ESRF

Experiment title:

XBIC and XEOL studies of contacted p-n and blue LED wire-based structures

Experiment number: **MA- 2415**

Beamline: ID16B-NA

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Report:

- A first series of samples are grown at CEA INAC and have been contacted by Agnès Messanvi (PhD student) at Institut d'Electronique Fondamentale (Paris). The electrical and optical device properties have been tested before ESRF experiments. The metallic bondings being quite complex we concentrate the study to the complete wire-based LED structure shown in Fig. 1 with ohmic and schottky barriers.

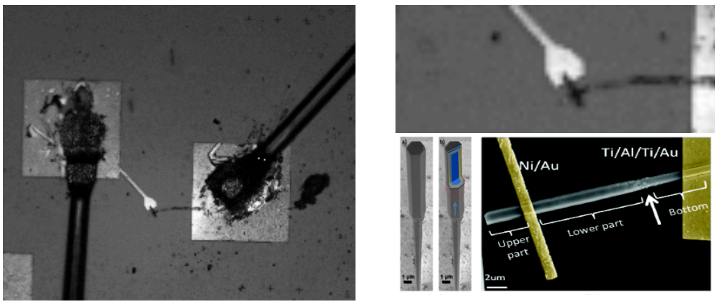


Fig. 1. Bonding of wires with InGaN/GaN core shell multiple quantum wells at the top of n-doped GaN template.
Left, Au wires are connected to chip pads for voltmeter or amperemeter measurements.
Right: the wire is connected on lithographic patterns by ohmic and schottky metal depositions (see details in the lower part of the figure).

- A second serie of sample corresponds to a planar LED structure with a back side contact has been realized at CEA Grenoble by Anna Muhktarova (see Fig. 2). The nature of the contacts (p-doped in the top and n-doped in the botton) allows current injection and voltage measurement.

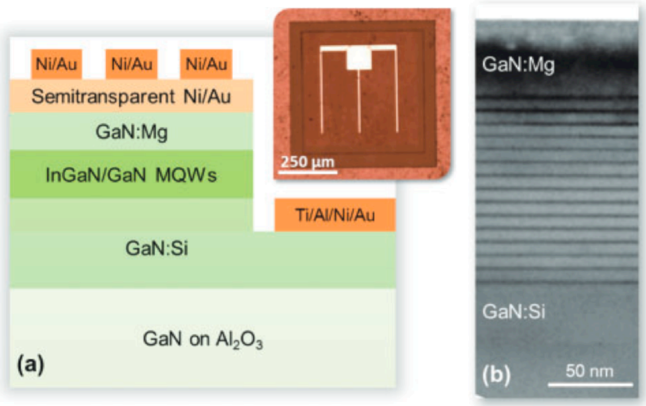
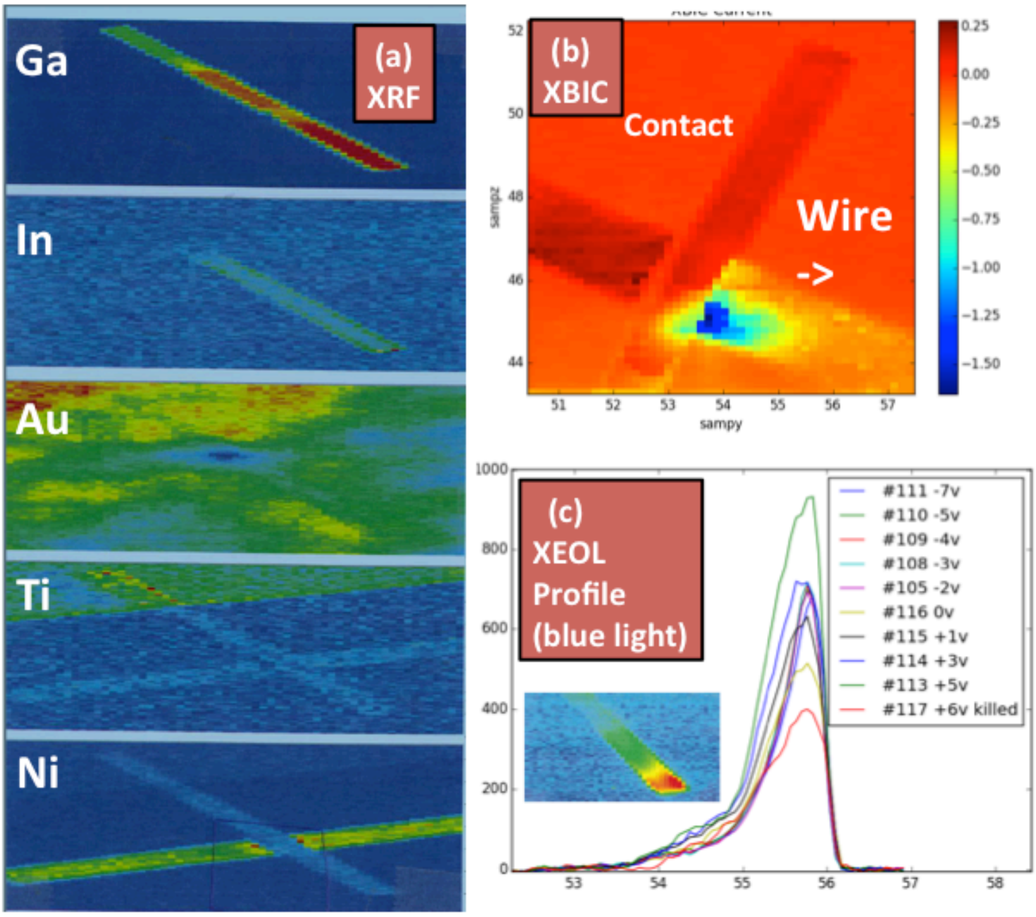


