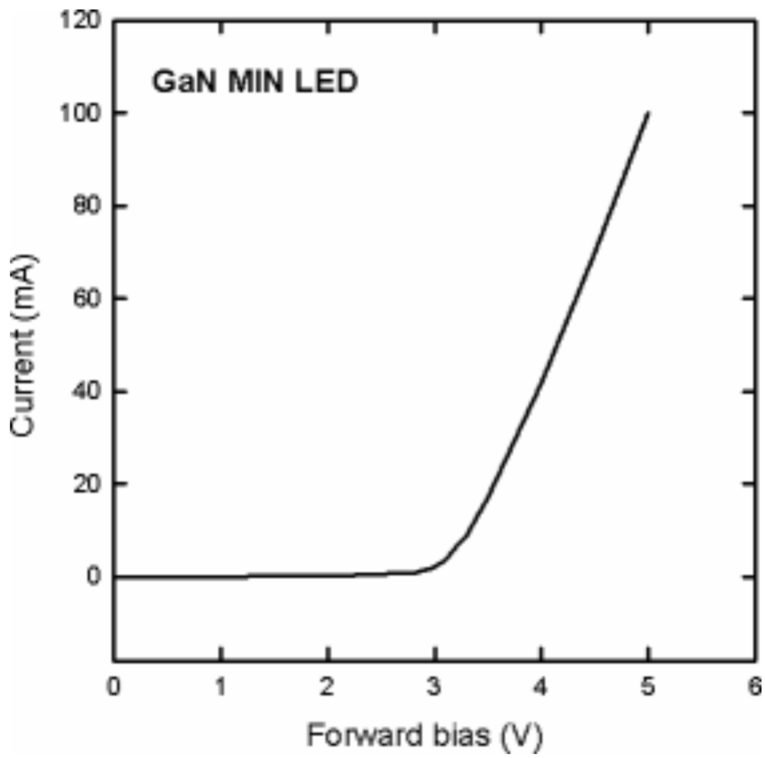

Figure 3. Current-voltage characteristic of m-i-n GaN LED under forward bias. Substantial conduction began at about 3 V. The current reached 100 mA at 5 V.

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