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10 Milliwatt Pulse Operation of 265 nm AlGaN Light Emitting Diodes

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We report on the development of solid-state deep ultraviolet light sources optimized for the germicidal applications. Pulsed power levels in excess of 10 mW were achieved for AlGaN based 265 nm light emitting diodes by improving the material quality using Migration-Enhanced Metal Organic Chemical Vapor Deposition. Packaged devices reached the continuous-wave power of 237 µW at 30 mA and a pulse power exceeding 10 mW for 1.2 A driving current.

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High efficiency solid-state ultraviolet (UV) light sources with emissions in the UVC range ($100\,\text{nm} < \lambda < 290\,\text{nm}$) are expected to be used for bio-agents detection, water and air purification, and food sterilization. Other potential uses include UV curing, fire detection, non-line-of-sight short range communications, and incorporation in biomedical systems. Results to date for sub-290 nm UV light emitting diodes (LEDs)[1–8)] indicate that high-temperature thick AlN buffers and strain-management/defect-filtering AlN/AlGaN superlattices[9–12)] are crucial for obtaining high-performance devices. Recently, we reported on high-efficiency 280 nm LEDs with continuous-wave (CW) powers in excess of 1 mW at 20 mA.[13,14)] Optimized multiple-quantum-well (MQW) designs and improved AlGaN quality through Migration-Enhanced MetalOrganic Chemical Vapor Deposition (MEMOCVD) were the key to obtaining these high powers.

The DNA strands for several common bacteria are strongly affected by radiation at 265 nm, which makes 265 nm UV LEDs an ideal source for water purification and food sterilization.[15)] In addition to these applications, 265 nm light sources are also useful for calibration of fire detection systems. The development of high-efficiency 265 nm UV LEDs requires AlGaN layers with Al-fraction exceeding 60%, resulting in unique challenges for growth, processing, doping, defect-control, and contact-fabrication. In this letter, we report on the use of MEMOCVD growth approach and a novel device design to fabricate 265 nm LEDs. A flip-chip packaged single device on TO39 header produced CW powers as high as 0.24 mW at 30 mA. The output power exceeded 10 mW for a pulsed pump current of 1.2 A.

The heteroepitaxial structure for our 265 nm LEDs was grown on a basal plane sapphire substrate using a custom-designed vertical metalorganic chemical vapor deposition (MOCVD) system, with trimethyl aluminum (TMA), trimethyl gallium (TMG), silane, Cp2-Mg, and NH_3 as precursors. The device structure has been previously reported[1,2,13,14)] with differed in the AlGaN compositions in the buffer, barrier and cladding layers increased for these shorter wavelength devices. The high-temperature AlN buffer and the defects-filtering AlN/AlGaN superlattices were grown by the MEMOCVD approach[11)] with the precursor pulse durations and overlaps optimized to the highest quality as measured by surface roughness and x-ray diffractions. For the AlN buffers and AlN/AlGaN superlattices the full width at half maximum was measured to be ≤9 arcsec for (0002) ω-scan (240 arcsec for (20–24) ω-scan). A 2.8 µm Si-doped $Al_{0.6}Ga_{0.4}N$ ($n = 1 \times 10^{18}\,\text{cm}^{-3}$) buffer layer grown on top of the superlattices was followed by the active region, which consisted of 5 periods of Si-doped $Al_{0.55}Ga_{0.45}N/Al_{0.45}Ga_{0.55}N$ quantum wells with the barrier and well thicknesses of 60 Å and 30 Å, respectively. Finally, the structure was capped by 500 Å p-$Al_{0.65}Ga_{0.35}N$ and 1000 Å p-GaN Layers.

To avoid current crowding, $100 \times 100\,\mu\text{m}^2$ mesa type LED devices were fabricated by accessing the bottom n-$Al_{0.6}Ga_{0.4}N$ layer using chlorine-plasma reactive-ion-etching. The Ti/Al/Ti/Au n-type ohmic contact metallization was annealed at 950°C. Transfer length measurements (TLM) were performed to determine the contact resistance. Figure 1(a) shows the current–voltage (I–V) curve for the n-type TLM pads with the width and length of 200 µm and 4 µm, respectively. The linear I–V curve indicates good quality ohmic contacts to the n-$Al_{0.6}Ga_{0.4}N$ layer. The TLM data in Fig. 1(b) yields a specific contact resistance for the n-contact of $1.06 \times 10^{-5}\,\Omega\text{-cm}^2$. The sheet resistance of the n-$Al_{0.6}Ga_{0.4}N$ layer extracted was 250 Ω/□, which agrees well with the sheet resistance value of 258 Ω/□ from contactless mapping. Ni/Au metals were used for the p-side contact. The p-type specific contact resistance and sheet resistance values also measured by TLM were found to be $2.34 \times 10^{-4}\,\Omega\text{-cm}^2$ and 36 kΩ/□, respectively. These values are similar to those measured on our 280 nm LEDs.[13)] Figure 2 shows a representative I–V curve for the 265 nm LEDs. At −5 V reverse bias the device leakage current was approximately 0.1 nA. The forward operating voltage at 20 mA was 6.8 V with a series resistance of 42 Ω. The device forward characteristics indicated a behavior typical of two (or more) connected diodes. At approximately 4 V forward bias, Fig. 2 shows behavior typical of parallel shunt diodes. These parasitic diodes might arise from the p-contact or p-GaN/p-AlGaN interface. We expect that eliminating these diodes should improve the 265 nm LED performance.

