Deep analysis of Selective area growth InGaAlAs SAG MQWs structures using micro beam high resolution X-ray diffraction and micro photoluminescence

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Recently InGaAlAs materials system has been successfully utilized for directly modulated lasers operating at 10 Gb/s at high operation temperatures (>100 °C) and for high-speed 40 Gb/s electro-absorption modulators. The superiority of this material system compared to the traditional InGaAsP/InP for these specific applications is due to its larger conduction-band gap offset. On the other hand, the development of Selective Area Growth (SAG) of strained InGaAlAs multiple quantum well (MQW) structures is a very promising approach for a new generation of integrated optoelectronic devises. Up to now little is known about effective diffusion length ***D/k*** for Al precursor and other specifics of Selective Area Growth of MQW structures with the three group-III elements (In, Ga, and Al).

In this study we combined two experimental approaches: (*i*) a novel technique of micro-beam High Resolution X-ray diffraction at the CHESS A2 wiggler beamline and (*ii*) conventional Photoluminescence (PL) technique with 4 µm diameter of the laser beam in order to analyze InGaAlAs-based MQW SAG structures. SAG samples were grown in a commercial EMCORE MOVPE reactor on 2-inch InP substrates at low pressure, a growth temperature of 600 °C, and with growth rates between 1 and 2 Å/s. We investigated a standard 1.3 µm InGaAlAs MQW laser structure with seven periods of quantum wells. In the field parts of the wafer (far from the SiO_2 mask) the period of MQW was 147 Å and composition of the quantum wells and barriers were $In_{0.65}Ga_{0.19}Al_{0.16}As$ and $In_{0.48}Ga_{0.19}Al_{0.33}As$, respectively. These compositions of the well and barrier materials correspond to a composite strain of 0.24% in the MQW part of the laser structure. SAG structures were grown between two 600 µm-long SiO_2 mask stripes with the stripe width ***A*** and the opening between two mask stripes ***B***. About 100 different combinations of ***A*** and ***B*** were investigated, where the stripe width ***A*** changed from 15 to 140 µm and the opening ***B*** varied from 15 to 80 µm.

The micro-beam experimental setup is shown in Fig. 1 (see Ref. [1] for more details). A one-bounce imaging capillary with the working distance of 30 mm and gain of 75 produced an X-ray beam with the size of 10 µm and an angular divergence of 4 mrad. The energy of the X-ray beam was tuned to 12.5 keV. The position of the x-ray beam in the SAG structures was controlled by monitoring Ga-K and As-K fluorescence by using an energy dispersive XFlash detector. High angular resolution of 4 arcsec, which is sufficient for dynamic diffraction theory analysis of the measured diffraction spectra, has been provided by a three-bounce Si(004) channel-cut analyzer crystal. To obtain parameters of the measured SAG MQW structures, such as strain and thickness of the wells and barriers, the measured XRD diffraction curves have been analyzed using commercial RADS Mercury BEDE software.

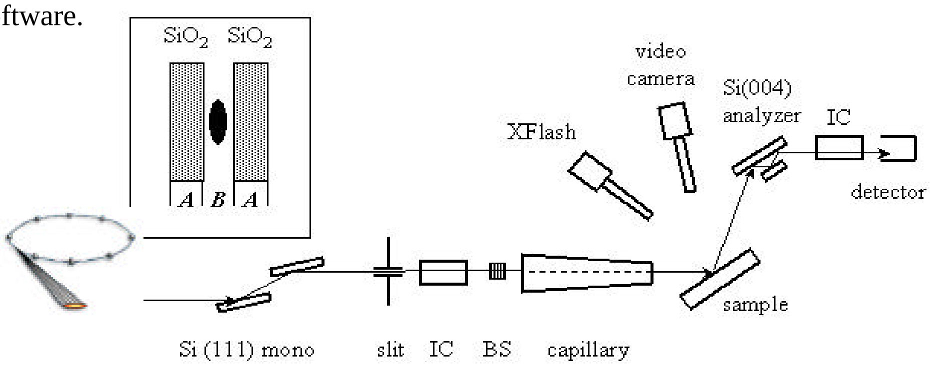

*Fig. 1. Micro-beam XRD setup at CHESS A2 beamline. Inset shows the x-ray beam position in the MQW SAG structure. The distance **B** separates the oxide stripes, which are shown schematically with rectangles with a length of 600 mm and a width **A**.*

