Improvement of external quantum efficiency of blue and green InGaN LEDs using corrugated interface substrates

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In recent years, an extensive investigation has been undertaken by many research groups in order to improve the external quantum efficiency (EQE) of InGaN-based blue and green light emitting diodes (LEDs), and several approaches have been proposed and demonstrated. Since its first demonstration in 2001 [1], the use of the corrugated interface substrate (CIS) technology appears to be very promising [2,3] due to the minimization of total internal reflection at the Sapphire/GaN interface.

Here we present our recent results on the improvement of external quantum efficiency of blue (450 nm) and green (550 nm) InGaN LEDs by the use of CIS technology. Four different combinations of CIS geometries have been designed and fabricated (Table 1.) with the aim of maximizing efficiency improvements. The blue and green emitting structures were grown on CIS substrates with micro lenses of varying size and spacing [4]. We demonstrated an improvement of EQE for the CIS structures over flat substrates of up to 34% (Fig 1.) for the green (550 nm) and up to 20% for the blue (450 nm) LEDs using the design with a 2.5-µm truncated cone geometry in a 6.5 µm hexagonal lattice. These results can be explained by the greater Stokes shift in green LEDs, and hence, less absorption in the active region (with twice the absorption at 450 nm compared to 550 nm). Moreover the metallic contacts and p-GaN cladding layer also have higher absorption in the short wavelength region.

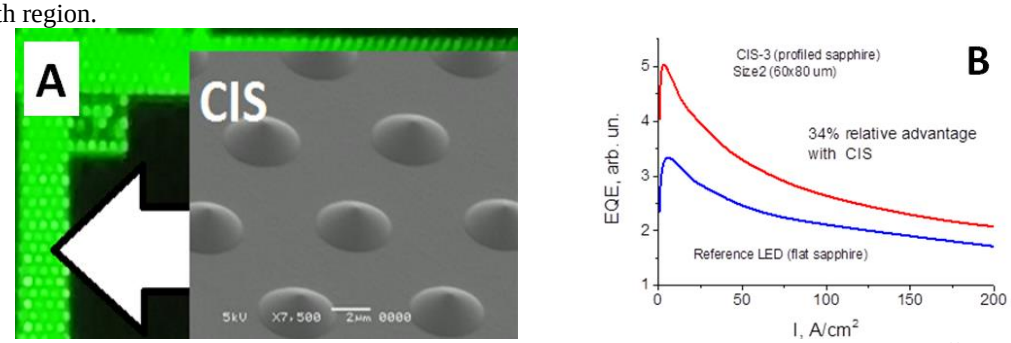

Fig. 1. A – SEM microcones image and InGaN green emitting LED with CIS substrate; B - External quantum efficiency versus current of green emitting CIS and flat reference chips.

Future work will focus on increasing the fill factor up to the MOCVD epi-technology limit and investigation of a monolithic two-color LED design that will allow a direct comparison of light extraction efficiencies for green and blue wavelengths.

Table 1. Parameters of the investigated four CIS geometries with various sizes and shapes of CIS cones.

CIS variant	Diameter (nm)	Lattice type	Lattice constant (µm)	Shape	Fill factor	Average relative EQE
1	1600	Hexagonal	6.5	Cone	0.055	19.6%
2	1600	Hexagonal	8.5	Cone	0.032	19.8%
3	2500	Hexagonal	6.5	Truncated cone	0.134	22%
4	2500	Hexagonal	8.5	Truncated cone	0.078	12%

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35 word abstract:

We demonstrated an improvement of external quantum efficiency in blue (20%) and green (34%) InGaN based light emitting diodes by the use of the optimized cone shaped Corrugated Interface Substrate technology.