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Highly transparent Pt ohmic contact to InGaN/GaN blue light-emitting diodes

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Abstracts – We report on the fabrication and characterization of InGaN/GaN multiple quantum well light-emitting diode (LED) with a highly transparent Pt ohmic contact as a current spreading layer. The value of light transmittance of a Pt thin film with a thickness of 8 nm on *p*-GaN was measured to be 85% at 450 nm. The peak wavelength and the full-width at half-maximum (FWHM) of the emission spectrum of the LED at 20 mA were 453 nm and 23 nm, respectively. Pt-contacted LEDs show good electrical properties and high light-output efficiency compared to Ni/Au-contacted ones. These results suggest that a Pt thin film can be used as an effective current spreading layer with high light-transparency.

I. Introduction

GaN is promising material for application to optical devices operating in the blue and ultraviolet wavelength regions such as light emitting diodes (LEDs) [1-4] and laser diodes (LDs) [5]. In order to improve the performance of LEDs, the development of high-quality ohmic contacts to a *p*-type GaN is essential. In a GaN based LED, Ni/Au alloy is commonly used as an ohmic contact to a *p*-type GaN layer. However, the low doping level of a *p*-type GaN film may not result in a moderate ohmic contact, thereby degrading the performance of the LED [6]. In addition, another condition for high efficiency in an LED is that the current spreading layer must have a high transmittance in the visible region for the maximum amount of light to be coupled out. Thus, a low resistive *p*-electrode with high transparency is an important issue for the fabrication of GaN-based LED [7].

In the present work, we report on the use of a Pt thin metal film as an ohmic contact to *p*-GaN by demonstrating efficient current spreading and high light-transparency in the visible/violet wavelength range. We also compare a Pt thin film with a Ni/Au film for use as a current spreading layer contact.

II. Experimental

The GaN samples used in this study were grown on sapphire substrates with a (0001) orientation (c-face) by metalorganic chemical vapor deposition (MOCVD) at 200 Torr. The epilayer structure for the multiple quantum well (MQW) LED consists of a five-period InGaN/GaN MQW sandwiched between a 1.5-μm-thick n ($n = 1\times10^{18}$ cm^{-3}) and a 0.25-μm-thick *p*-GaN (p=2×10^{17} cm^{-3}) layer. The GaN barrier and InGaN well layer of the MQW structure was 7.5 and 4.5 nm, respectively. Disilane and Cp_2Mg were used for the *n*- and the *p*-type dopants, respectively. A rapid thermal annealing (RTA) process at 950 for 1 min was used to activate the *p*-type dopants.

The LED chips were fabricated as follows. First, the surface of the *p*-type GaN layer was partially etched using the inductively coupled $CH_4/Cl_2/H_2/Ar$ plasma until the *n*-GaN layer was exposed. Secondly, a Ti/Al (30 nm/80 nm) film was deposited as the *n* ohmic contact via e-beam evaporation. And then, a Ni/Au film with a thickness of 5 nm/7 nm in thickness and a Pt thin film with a thickness of 8 nm were evaporated onto the *p*-GaN layer as the current spreading layer, respectively. Finally, Ni/Au (30 nm/ 80 nm) were subsequently deposited on the current spreading layer as the top electrode. These metals were patterned by a standard metal lift-off technique. All contacts were annealed at 500°C for 30 s under a N_2 gas ambient.

III. Results and discussion

In order to investigate the light transmittance of Pt thin film (8 nm) in the visible/violet region, we measured the light-transmission spectra of as-deposited and Pt contact annealed at 500, 600°C on *p*-GaN film by means of a UV/VIS spectrometer, respectively. The results are shown in Fig. 1. The *p*-GaN samples were used as references to calibrate the light-transmission measurements. As shown in Fig. 1, the values of light transmittance for Pt contacts are 66 %, 85 % and 77 % (at 450 nm) for an as-deposited sample and 500, 600°C annealed ones, respectively. The light-transmittance decreases with increasing the wavelength of incident beam as shown in Fig. 1. One possible explanation for lower transmittance in long wavelength region is that the reflective index of Pt film increases with increasing the wavelength in the visible wavelength range, leading to a higher reflectance. Hence, with increasing the wavelength, the light-transmittance decreases. The light-transmittance of a Ni(2 nm)/Au(6 nm) bilayer metal film was found to be 83 % [7] and this value is slightly lower than that of Pt (8 nm) film, suggesting that Pt has a higher light output efficiency than Ni/Au film.

Figure 2 shows a typical *I-V* curve of an InGaN/GaN MQW LED at room temperature. The turn-on voltage is less than 3 V for the Ni/Au and Pt contacts and the forward voltage is 3.5 V for Ni/Au and 3.3 V for Pt at 20 mA, respectively. Acceptable electrical properties are also exemplified by the low leakage current which is less than 10 μA at -10 V for both cases. The typical on-series resistance measured by *I-V* curves is 25.9 Ω for Ni/Au and 22.6 Ω for Pt, respectively. These results suggest that the electrical properties of the LED, which had been fabricated using Pt as the current spreading layer contact, are superior to those of the Ni/Au. It has been reported that the specific contact resistance of a Pt-based contact on *p*-type GaN is lower than that of Ni-based contact [8]. Therefore, the superior electrical properties of an LED fabricated using Pt are due to the improved electrical contact to the *p*-type GaN.

