380-nm Ultraviolet Light-Emitting Diodes with InGaN/AlGaN MQW Structure

Sung-Bum Bae, Sung-Bok Kim, Dong-Churl Kim, Eun Soo Nam, Sung-Mook Lim, Jeong-Hwan Son, and Yi-Sang Jo

In this paper, we demonstrate the capabilities of 380-nm ultraviolet (UV) light-emitting diodes (LEDs) using metal organic chemical vapor deposition. The epi-structure of these LEDs consists of InGaN/AlGaN multiple quantum wells on a patterned sapphire substrate, and the devices are fabricated using a conventional LED process. The LEDs are packaged with a type of surface mount device with Al-metal. A UV LED can emit light at 383.3 nm, and its maximum output power is 118.4 mW at 350 mA.

Keywords: GaN, UV, LED, MQW, MOCVD.

I. Introduction

III-nitride materials, AlN (6.2 eV), GaN (3.4 eV), and InN (0.8 eV), have a direct bandgap and cover a wide wavelength range of ultraviolet (UV) to visible red [1]. Technology breakthroughs, such as a low-temperature buffer layers [2] and p-type activation [3], have focused a lot of attention on optoelectronic devices. After the commercialization of blue and white light-emitting diodes (LEDs) [4], several research groups developed an interest in the UV region because of its wide range of applications as a function of wavelength [5]-[7]. The UV-A region of 320 nm to 400 nm is useful for UV curing, counterfeit banknote detection, tanning, photocatalysis air purification, and lighting applications. The UV-B region of 280 nm to 320 nm is useful for phototherapy, the treatment of skin disease, DNA analysis, and chemical sensor applications. The UV-C region under 280 nm is useful for laser knives, sterilizers, and water or air purifiers [8]. Traditional UV lamps, such as mercury, metal halide, and xenon lamps, have been used for many of these applications, but, in the future, UV lamps will be replaced with UV LEDs, owing to significant advantages in size, power consumption, lifetime, wavelength control, and safety.

The fabrication of UV LEDs using standard technologies, particularly for UV-B and UV-C, has many problems, such as the substrate absorption of UV light, high Al-content growth, low doping efficiency, cracking, and a low growth rate of epi-layers. In the case of a UV-A LED, particularly for near-UV (360 nm to 400 nm), the LED structure consists of an active layer based on InGaN materials and n-/p-contact layers with low Al-content. The internal quantum efficiency (IQE) of an LED is therefore higher than that of UV-B and UV-C.

In this paper, we discuss several technologies for achieving

Fig. 1. Cross-section view of PSS.

1.6 μm   0.5 μm   2.7 μm

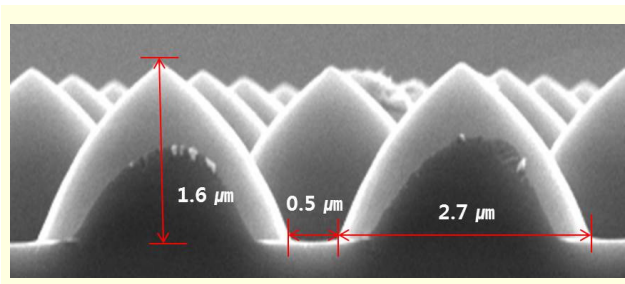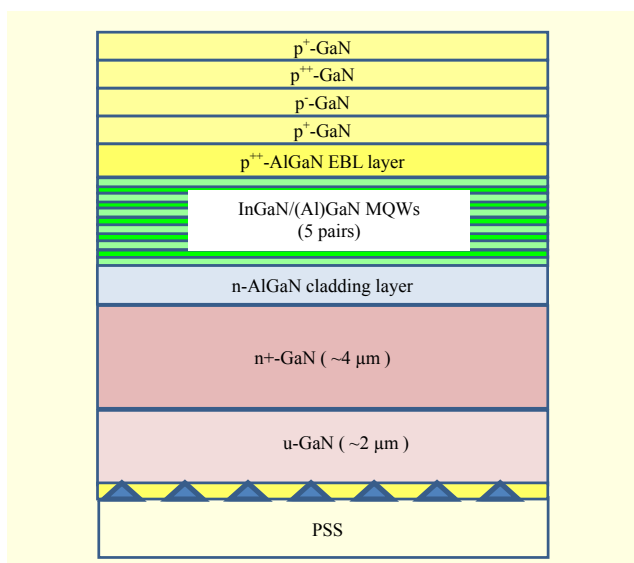| p⁺-GaN |
| p⁺⁺-GaN |
| p⁻-GaN |
| p⁺-GaN |
| p⁺⁺-AlGaN EBL layer |
| InGaN/(Al)GaN MQWs (5 pairs) |
| n-AlGaN cladding layer |
| n+-GaN (~4 μm) |
| u-GaN (~2 μm) |
| PSS |