Fig. 2. (a) Schematic description of InGaN/GaN MQW solar cell structure used in this study as a LED device. This structure corresponds to the upper part of the shell of the wire shown in Fig. 1. Inset: Top-view optical microscopy image of a solar cell with 0.5x0.5mm^2 mesa.
(b) TEM image of n-GaN/i-MQW/p-GaN stack grown on vicinal c-sapphire.

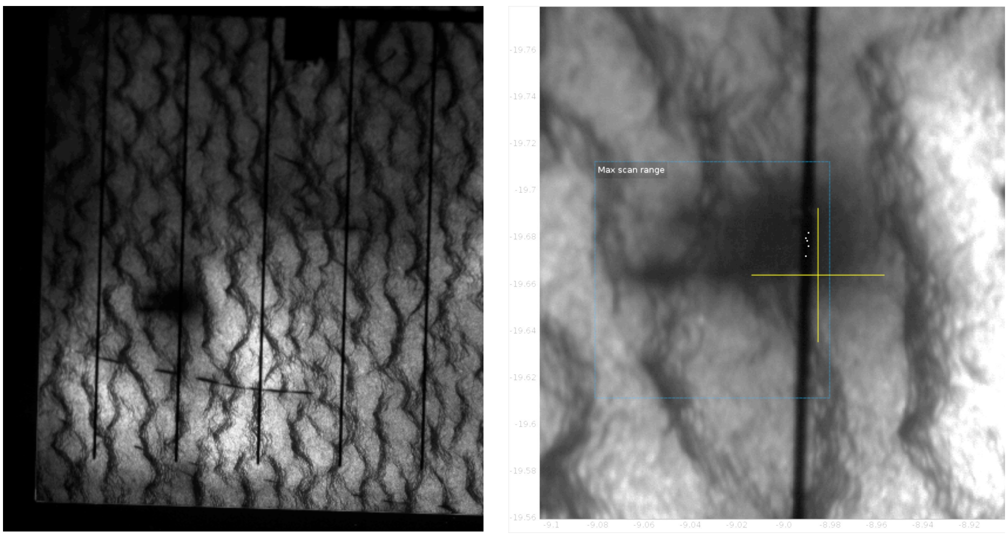
The excitation of hard X-rays (29.6 keV) has been used to generated carriers both in contacted wire-based structures and planar devices. We were able to collect the current and measure XBIC, but also XEOL thanks to mappings that discriminate the blue colour coming from the design of the multiple quantum wells (In composition, thickness...) from the yellow-defect band. In parallel, we measure the In composition from XRF mappings. Some illustrative results are presented in the figures 3 and 4.

<u>Wire-based LEDs:</u>



<u>Fig. 3.</u> Example of: (a) X-Ray Fluorescence analysis showing Ga, In (wires) and Au, Ti, Ni contacts (see Fig. 1, right). (b) X-ray Beam Induced Current (image rotated with respect to (a)). (c) X-ray Excited Optical Luminescence mapping of the blue light emission (inset) as well as its profile changes as a function of the applied tension to the device shown in Fig. 1.

<u>Planar-based LEDs:</u>



*<u>Fig. 4.</u> Example of:
Left: microscope view of planar device illuminated by the LEDs emission at 3V. Background structure is coming from the vicinal surface.
Right: zoom showing the scanned area for this experiment. Note the line corresponding to line scans.*

Measurements have been also performed without beam, with microscope ON/OFF, room light ON/OFF to have convenient references for the quantitative analysis of the data. We also evaluated defects induced by radiation to take care about artefacts.

