AlInGaN Based Deep Ultraviolet Light Emitting Diodes and Their Applications Technology

Prof. Asif Khan,
University of South Carolina, Columbia SC, USA

asif@engr.sc.edu

Several key application systems for air-water purification, polymer curing and bio-medicine require the use of ultraviolet light with wavelengths in the 250-300 *nm* range. Currently the mercury lamp is the primary deep ultraviolet (DUV) light source for these applications. As a potential replacement for mercury lamps, several global research teams are developing AlInGaN based DUV light emitting diodes (LEDs) and Lamps over sapphire and AlN substrates. The growth and processing technology for these devices is very challenging due to the high *Al*-fraction AlGaN layers needed for the deep UV emission region. The hetero-epitaxy of these high-*Al* content layers over sapphire or AlN leads to several issues such as high strain, large number of active region defects and excessive junction heating which limited the device efficiencies to around 1% in the early devices. Several different innovative material growth, device design and device processing-packaging approaches were then employed to mitigate these issues and yield devices suitable for commercial applications.

The current focus for the 250-300 *nm* deep UV LED research has been primarily towards increasing the output power, wall-plug efficiency (WPE) and device lifetime. To improve the internal quantum efficiency for sapphire/AlN based DUV LEDs, innovative high-temperature and pulsed epitaxial growth approaches are now being used to fabricate low-defect $Al_xGa_{1-x}N$ ($x > 0.4$) templates, heterojunctions and multiple-quantum-wells. These low-defect templates combined with new doping schemes enable the growth of highly conductive *n*- and *p*-type $Al_xGa_{1-x}N$ ($x > 0.4$) layers. In contrast to the first generation devices (WPE < 1%), these new *p*-GaN free device epilayer structures with the highly conductive $Al_xGa_{1-x}N$ layers also increase the output powers by avoiding absorption of the light travelling towards the *p*-contact thereby further increasing the efficiency.

In addition to the IQE improvement, research efforts are also targeting improved light extraction. This includes the use of substrate shaping and reflective *p*-contacts coupled with the exploration of new device geometries. The improvement in IQE and the light extraction has now yielded 270-280 nm DUV LEDs with powers as high as 4-8 *mW* at pump currents of 20 *mA* with WPE values as high as 3-6 %. These devices have stable operation under *cw*-pumping for well over 3000 hours. Finally large area deep UV LED Lamps are also being developed to get higher emitted powers by increasing the pump currents to well over 100 mA while still maintaining a lower current-density and hence increased device lifetimes. In these high-power devices the junction heating reduction is also achieved by employing new micro-pixel and substrate lifted-off device geometries. The Micro-pixel geometry DUV Lamps benefit from the use 20-60 μm diameter interconnected pixels. These Lamps yield powers as high as 25-40 *mW* at pump currents of 100 *mA*.

Several companies in the US, Japan and Korea are now supplying deep UV LEDs to system developers. The initially targeted systems are for air-water purification and bio-medical instrumentation. In addition to the supply of modest volumes of product development samples many global players are now undergoing expansion of their fabrication facilities to address the anticipated large volume market needs. It is exciting to see the real time maturing of a technology which was pioneered not too long ago in early 2000.

In this presentation we will review the key innovations in materials growth, device design and processing-packaging technologies that have led to devices with performance levels high enough for system applications. In addition latest results for the 250-300 nm emission DUV LEDs and Lamps over sapphire and AlN substrates will be presented. We will also discuss the design and performance of a DUV LED based water purification system.