Control of light emission angle and light extraction efficiency in deep-ultraviolet light-emitting diodes using Fresnel zone plates

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Fresnel zone plate (FZP) is a two-dimensional structure that uses diffraction and interference of electromagnetic waves. It is widely applied in focusing techniques, such as nano-focusing of x-rays. For the flip-chip deep-ultraviolet light-emitting diodes (DUV-LEDs) on AlN substrate, we can use dry etching technology to fabricate FZP on the AlN substrate to control the light emission angle and enhance the light extraction efficiency (LEE). In this study, we mainly discuss the influence factors of the light emission angle and LEE using FZP in DUV-LEDs.

The conventional amplitude-type FZP controls the light emission angle by forming transparent and opaque rings alternatively to make the light interfere constructively. However, the diffraction efficiency of the amplitude-type FZP is very low, and therefore the LEE of the LEDs may be degraded if it was used in the DUV-LEDs. In contrast, Phase-type FZP uses transparent materials in all rings, which can make the LEE much higher than that of the flat structure LEDs. As a result, the light emission angle can be effectively controlled associated with an enhancement of LEE by fabricating phase-type FZP on the light extraction surface of LEDs. The phase-type FZP controls the light emission angle by delaying a π phase for the two beams of light with an optical path difference of $\lambda/2$ to generate a constructive interference. The depth and sidewall angle of the FZP formed on the substrate could greatly affect the light emission angle of the LED by affecting the phase shift of the light when it propagates through the transparent material. It can also modulate the intensity of the zero-order diffracted light and the high-order diffracted light, and finally affect the full width at half maximum angle of the emission pattern. The F-number, which is defined as the ratio of the focal length and the diameter of the FZP, has a significant effect on the LEE of device. Our research shows that a low F-number of the FZP is required to enhance the LEE of the DUV-LEDs and make light beams much more converge at the place of the zero-order diffracted light through the FZP. The FZP is formed on the light extraction surface of the LED, the focal length of the FZP is therefore equal to the substrate thickness in flip-chip DUV-LEDs. It is therefore a fabrication of FZP with large diameter is desired. As a result, we need to control the etched depth and sidewall angle of the FZP in order to control the angle of the light emitted by the LED. At the same time, a large area of FZP fabrication is desired in order to improve the LEE of the LED and to make the beam converge as much as possible at the zero-order diffracted light. More details will be present at the conference.