Wide band gap nanowires for LED applications

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Wide band gap semiconductors such as III- nitrides or II-oxides are materials of choice for blue to near UV LEDs applications, in particular for solid state lighting. Resorting to nanowires NWs of these materials opens up news possibilities in terms of device design, related for instance to their high surface/volume ratio, or to the natural and easy light extraction efficiency. It is also speculated that doping difficulties, e.g. p type doping in ZnO, might be circumvented because of the low dimensionality of these nanostructures. After describing the issues related to solid state lighting, and how the use of NW LEDs might overpass these limitations, we will first present the state of the research on the subject. This will be followed by a description of some of our work at CEA/LETI, based on the use of either ZnO or GaN nanowires.

For MOVPE grown ZnO NWs, we could recently demonstrate the growth of core-shell ZnO / ZnMgO quantum well hetero-structures (Cf. figure 1) with a high room T° quantum efficiency of more than 50%. Interestingly, by varying the Mg concentration in the barriers of the core-shell heterostructures, it was possible to assess for the first time the plastic relaxation processes in these one-dimensional structures and to show that the optical efficiencies are clearly related to the absence of extended defects in the 1D radial structures. Selected area growth of ZnO NWs was also achieved on pre-patterned sapphire substrates opening the way to a better control of these radial heterostructures.

As for GaN NW based LEDs, we used MBE to devise axial p-n multiple InGaN / GaN quantum well heterostructures on n type silicon substrates. Thanks to the coalescence of the p-type Mg doped top region of the NWs grown at low temperature, some self-planarization can be achieved, which makes the LED technological integration much easier. The optimisation of the structure, for instance through the use of an electron blocking layer, led to clear blue to red emission under electrical injection, the emission wavelength depending on the indium concentration in the barrier. Local characterization was carried out through the use of combined electro- and photo-luminescence (EL , PL) in a confocal microscope, which allowed us to differentiate between material and electrical problems as the cause of non uniformities of the emission. As in the case of 2D LEDs, the observed blue-shift of the emission with increasing injected current is the signature of quantum confined Stark effect (QCSE).

To deal with this detrimental effect which is associated to the non centro-symmetry of the hexagonal material, one solution relies in using radial heterostructures - so call core-shell - : in this case , the quantum wells are grown along non polar surfaces (the side facets of the nanowire). Up to now, the growth of core –shell NWs can only be achieved by using MOVPE growth processes .

The LED NW heterostructure consists of an n-type GaN:Si core radially covered by InGaN/GaN quantum wells and a p-type GaN:Mg outer shell, the whole structure being grown onto 2 inch doped silicon. Micro PL and cathodo-luminescence revealed that there was no blue shift of the radial well emission wavelength with increasing injection current, clearly indicating the absence of any quantum confined stark effect. Room temperature continuous-wave electrical injection through the Si substrate is successfully demonstrated, producing blue electroluminescence at 450 nm in this vertically integrated 1cm²-chip nanowire LED.

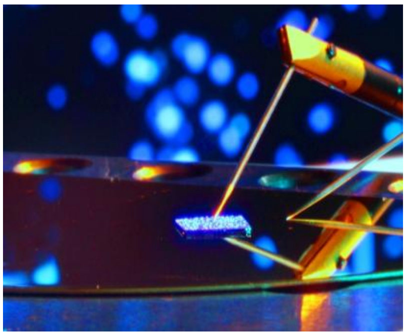

Figure 2: Electroluminescence of GaN based core-shell nanowires

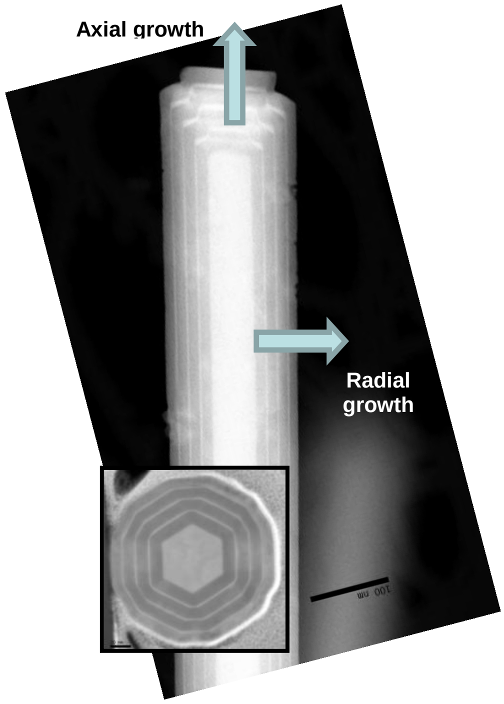

Figure 1 : STEM micrographs of a ZnO based core-shell nanowire