Fig. 2. Schematic view of UV LED epi-structure.

high-power UV LEDs. First, we use a patterned sapphire substrate (PSS) to increase the IQE by reducing the screw dislocation and improving the light extraction efficiency (LEE) [9]-[11]. We then use InGaN-based multiple quantum wells (MQWs) in a UV LED structure. The MQW structures based on InGaN with low In content are important for improving the IQE of an LED. Finally, we use a surface mount device (SMD) package with a metal frame due to the heat dissipation from the LED chip.

II. Experiments

Figure 1 shows a cross-section view of the PSS used in this study. PSS patterns are optimized for the LED and fabricated using photolithography and a dry etching process. The height and width of the pattern are 1.6 μm and 2.7 μm, respectively, and the distance of the pattern is 0.5 μm. Figure 2 shows a schematic view of the UV LED epi-structure used in this study. The UV LEDs are grown on a PSS using metal organic chemical vapor deposition (MOCVD).
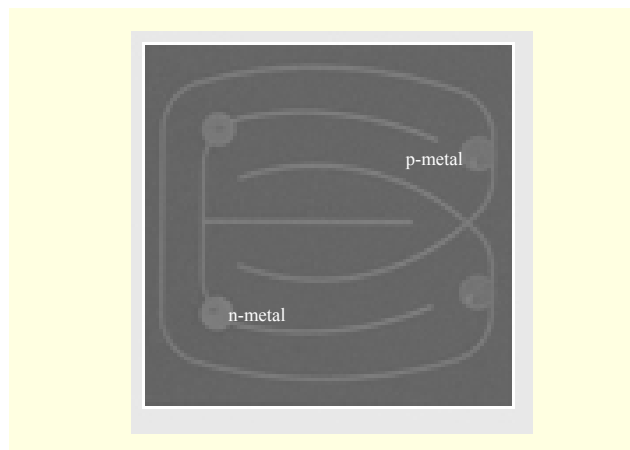
In this study, the UV LED structure consists of a 30-nm-

Fig. 3. SEM image of UV LED device structure.

thick low-temperature buffer layer at 530ºC, a 2-μm-thick high-quality un-doped GaN layer, a 4-μm n^+-GaN contact layer, a 25-nm-thick n-$Al_{0.2}$GaN cladding layer, five pairs of InGaN/(Al)GaN MQW layers, a 25-nm-thick p-$Al_{0.2}$GaN electron blocking layer (EBL), and a 120-nm-thick p-GaN contact layer.

The MQWs of the LED consist of Sample A, which is an $In_{0.05}$GaN (3 nm)/GaN (10 nm) structure, and Sample B, which is an $In_{0.05}$GaN (3 nm)/$Al_{0.05}$GaN (10 nm) structure. The growth temperatures of the MQWs vary from 790ºC for the $In_{0.05}$GaN well layer to 850ºC for the (Al)GaN barrier layers. Comparing a GaN barrier with an $Al_{0.05}$GaN barrier, it is clear that the latter is better for improving the LED output power.

Figure 3 shows the pattern of the UV LED devices. The chip process utilizes a conventional LED fabrication using a 1 mm × 1 mm size. First, 100-nm-thick indium tin oxide (ITO) thin films are deposited onto an LED wafer using a sputtering method for the transparent contact layer (TCL). After deposition, a rapid thermal annealing (RTA) process is carried out for 20 minutes at 520ºC for p-GaN activation and for improving such ITO properties as conductivity and transmittance. The device pattern is formed using inductively coupled plasma (ICP) etching, and Cr/Au is used for n-/p-type metal contacts.

