ESRF	Experiment title: Micro-diffraction and micro-fluorescence and micro-XAS of compositional gradiented Multiple Quantum Well (MQW) Electro-Absorption Modulated Lasers (EML)	**Experiment number**: **MA-524**
Beamline: ID22	**Date of experiment**: from: 30/04/2008 to: 05/05/2008	**Date of report**: 01/10/2009
Shifts:18	Local contact(s): Gema Martinez Criado	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Lorenzo Mino[(1*)], Diego Gianolio[(1*)], Giovanni Agostini[(1*)], Andrea Piovano[(1*)], Marco Truccato[(2*)], Angelo Agostino[(3*)], Stefano Cagliero[(2,3*)], Simone Codato[(4)], Carlo Lamberti[(1*)]

[(1)] Department of Inorganic, Materials and Physical Chemistry, NIS Centre of Excellence, University of Turin, Italy.
[(2)] NIS Centre of Excellence, Department of Experimental Physics, University of Turin, Italy.
[(3)] NIS Centre of Excellence, Department of General and Organic Chemistry, University of Turin, Italy.
[(4)]Avago Technologies Italy S.r.l., Torino Technology Centre, Turin, Italy.

Advanced optoelectronic devices require the monolithical integration between different functions at chip level. This is the case of Multi Quantum Wells (MQW) Electroabsorption Modulated Laser (EML) employed in long distances high frequency optical communications. Such devices are realized by monolithic integration of a Electro Absorption Modulator (EAM) with a Distributed FeedBack laser (DFB) using the Selective Area Growth (SAG) technique. SAG is based on the fact that deposition doesn't occur on semiconductor areas covered by a dielectric material mask (usually SiO_2). Species that impinge the mask can desorb or migrate through the unmasked semiconductor where the growth can take place. This means that reactive species coming from the gas phase are enriched by those coming from the mask in the neighborhood of it. Since the reactive species have different diffusion lengths, the result is a variation in composition and thickness of semiconductors grown near (SAG region) and far (field region) from the mask (Fig. 1). Optimization of the growth parameters is done by empirical approaches as no direct structural characterization of the MQW is possible with laboratory X-rays sources, owing to the μm-variation of composition and thickness inherent to the SAG technique. We exploited the μ-beam available at the ID22 beamline in order to directly measure the determinant structural parameters of a $Al_{xw}Ga_{yw}In_{1-xw-yw}As/Al_{xb}Ga_{yb}In_{1-xb-yb}As$ (compressive-strained well/tensile-strained barrier) MQW EML structure, grown on InP by MOVPE.

In Fig. 2a we report few CCD images obtained by rotating the sample around the InP(004) reflection: integrating the diffracted intensity at 176 different angular positions we obtained a standard full XRD pattern. This procedure was repeated for 35 different spatial points along the Y-line (Fig. 1), see Fig. 2b where a selection of patterns is reported. With such data, it is possible to obtain the width (w_b, w_w, Fig. 3a) and the mismatch (m_b, m_w, Fig. 3b) of the barrier and of the well performing a fitting of the observed pattern in the frame of the dynamic theory of X-ray diffraction (Fig. 2c). These are the key information that coupled with the μm-determination of the energy gap by photoluminescence allows to understand the structural gradient of the MQW structure along the Y line from SAG to field region. Both w_b and w_w undergo a modulated increase moving from field to SAG regions (Figure 3a): this is the direct measure of the material enriching in the SAG region. Both m_b and m_w values decrease almost monotonically moving from SAG to field (Fig. 3b) reflecting the expected modulation of the $Al_xGa_yIn_{1-x-y}As$ composition of both barrier and well layers, that allow to obtain two MQW heterostructures with two different functions monolithically integrated in the same epitaxial growth (see Fig. 1). The overall mismatch, $m = (m_b \bullet w_b + m_w \bullet w_w)/P$, is progressively reduced from (+1300 ppm, compressive strained MQW) in the SAG region, to almost zero (strain compensated MQW: -100 ppm) in the field region.

The results obtained from the μ-XRD study were further confirmed by a μ-X-Ray Fluorescence (XRF) study reported in Fig. 4. The increased counts In the SAG region observed in the As Kβ map (Fig. 4). are

due to the higher growth rate induced by the additional precursor flux coming from the SiO_2 stripes, visible as low counts region, where no growth occurs. The presence of a gradient in the average well/barrier chemical composition is directly visible in the map reporting the ratio between Ga and As counts (Fig, 4). In the SAG region the Ga/As ratio is lower then in the field: this means that the Ga content of the quaternary progressively decreases along the Y line by moving from field to SAG. This is a direct measurement of the SAG effect due to the shorter diffusion length of In with respect to that of Ga and Al.

