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Optimization of light out-coupling in optoelectronic devices using nanostructured surface

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Light-emitting diodes (LEDs) are emerging as a future market leader for indoor and outdoor lighting because it has higher energy-efficiency, longer lifetime, more compact size and more flexible spectral design, compared to the conventional incandescent lamp and fluorescent light tubes. In order to fully explore the potential of this new light sources, huge amount of effort has been made to enhance the light extraction efficiency, which is usually very low due to the large refractive index difference between the semiconductor materials and the air, thus is very crucial in order to improve the overall efficiency of the LEDs. In this paper we have developed various methods for two important semiconductors: silicon carbide (SiC) and gallium nitride (GaN), and demonstrated enormous extraction efficiency enhancement. SiC is an important substrate for LED devices. It has refractive index of 2.6, and only a few percent of light could escape from it. We have developed periodic nanocone structures by using electron-beam lithography, periodic nanodome structures by using nanosphere lithography, random nanostructures by using self-assembled metal nanoparticles, and random nanostructures by directly using the self-masking effect of thin Al films, as shown in Fig.1. All these nanostructures have shown increased transmittance or reduced reflectance compared to the bare surface. Fluorescent SiC samples show tremendous photoluminescence enhancement (up to 210%) after the surface nanostructuring. As active material for LEDs, GaN also has high refractive index of 2.4. So, it is also very important to extract more light out by roughening the surface. For GaN, the self-assembly method was applied. The same transmittance enhancement (15~20%) is demonstrated, similar to SiC. In addition to SiC and GaN, these developed methods could be applied to other semiconductors such as Si, etc. Furthermore, all optoelectronic devices having an optical interface such as solar cells, photo-detectors, could benefit from these developed methods for opto-electronic performance improvement.

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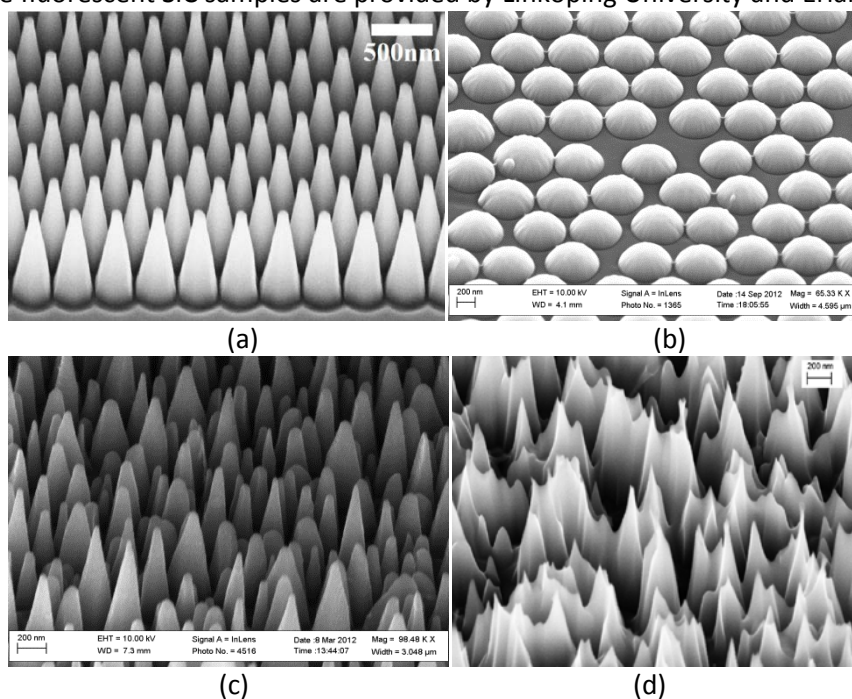


Figure 1. (a) Periodic nanocone structures by E-beam lithography, (b) Periodic nanodome structures by nanosphere lithography, (c) Random nanostructures by self-assembled metal nanoparticles, (d) Random nanostructures by Al thin films