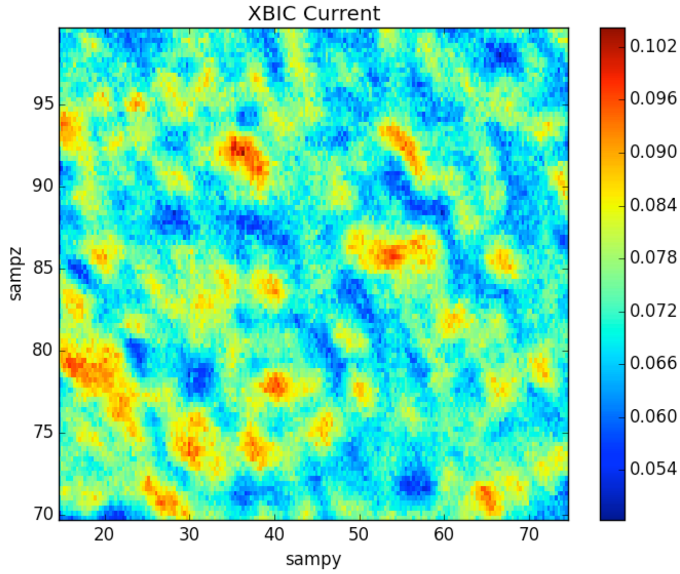


Fig. 5. *Example of XBIC mapping (nA units for intensity, microns for length) for an area similar to that shown in Fig. 3 (left).*
Such mappings have been also done along lines to save time and to measure both XRF and XEOL.

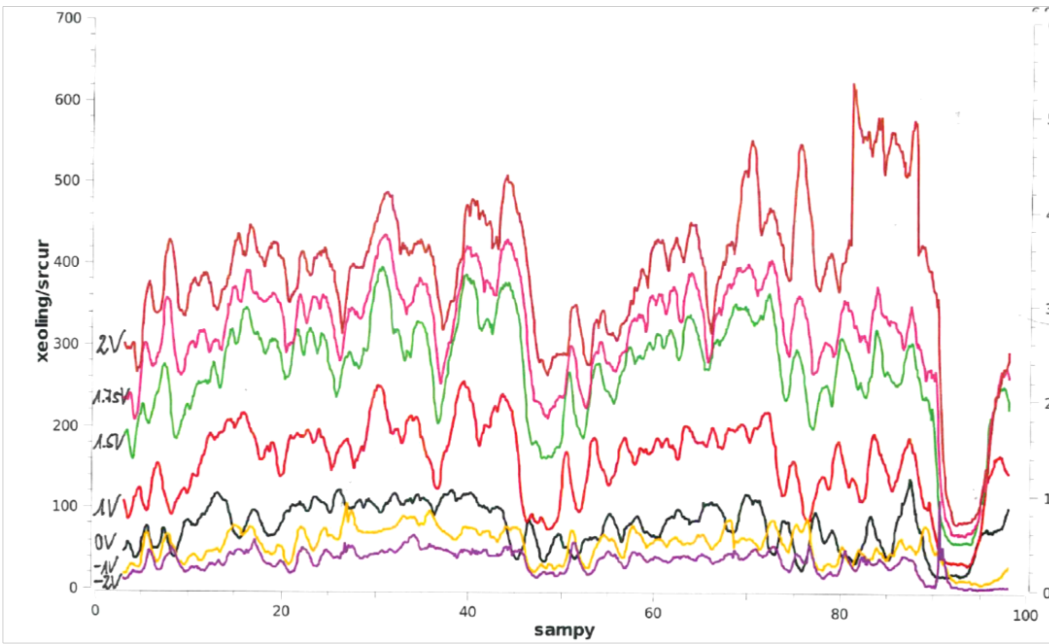


Fig. 6. *Example of the evolution as a function of the voltage (-2, 2, 0, 1, 1.75, 2 V) of the blue XEOL. The tension is below the LED threshold shown in Fig. 4 that blurs the X-ray excitation.*
The filling of zones where carriers localizations occur has been carefully studied.

We are very satisfied of the results we get from this experiments that are really original in the literature and also impressed by the ID16 beamline setup and environment quality. All the expected results of the proposal have been obtained, i.e.:

- The tuning of the junction collection, transport efficiency and light emission as a function of the direct and reverse bias.
- The measurement of XBIC excitation that will be compared to EBIC excitation.
- The homogeneity of light emission (carriers recombinations) that provides clear correlation distances at the mesoscopic level (i.e. not related to short-range order and not at a large device scale).

These results will be presented as invited paper in the 11th International Conference on Nitride Semiconductors (ICNS-11), August 30th - September 4th, 2015, Beijing, China and a regular publication is under writing.

It opens the way of very interesting studies dedicated to the development of a spectroscopic mode of the emission in using the spatial resolution of the beam (and perhaps temporal resolution and low temperature) of the ID16 setup to quantify alloy fluctuations that are so particular (and useful) to nitride devices. We hope to propose such experiments in the September 2015 round.

We thank the ID16 staff, especially Damien Salomon, for his huge contribution to the success of this experiment.