Enhanced color-conversion efficiency in nano-grooved LEDs utilizing non-radiative energy transfer

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Recently, the development of light-emitting diodes (LEDs) has been widely studied for practical applications in the field of sold-state lighting. As the technologies for fabricating GaN-based LEDs and for synthesizing semiconductor colloidal nanocrystals (NQDs) mature, Colloidal QD-GaN LED are becoming promising candidates for highly efficient multicolor lighting[1-3]. Many researchers have demonstrated color-conversion LED consisting of a LED and colloidal QDs that promotes efficient non-radiative energy transfer from a higher-energy epitaxial light source to lower-energy emission fluorophores has been proposed. Achermann et al [4]. demonstrated an efficient way of color conversion, exciton transfer was limited. This is because only one quantum well could contribute to the color conversion though the non-radiative energy transfer process. Chanyawadee et al [5]. used an LED structure epi-wafer having holes with elliptical cross-sections that reach down to the active QWs. This work uses LED structures following standard microfabrication and additional nanopatterning techniques including nanoimprint lithography as well as plasma etching such as inductively coupled reactive ion etching. Nevertheless, the performance of this device is not comparable with that of conventional lateral type LEDs.

In this study, we have investigated color-conversion efficiency in nano-grooved Light emitting diodes utilizing non-radiative energy transfer. For this purpose, we design square patterned ITO layer on p-GaN layer as a self-aligned etch mask has been investigated. In addition, we also demonstrated nano-grooved LEDs by using self-assembled ITO nano-dot etch mask into the square patterned ITO layer on p-GaN layer. Colloidal QDs have been deposited into the gaps between the InGaN/GaN MQW nano-grooved LEDs, leading to thin p-GaN coupling between the QDs and InGaN/MQW emitter. The results will show that the nano-grooved LEDs are high color conversion efficiency and the calculated recombination rate of non-radiative QD-QW energy-transfer compare to ITO patterned LEDs. A 2 um thick undoped GaN was grown on a sapphire substrate followed by a 2 um thick n-GaN. The active layer consisted of five InGaN/GaN QWs and a 150 nm thick p-GaN was grown on top. The Reference-LED is fabricated by using the standard LED fabrication process as described above. The Nanotextured-LED is also fabricated by using the same standard LED fabrication process except for additional nanotexturing steps after the p-contact metal photolithography and deposition. Following the p-metal photolithography and deposition step, ITO layer was deposited onto the micro-patterned p-contact metal slot using an electron beam evaporator. The sample with the ITO/micro-patterned p-contact metal slot was dipped into chemical solution containing HCl, which results in the formation of nano-dots from ITO films. The wafer is then etched in ICP/RIE by using the gas chemistry of Cl_2 /BCl_3 as the mesa etch recipe. We used CdSe/ZnS core/shell QDs as color-selectable phosphors. Following purification, the QDs were dissolved in toluene and spin-coated as a single monolayer onto an LED. Electrical and optical properties of tree type devices were measured by an on-wafer measurement system.

The results will show that the nano-grooved LEDs are high color conversion efficiency and the calculated recombination rate of non-radiative QD-QW energy-transfer compare to ITO patterned LEDs.

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