LESLED

NANOSTRUCTURED LIGHT EXTRACTION SKIN FOR III-NITRIDE LEDS

KTH
CEA-LETI
CTH-Chalmers Institute of Technology

Project context and objectives

High refractive indices (~2.5) of most semiconductors (SCs) used in LEDs limit the fraction of light that can be extracted on from the device. Most of the light is trapped in the SC layer by total internal reflection. The total light emitted (into air) out of a flat semiconductor surface is only a few % (typ. 6-10% for III-Nitride around 450nm), limiting the overall LED efficiency. Thus, tremendous R&D efforts and resources have been invested to overcome this limitation. Most efficient approaches rely on direct structuring of the GaN material, which is difficult to implement in device structures having thin surface layers.

The project addresses methods for enhancing light extraction in visible LEDs based on III-Nitride semiconductors. Specifically, the project develops a photonic nanostructure layer provided at the top of the LED for efficient light extraction. Such a layer is beneficial from a processing point of view since direct structuring of the LED material can be avoided. The target is to achieve light extraction efficiency in excess of 70% at the same time providing new solutions for LEDs where the device layer thickness is too small to use conventional KOH etching as well as in situations where non-planar chips prevent the direct use of conventional lithography techniques. In addition, the LES concept can be adapted for NIR LEDs, photo-detectors and PV.

Brief description of the main results

The nanostructure light extraction layer design was optimized and 3D-FDTD simulations show that light extraction efficiencies up to 50-60% can be obtained on realistic vertical thin film LEDs or thin-film flip-chipped LEDs

The optical interface between the light extraction layer and the GaN top surface was investigated by numerical simulations of light extraction as well as reflectivity. The simulations indicate that the material (refractive indices) and light coupling properties of the optical interface are wavelength sensitive and play a critical role. As a simpler approach, experimental investigations focused on reflectivity and confirm the trends predicted by simulations. Thus, the design of a light extraction layer has to take into consideration the actual optical interface resulting from typical fabrication methods.

The technology effort included the growth of GaN/InGaN wafers, dry etching to nanostructure the GaN surface, growth of a thick ZnO seed layer and ZnO nanowires on GaN by a wet chemical approach. The project is planned to continue to investigate nanostructuring of the ZnO layer and implement this in LED device structures. ZnO nanowires grown on GaN substrates show random orientation and high surface coverage. The project is now in the implementation stage of these approaches on real LED structures and characterization.

Potential impact of project results

Although there are several technological challenges to overcome, implementation of the surface nanophotonic layer has major consequences on the development of efficient green emitting III-Nitride GaN LEDs in which the stress induced by higher In concentration (in InGaN) limits the thickness of available GaN for direct structuring. It is also relevant in situations where non-planar chips prevent the direct use of conventional lithography techniques. In addition, the general design guidelines for the nanophotonic layer can be adapted for NIR LEDs, photo-detectors and PV.