Figure 3 shows the electroluminescence (EL) spectra, which is plotted as a function of the forward drive current, obtained from the InGaN/GaN MQW LED fabricated using a Pt thin film as a current spreading layer. The peak wavelength and the full-

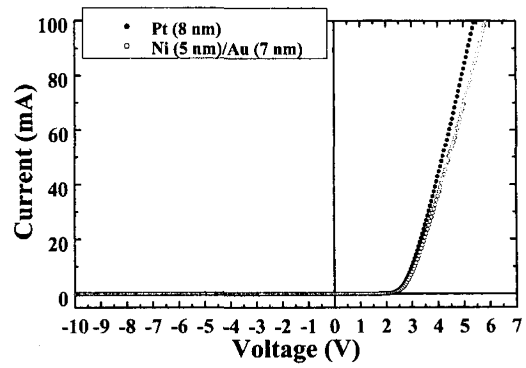

Fig. 2. Current-voltage (*I-V*) curves for an InGaN/GaN MQW LED with different current spreading contacts: (a) 5 nm/7 nm Ni/Au, (b) 8 nm Pt.

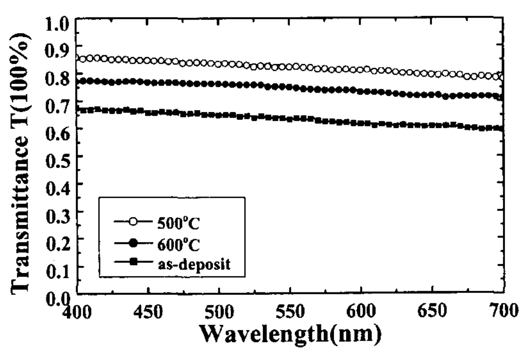

Fig. 1. Light transmission spectra of as-deposited and Pt contacts annealed at 500°C, 600°C on *p*-type GaN films, respectively.

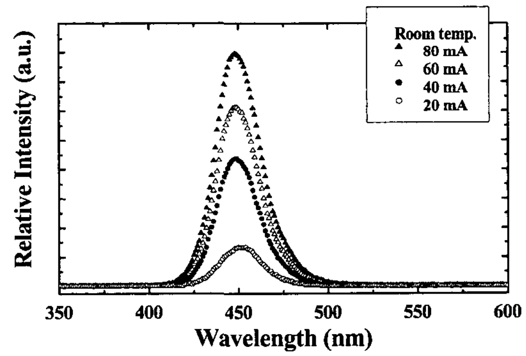

Fig. 3. Room temperature electroluminescence spectra obtained from an InGaN/GaN MQW LED under different forward currents.

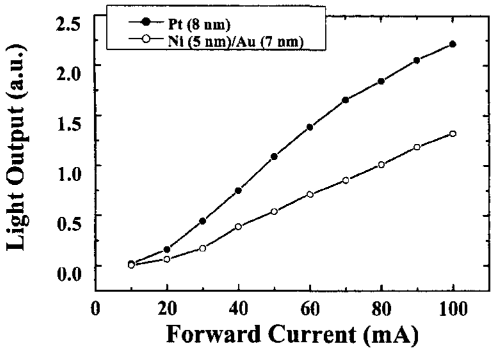

Fig. 4. Light output characteristics for an InGaN/GaN MQW LED with Pt and Ni/Au current spreading contacts.

width at half-maximum (FWHM) of the emission spectra of the LED at 20 mA were 453 nm and 23 nm, respectively. As the current is increased from 20 mA to 80 mA, the position of the peak shifts slightly to 449 nm. We believe that the slightly blue shift of 4 nm (2.44 meV) is attributed to the band filling effect.

The light output power for two different metal contacts as the current spreading layer as a function of forward drive current is shown in Fig. 4. In order to investigate the relative light output power for MQW LEDs fabricated using the two different current spreading layers, the light output power was measured through the current spreading layer using a calibrated Si photodiode. It should be noted that for these measurements, unpackaged LED devices were used, thereby making accurate power measurement relatively difficult. As shown in Fig. 4, the light output-power of the LED device with a Pt contact as the current spreading layer exceeded the light output power of the device with a Ni/Au contact to *p*-GaN by a factor of 2.5 at 20 mA. The relative value of these two light output-powers varies with increasing the drive current. The low light transmittance of the Ni/Au film can be attributed to the strong absorptive properties of Ni in the visible region [9]. In this study, we found that the Pt thin film has a high light transmittance in blue/violet region and a good electrical property as a transparent current spreading layer.

IV. Conclusions

The fabrication and characterization of an InGaN/GaN MQW LED using a Pt thin film as a current spreading layer is presented. The value of light transmittance for Pt thin film with a thickness of 8 nm was found to be 85% at 450 nm. The EL spectrum obtained from the LED device at 20 mA was centered at 453 nm and had a FWHM of 23 nm. The room temperature *I-V* curve shows that the electrical properties of LED with a Pt thin film as a current spreading contact are superior to those with a Ni/Au film. In addition, as for the light output efficiency, an InGaN/GaN MQW LED with the Pt-contacted layer is also superior to that with the Ni/Au-contacted one.

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