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Blue Light Emission from Flexible InGaN/GaN Nanowires LED Structures Down to 3 mm Radius of Curvature

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The interest in flexible light-emitting diodes (LEDs) is growing in industries with foldable smartphones or unconventional surfaces (glasses, windshields, or a new generation of e-paper), and some more specific applications can also be found in biomedical research. Compared to organic LEDs, devices based on inorganic semiconductor LEDs (ILEDs) present the advantage of high luminance and brightness. Additionally, these ILEDs are much more promising as far as downscaling is concerned, but the main issue is the difficulty of processing a flexible ILED. Recently, a fabrication method has been reported for elaborating flexible LEDs with self-organized GaN-based nanowires (NW) [1]. In this work, we extend this technique to the fabrication of flexible blue LEDs using a periodic array of core/shell semiconductor NW obtained by selective area growth (SAG) [2].

GaN/InGaN NWs with a typical diameter of $\sim 1 \mu\text{m}$ and height of $\sim 7 \mu\text{m}$ were grown on a GaN-on-sapphire template by MOVPE, using a dielectric selective mask, with a typical pitch of $\sim 1.5 \mu\text{m}$. CL spectra showed two different peaks, one centered around 400 nm and the other around 450 nm, related to the NW hexagonal shape with a pyramidal top, and corresponding respectively to the emission from the side facet (non-polar) and the top facet (semi-polar).

The fabrication process roughly follows the proposal of [1]. First, PDMS is spin-coated on the NW to fully encapsulate them and peel them off the growth sapphire substrate. This membrane is flipped onto an arbitrary host substrate to metalize the bottom of the NW with the appropriate n-contact (Ti/Al/Ti/Au). The membrane is then transferred n-side down onto an adhesive metallic foil that acts as an extension of the n-contact with another flip. After that, the PDMS that covers the top of the NW is dry-etched to allow the deposition of a semi-transparent p-contact (Ni/Au). Finally, Ag NWs acting as a semi-transparent electrically-conductive layer (typical resistance $R_{\square} = 10 \Omega/\text{sq}$) are drop cast on the sample surface to promote the NW interconnection. After the localization of silver paint macro-pads on the top, electrical contacting was performed between a microprobe localized onto these pads and the n-side common backside contact.

NW macro-LED properties (I-V curves, EL spectra, and surface emission imaging with a CMOS camera) were retrieved under CW current injection using a specific characterization bench that made it possible to operate the LED either flat or bent down to a radius of curvature (ROC) down to 3 mm. To achieve this, the LED device was fixed between an exchangeable cylinder with a given ROC at the bottom, and two smaller cylinders at the top. The two top cylinders are placed on both sides of the device to push it onto the bottom cylinder to bend it reproducibly according to its ROC. The whole is designed to maintain the LED surface at a fixed height when the ROC is varied. The open area of $\sim 50 \text{ mm}^2$ between the two top cylinders allows for the optoelectrical characterization of the LED so that we can measure the EL spectra from the top of the device, between the two top cylinders.

We were able to successfully measure the EL spectra for a flat LED and for ROC of 8, 5, and 3 mm. No significant changes were observed in the emission of the LEDs in terms of optical power and EL spectra peak wavelength. Emissions from the non-polar and the semi-polar planes were obtained, but mostly from the non-polar plane. Some emission inhomogeneities were evidenced from CCD camera imaging, showing that not all the NW were contacted simultaneously, leading to low brightness. In further processing, current injection could be drastically improved by modifying the p-contact, and by downscaling the process to isolate micro-LEDs.

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