Enhancement of light extraction efficiency in vertical light-emitting diodes with MgO nano-pyramids structure

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GaN-based light-emitting diodes (LEDs) are attracting great interest as candidates for next-generation solid-state lighting, because of their long lifetime, small size, high efficacy, and low energy consumption. However, for general illumination applications, the external quantum efficiency of LEDs, determined by the internal quantum efficiency (IQE) and the light extraction efficiency, must be further increased. The IQE is determined by crystal quality and epitaxial layer structure and high value of IQE more than 70% for blue LEDs have been already reported. However, there is much room for improvement of light extraction efficiency because most of the generated photons from active layer remain inside LEDs by total internal reflection at the interface of semiconductor with air due to the high refractive index difference between LEDs epilayer (for GaN, n=2.5) and air (n=1). The light confining in LEDs will be reabsorbed by the metal electrode or active layer, reducing the efficacy of LEDs.

Here, we present the first demonstration of enhanced light extraction by forming a MgO nano-pyramids structure on the surface of vertical-LEDs. The MgO nano-pyramids structure was successfully fabricated at room temperature using conventional electron-beam evaporation without any additional process. The nano-sized pyramids of MgO are formed on the surface during growth due to anisotropic characteristics between (111) and (200) plane of MgO. The ZnO layer with quarter-wavelength in thickness is inserted between GaN and MgO layers to increase the critical angle for total internal reflection, because the refractive index of ZnO (n=1.94) could be matched between GaN (n=2.5) and MgO (n=1.73). The MgO nano-pyramids structure and ZnO refractive-index modulation layer enhanced the light extraction efficiency of V-LEDs with by 49 %, comparing with the V-LEDs with a flat n-GaN surface. The angular-dependent emission intensity shows the enhanced light extraction through the side walls of V-LEDs as well as through the top surface of the n-GaN, because of the increase in critical angle for total internal reflection as well as light scattering at the MgO nano-pyramids surface.