**Ultra High Output Power 365 nm Ultraviolet Light Emitting Diodes**

Daisuke MORITA, Masashi YAMAMOTO, Kazuyuki AKAISHI, Kousuke MATOBA, Katsuhiro YASUTOMO, Yoshio KASAI, Masahiko SANO, Shin-ichi NAGAHAMA and Takashi MUKAI

Nitride Semiconductor Research Laboratory, Nichia Corporation
491 Oka, Kaminaka, Anan, Tokushima 774-8601, Japan

GaN-based light emitting diodes (LEDs) are the great attractive optoelectronic devices with extensive spectral region, which is between deep-ultraviolet (UV) and infrared. Visible LEDs, such as blue, green, white LEDs have very high efficiency. Recently, several groups actively developed UV LEDs, and the output power ($P_o$) has been improved. However, the efficiency of UV LEDs is much lower than visible LEDs. At present, mercury lamps have been used as UV light sources in various industrial fields. However, the Hg-free UV light sources have been required from the viewpoint of environmental protection. Generally speaking, LEDs are small and have high emission efficiency and long lifetime, and these features enable diversified applications from general uses to industrial uses. Moreover, GaN-based LEDs don't contain any toxic substances. Therefore, there are considerable advantages for both industry and environment to replace mercury lamps with GaN-based UV LEDs. Accordingly, we have been studying to improve the emission efficiency and to increase the $P_o$ of UV LEDs.

In this study, we fabricated ultra high power UV LEDs, whose emission wavelength is 365 nm. We found that, in order to improve the external quantum efficiency ($\eta_{ex}$) of UV LEDs, it is very important to reduce the optical self-absorption and the threading dislocation density (TDD) of epi-layers. Therefore, at first, UV LEDs epi-layers were grown on high-quality GaN templates (TDD=$1x10^8/cm^2$) with sapphire substrates, and then the GaN templates and the sapphire substrates were removed by using laser-induced lift-off and polishing techniques. As a result, we obtained the low self-absorption and low TDD UV LEDs. When this UV LED was operated at a forward-bias pulsed current of 1 A at room temperature (RT), the peak wavelength, $P_o$, the forward voltage ($V_f$) and the $\eta_{ex}$ were 365 nm, 1.0 W, 4.4 V, 29%, respectively. Moreover, at a forward-bias direct current of 1 A at RT, $P_o$, $V_f$ and $\eta_{ex}$ were 0.87 W, 4.3 V, 26%, respectively. Furthermore, in order to improve the extraction efficiency, this LED chip was molded by silicone resin. Consequently, the $P_o$ of the resin molded UV LED increased by 1.5 times and reached 1.5 W at a forward-bias pulsed current of 1 A at RT. Then the $\eta_{ex}$ was 44%.