A representative electroluminescence (EL) spectrum of the 265 nm LEDs is shown in Fig. 3(a). The spectra plotted in semi logarithm scale showed a monochromatic peak at

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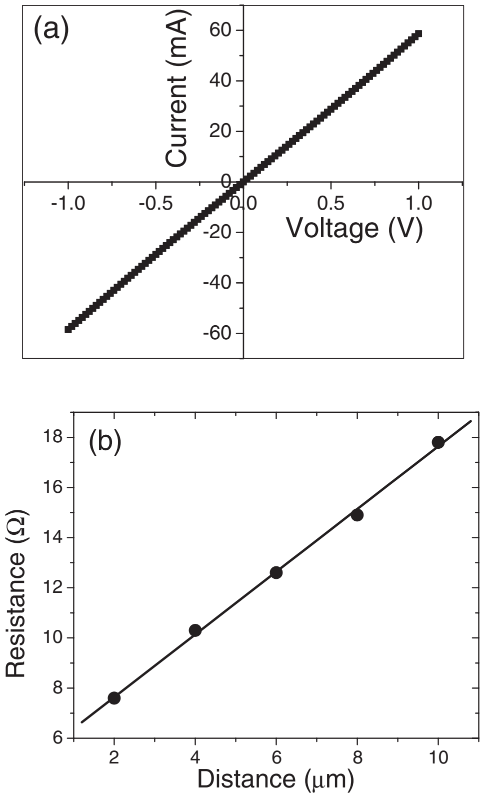

Fig. 1. I–V curve measured between adjacent n-TLM pads ($W/L = 200\,\mu m/4\,\mu m$) (a), and the n-contact TLM results ($W = 200\,\mu m$) (b).

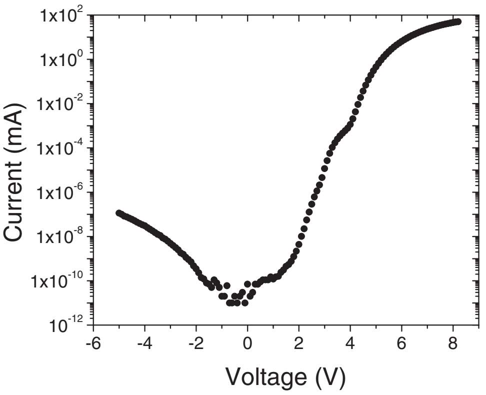

Fig. 2. IV characteristic for a $100 \times 100\,\mu m^2$ 265 nm LED.

265 nm. The main/long-wavelength emission ratios improved approximately from 70 to over 1000 with the pump current density increased from 10 to 100 A/cm^2. After initial EL testing, devices were flip-chip mounted on commercial TO39 headers with parabolic UV-reflectors for power measurements. Figure 3(b) shows both cw and pulse power measurements for the packaged device using an integration sphere (UV/VIS OL770). The maximum saturated CW power of 237 μW at 30 mA was limited by heating. With advanced heat removal packaging, the updated 265 nm LED CW power was 1.8 mV at 200 mA. In pulsed operation (with 1 μs pulse duration and 1% duty cycle for $I \leq 200$ mA, 30 ns duration and 0.03% duty cycle for $I > 200$ mA), the power increased linearly with current to a value over 10 mW for a pump current of 1.2 A. We believe that the relatively large

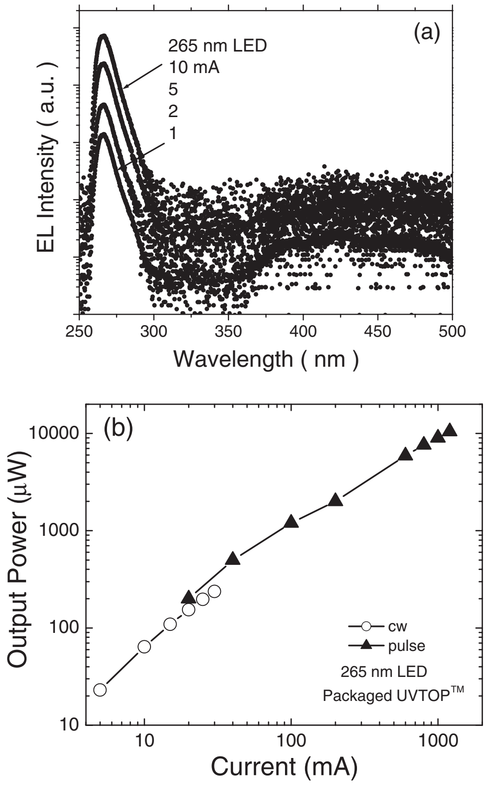

Fig. 3. 265 nm LED EL spectra (a). CW and pulsed (with 1 μs pulse duration and 1% duty cycle for $I \leq 200$ mA, 30 ns duration and 0.03% duty cycle for $I > 200$ mA) output powers for a packaged device (b).

numbers of threading dislocations in the LEDs coupled with the high p-type resistance are currently the primary factors limiting device performance for these 265 nm LEDs. Improving the material and p-contact quality, the power numbers can be further increased.

In summary, using the MEMOCVD technique for material quality improvement, we realized milliwatt power AlGaN based 265 nm LEDs. These powers are sufficient for several water purification applications.

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