The optical properties of LEDs are characterized through photoluminescence (PL) and electroluminescence (EL). The epi-structures are observed using transmission electron spectroscopy (TEM) and scanning electron microscopy (SEM). The output power (P_O) of the UV LEDs is measured at the Korea Photonics Technology Institute (KOPTI), which is a certification authority (CA) of optical devices.

III. Results and Discussion

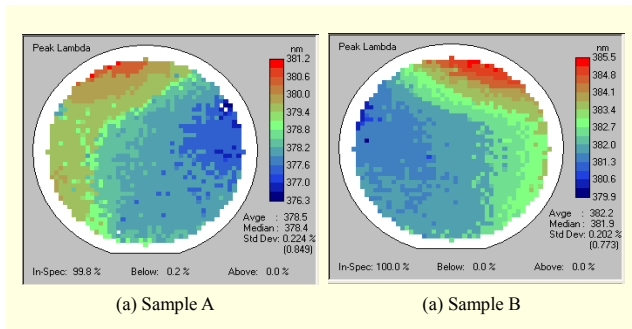Figure 4 shows the average wavelength (λ_{avg}) of the UV

(a) Sample A   (a) Sample B

Fig. 4. PL mapping of UV LED epi-wafers.

(a) STEM and TEM images of Sample A
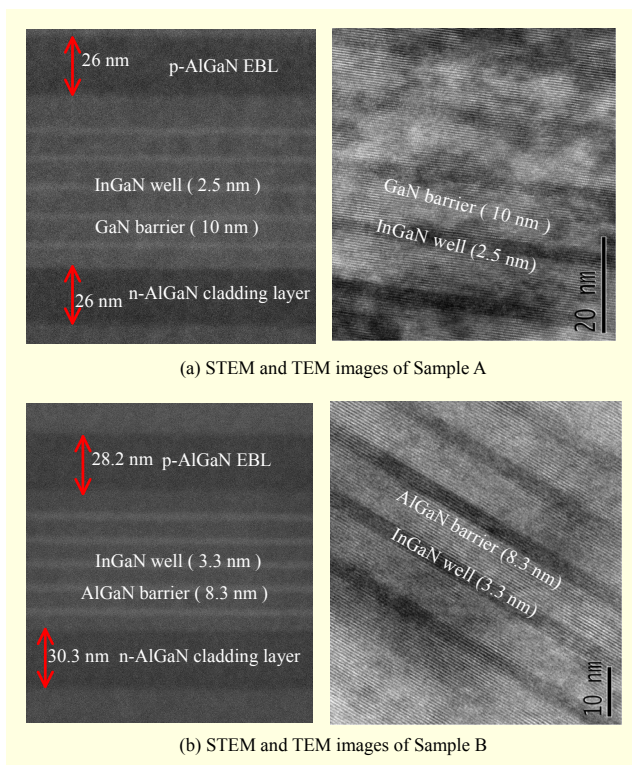

(b) STEM and TEM images of Sample B

Fig. 5. STEM and TEM images of (a) Sample A and (b) Sample B.

LED epi-wafers using a PL mapping system. The λ_{avg} of Sample A is 378.5 nm, and that of Sample B is 382.2 nm. One of the reasons for a red-shift of λ_{avg} is the different $In_{0.05}GaN$ well thicknesses in an MQW structure.

Figure 5 shows scanning transmission electron microscopy (STEM) and transmission electron microscopy (TEM) images of UV LED epi-structures. Figure 5(a) shows that Sample A has the same design structure as an LED except for the InGaN well thickness of the MQWs. Reducing the thickness of an InGaN well from 3 nm to 2.5 nm can reduce the λ_{avg} of the LED from 380 nm in the design structure to 378.5 nm. Figure 5(b) shows that the design structure of Sample B is not the same as that of an LED. The thickness of the $Al_{0.2}GaN$ layers

Table 1. LED chip results of Samples A and B.

Samples		PL (λ_{avg}) (nm)	LED chip (unpackaged)				
			V_F (V)	W_P (nm)	V_r (10 μA)	I_r (−5 V)	P_o (avg) (mW)
A	InGaN/GaN MQWs	378.5	3.85	377.3	12.1	0.46	16.2
B	InGaN/$Al_{0.05}$GaN MQWs	382.2	3.83	382.8	35.9	0.23	40.79

of the n-cladding and p-EBL is increased from 25 nm to 30.3 nm and 28.2 nm, respectively.