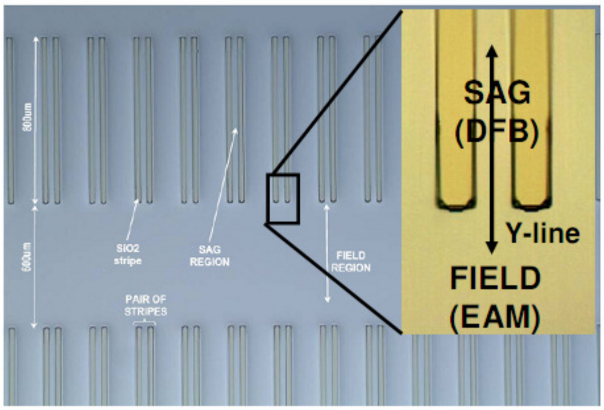

FIG. 1. Optical micrograph of the SiO_2 stripes-patterned InP substrate allowing SAG growth.

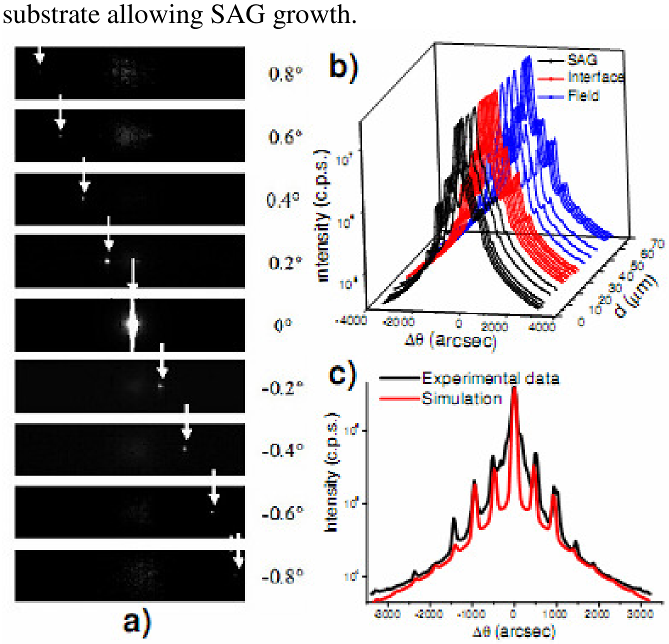

FIG. 2. a) Selection of 9 CCD images (out of 176) used to reconstruct a single XRD pattern. The rotation of the sample along the θ-angle allowed us to collect scans around the InP(004) reflection (which is visible at 0° rotation). b) Selection of some of the 35 full XRD patterns collected along the Y-line (see Fig. 1) starting 30 µm before the end of the stripes in the SAG region. c) Example of comparison between experimental and simulated XRD patterns.

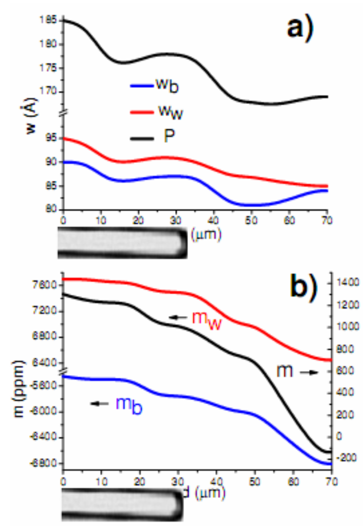

FIG. 3. a) Barrier and well widths and period as a function of the position along the Y-line, obtained by simulation of the 35 experimental XRD patterns (the image at the bottom shows where the masked region is). b) As part a) for the well, barrier and overall mismatches

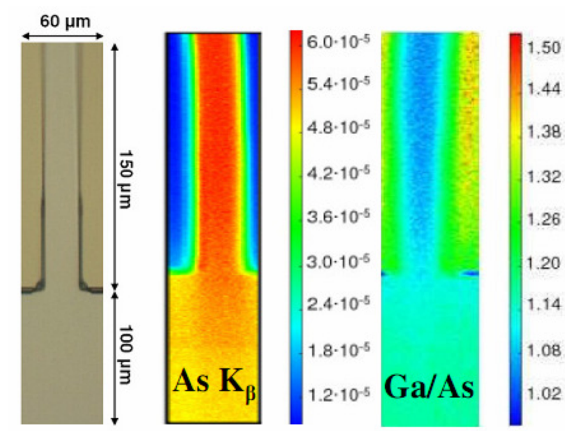

FIG. 4. Spatial maps of the fluorescence counts (beam energy 17 keV) of the As Kβ and of the ratio between Ga Kα and As Kβ. The optical micrograph on the left shows the area that has been sampled. The last map highlights the change in the average (between well and barrier) $Al_{lx}Ga_yIn_{1-x-y}As$ quaternary composition.

More details are reported in an article recently submitted manuscript [1].

[1] L. Mino, D. Gianolio, G. Agostini, A. Piovano, M. Truccato, A. Agostino, S. Cagliero, G. Martinez-Criado, S. Codato, and C. Lamberti, Structural characterization of multi quantum wells electroabsorption modulated laser by synchrotron radiation µm-beam, *submitted to Adv. Mater.*