Physics and applications of deep-UV LEDs

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III-nitride semiconductor-based deep-UV (DUV) LEDs are an enabling technology for diverse commercial, industrial, military, homeland security, biomedical and space applications. Until recently, AlGaN-based DUV LEDs were limited to wall-plug efficiency (WPE) between 1–2%, compared to much higher WPE for visible and near-UV LEDs reaching the record values of ~ 65%.

Improving materials quality and optimizing DUV LED design based on the device physics has allowed us to dramatically increase the DUV LED efficiency by more than a factor of 4. We will present an overview of our latest developments in the development of DUV LED technology with the main focus on novel device physics, including the effect of dislocations, Auger recombination in quantum wells, double scale fluctuating potential of localized states in quantum wells, strong nonuniformity in the emitted radiation across the device cross-section, and polarization induced hole gas in short period *p*-type superlattices that we use to increase the quantum efficiency.

Novel QW design has been implemented to suppress polarization effects and phonon engineering to increase electron trapping in the active layer of the devices. Very narrow (< 2.5 nm) and deep (total energy band offset > 0.4 eV) quantum wells were used to suppress Stark effect and increase radiative recombination. The active regions of DUV LEDs were embedded inside a deep potential well (larger than the optical phonon energy) to increase electron-LO phonon scattering and accelerate cooling of hot injected electrons. This allowed us to increase electron capture into the active region without using conventional electron "blocking layers" commonly used in visible LEDs.

Using a *p*-type ohmic contact that reflects in the DUV spectral range allowed us to significantly improve light extraction and increase output power of DUV LEDs by a factor of 2 times in the 275–300 nm range and a factor of 2.5 times in the 310–340 nm range.

We will also discuss how to improve light extraction and emission angle within the technological limitations of DUV LED design, consider aging mechanisms and device reliability issues and review the achieved device characteristics. Improved quality of epitaxial layers and device fabrication technology enabled to increase reliability of DUV LEDs and fabricate devices with peak emission wavelength in the 270–280 nm range with lifetime exceeding 10,000 hours for cw operation. We will also present reliability data for DUV LEDs operating under high current (up to 400 mA) in the pulsed operation mode.

New device fabrication technology allowed us to reduce ohmic contact resistance for DUV LEDs with peak emission wavelengths shorter than 250 nm. This resulted in the reduction of the forward bias from > 20 V to less than 8 V, making these devices suitable for cw operation.

We will also present recent results on 250–260 nm DUV LEDs qualified for space applications, which include reliability testing up to 26,000 hours (cw mode), shake and bake, and radiation hardness.