The InGaN well thickness is increased from 3 nm to 3.3 nm, and the $Al_{0.05}GaN$ barrier thickness is decreased from 10 nm to 8.3 nm. We believe the thickness variation of the LED structure is caused by a growth rate variation in the MOCVD system.

Table 1 shows the chip results of Samples A and B. The LED chips are measured using a wafer probing system. The measurement conditions of the forward voltage (V_F), EL peak wavelength (W_P), and P_O are carried out at a 350-mA operation.

The wavelengths of PL (λ_{avg}) and EL (W_P) are nearly the same in Samples A and B. The values of V_F in Samples A and B are higher than the typical value of a blue LED (approximately 3.2 eV), owing to a high series resistance in the n-$Al_{0.2}$GaN cladding layer. Both the reverse voltage (V_r) at 10 μA and the reverse current (I_r) at −5 V show the reverse characteristics of an LED chip. In terms of the reverse characteristics, Sample B is superior to Sample A because of a lower I_r and higher V_r. The adoption of the $Al_{0.05}GaN$ barrier in the MQWs is very effective in improving the reverse characteristics and output power of an LED. The output power of the UV LEDs is 16.2 mW for Sample A and 40.79 mW for Sample B.

Sample B undergoes a back-end process for packaging. The back-end process consists of a wafer back-grinding of up to 100 μm, die singulation, die inspection, and a sorting of the output power. The UV LED chips sorted in Sample B are mounted on two kinds of packaging. One type is an SMD 5050 size package of different materials, such as polyphthalamide (PPA), ceramic, and Al-metal. The other is a transistor outline (TO) package of different sizes, such as TO-39 and TO-46.

In Fig. 6, the optical output power of UV LEDs using different packages is plotted as a function of the injection current. In terms of the package type, SMDs show a higher P_O than the TO-types. This is caused by the fact that the radiation lights from an LED chip can be removed from TO packages with a metal-based body structure. For the SMDs, Al-metal and ceramic materials show a higher P_O, owing to their
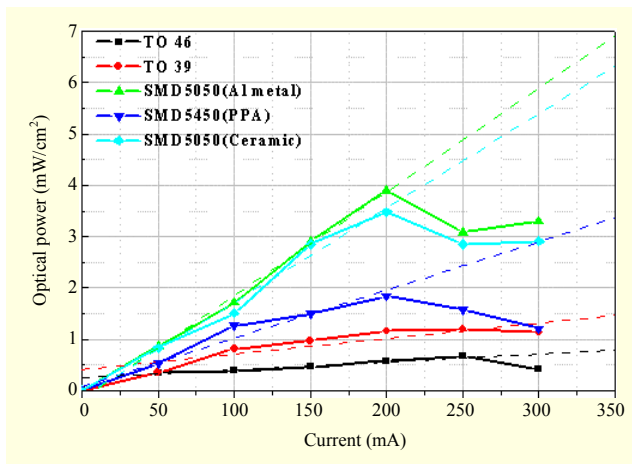
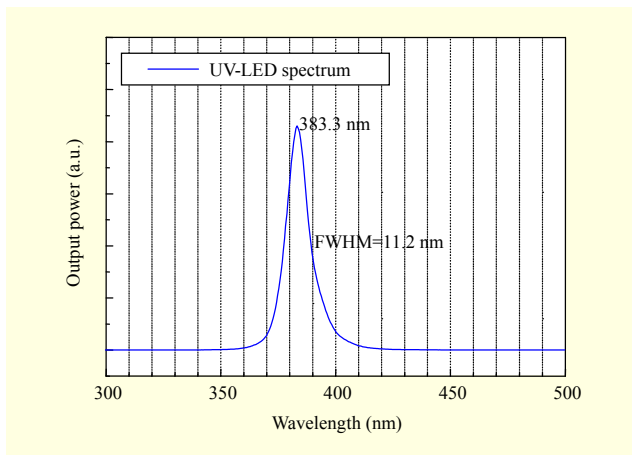Fig. 6. Optical power of UV LED with different packages.

