Enhancement of Light Extraction Efficiency in n-GaN Patterned Vertical Light-Emitting Diodes using Nanosphere Lithography

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Recently, vertical GaN-based light-emitting diodes (LEDs) fabricated by laser lift-off (LLO) have been widely investigated since they can provide a solution for high-brightness and high-power applications in areas where solid-state lighting systems. However, for the high-brightness GaN-based LEDs, the high refractive index of GaN (n=2.46) prohibits light extraction beyond a critical angle for the generated light to escape from the active region into the air (around 23^{o}) and it induced that only a small fraction of light can be extracted out of the device. Therefore, there is a still great need for improvements in the light extraction efficiency as well as in the internal quantum efficiency for high-power LEDs. Low-cost approaches to making patterns, using self-assembled polystyrene (PS) or SiO_2 nanospheres, have been employed to improve light extraction efficiency in nitride LEDs.

In this research, we report structural and optical properties of n-GaN patterned vertical LEDs fabricated using a nanosphere lithography (NSL) technique. Single layer of hexagonal close packed (HCP) PS nanospheres was coated onto the n-GaN layer by a simple spin-coating method. Reactive ion etching (RIE) with incident oxygen (O_2) plasma was performed to shrink the size of the PS spheres. For making hole patterns, a layer of Ni was deposited on the single layer of PS nanospheres by E-beam evaporation. This layer acted as a mask after remove the PS nanospheres. Inductively coupled plasma reactive ion etching (ICP-RIE) was used to make patterns with BCl_3 and Cl_2 gases. It was found that the optical power of the vertical LEDs with hole patterned n-GaN layers was enhanced by 4.1~4.9 times, as compared to that of the conventional Vertical LEDs. More details on the performance of vertical LEDs proposed in this work will be presented at the conference.

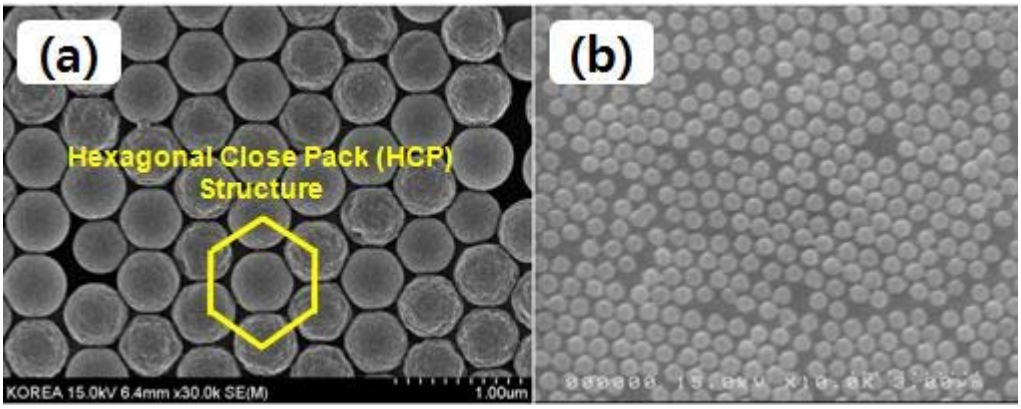

Figure 1: The SEM images of (a) the single layer of 500 nm PS nanospheres, (b) tailor the size of the PS nanospheres by RIE.

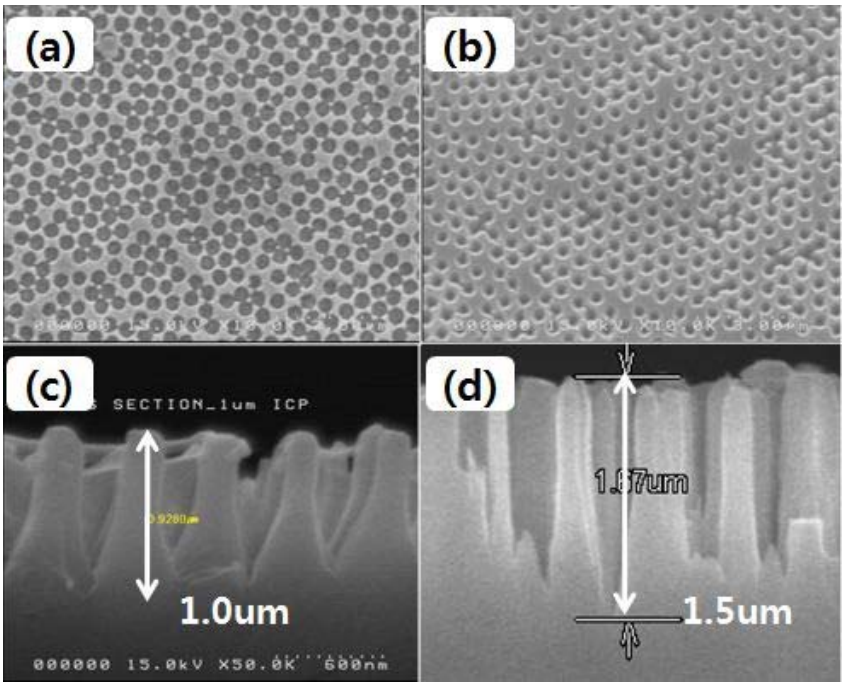

Figure 2: The SEM images of (a) the Ni etching masks, (b) Top view image of hole patterns, and the cross sectional view image of (c) 1.0um hole patterns, (d) 1.5um hole patterns.

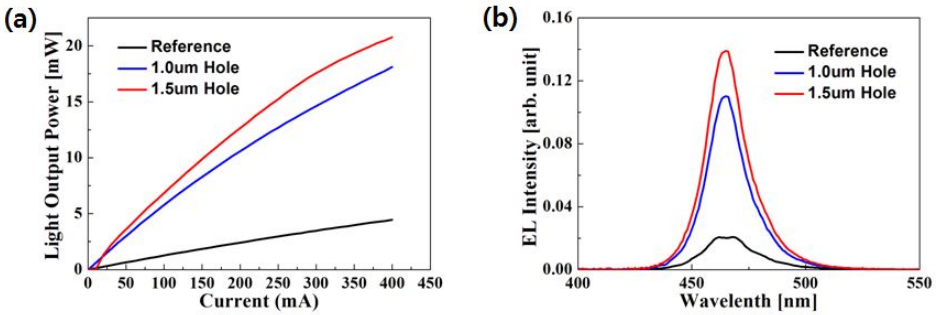

Figure 3: (a) The light output power vs. injection current (L-I) characteristics and (b) The electroluminescent (EL) characteristics