Fig. 7. EL spectrum of UV LED (packaged).

desirable thermal dissipation properties. The value of P_O is increased as a function of the injection current up to 200 mA. Over 200 mA, the value of P_O is slightly decreased. This indicates that the heat dissipation property is a critical issue in UV LEDs.

Figure 7 shows the EL spectrum of the 380-nm UV LED package. The peak wavelength is 383.3 nm, and the full width at half maximum (FWHM) is 11.2 nm. The P_O of the UV LED is 51.3 mW at 150 mA and 118.4 mW at 350 mA, as measured by KOPTI (CA).

IV. Conclusion

In conclusion, we demonstrated the use of 380-nm UV LEDs. The epi-structure consisted of PSS technology and InGaN-based MQWs using MOCVD. To improve the thermal properties, we used an SMD 5050 package with Al-metal. The W_P of the UV LED was 383.3 nm, and the P_O was 118.4 mW at 350 mA.

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Sung-Bum Bae received his BS and MS in electronics engineering from Kyungpook National University, Daegu, Rep. of Korea, in 1997 and 1999. His thesis research was on the growth and characterization of InGaN thin films for optical device application. He has been with ETRI, Daejeon, Rep. of Korea, since 2001, as a senior researcher. His current research interests include the epitaxy of III-nitride semiconductors using the MOCVD system and applications of optoelectronic devices.
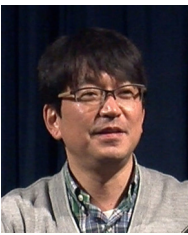
Sung-Bock Kim received his MS and PhD in physics from Yonsei University, Seoul, Rep. of Korea, in 1992 and 2005, respectively. In 1993, he joined ETRI, Daejeon, Rep. of Korea, as a principle researcher. With a research background in compound semi-conductor epitaxy growth, he has been studying optoelectronic materials and photonics devices grown by MOCVD. His current research interests include the development of applications of GaN-based optical and power devices. He is currently the leader of the Optical Internet Devices Research Team of ETRI.

Dong-Churl Kim received his BS, MS, and PhD in physics from Kyung Hee University, Seoul, Rep. of Korea, in 1993, 1995, and 2000, respectively. Since 2000, he has been with the Photonic/Wireless Convergence Components Research Department of ETRI, Daejeon, Rep. of Korea, where he is a senior researcher. His research interests concentrate on GaN-based LEDs and LDs and photonic integrated devices for optical communication and optical signal processing.

Eun Soo Nam received his BS in physics from Kyungpook National University, Daegu, Rep. of Korea, in 1983 and his MS and PhD in physics from the State University of New York at Buffalo, Buffalo, NY, USA, in 1992 and 1994, respectively. In 1985, he joined ETRI, Daejeon, Rep. of Korea, where he conducted research on compound semiconductor devices, including heterojunction bipolar transistors (HBTs), microwave monolithic integrated circuits (MMICs), long wavelength InP semiconductor photonic devices, and optoelectronic integrated circuits (OEICs) for microwave circuits and optical fiber communications. In 2006, he was a visiting scholar with the Division of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA. His current research interests include microwave photonic modules operating in the millimeter wave region to realize broadband photonic wireless communication and eye safe laser radar. He is now the director of the Photonics/Wireless Convergence Components Research Department of ETRI.

Sung-Mook Lim received his BS and MS in physics from Chungnam National University, Daejeon, Rep. of Korea, in 2001 and 2003. He worked for Cowell until 2007 and has been with Genicom since 2008. He is interested in GaN-based epitaxy, such as UV sensors and UV LED and their application.

Jeong-Hwan Son received his BS in electronics engineering from Sogang University, Seoul, Rep. of Korea, in 1988 and his MS and PhD in electrical and electronics engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Rep. of Korea, in 1990 and 1995, respectively. He worked for Hynix and Optowafertech until 2004 and has been with Genicom as the director since 2004. He is interested in optical devices in the UV region and their application.

Yi-Sang Jo received his BS in aerospace engineering from Chungnam National University, Daejeon, Rep. of Korea, in 2010. He worked for Epivalley as a LED chip process engineer until 2012. He currently works for Genicom as an epitaxy engineer.