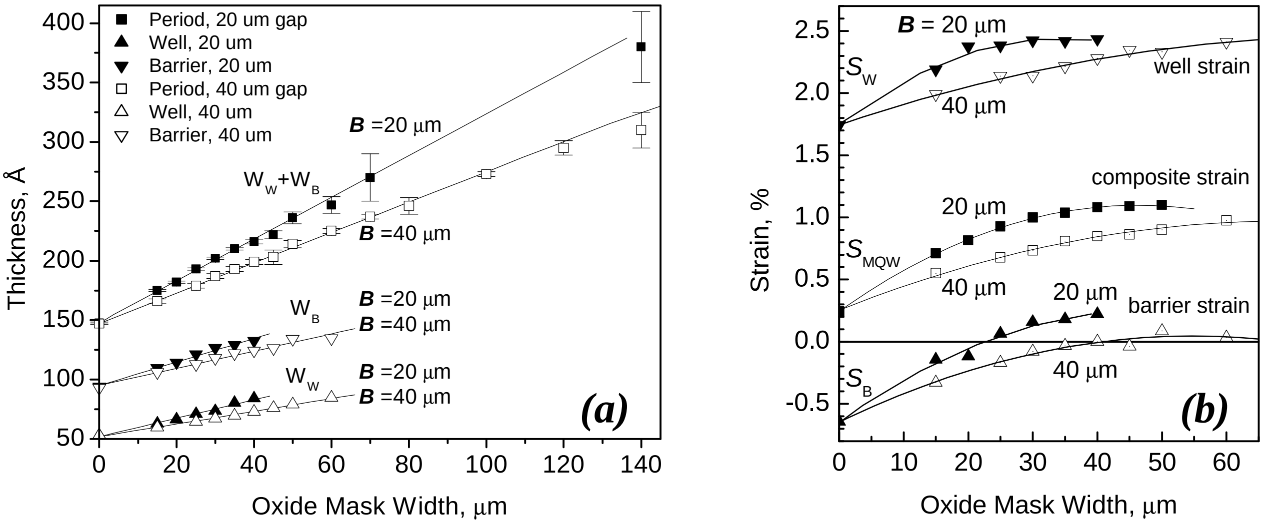

*Fig. 2. (a) Period of the MQW's $W_W + W_B$ and the thickness of the well and barrier layers measured for the MQW SAG structures as the oxide mask width **A** varied between 15 and 140 mm for two values of the gap between the oxide masks of **B** = 20 mm and 40 mm. (b) Strain measured in the same SAG structures.*

The thickness and strain variations in the quantum wells and the barriers in the SAG MQW structures have been analyzed for the oxide mask width ***A*** in the range of 15 to 140 µm with the gap between the oxide masks ***B*** in the range of 15 to 80 µm. Thickness enhancement ratio of tensile barriers and compressive wells have been determined as a function of the mask geometry [see Fig. 2(a,b)]. We have also analyzed structural changes between the perfect quality MQW's in the narrow-mask SAG structures with ***A*** ≤ 50 µm and relaxed MQW's in the "aggressive" SAG regime with the wide oxide masks ***A*** > 50 µm. We determined parameters of the SAG mask geometry that assess the quality of the grown MQW's and provide the superior photoluminescence efficiency. Micro PL revealed a strong variation of the confined MQW bandgap between 1.3 and 1.51 µm for simultaneously grown laser structures with different parameters of the oxide mask (***A*** and ***B***). In elastically strained MQWs with ***A*** ≤ 50 µm, the PL efficiency is 2 times higher compared to that in the field regions of the same wafer. The typical PL shift in our InGaAlAs-based SAG structures is close to that of the conventional InGaAsP-based structures with the same SAG mask parameters. For example, the PL shift in the SAG with ***A*** = ***B*** = 20 µm is about 100 nm for both InGaAlAs (this work) and InGaAsP-based MQW's [2]. This experimental observation demonstrates a big potential of the InGaAlAs SAG structures for integrated EML devices and laser arrays in the range between 1.3 and 1.5 µm.

Based on the combination of x-ray results for the strain and micro PL data, we calculated the composition variation in the well material for the elastically strained SAG structures. The increase of In composition in the wells is from 0.65 up to to 0.7 in the SAG with ***A*** = 60 µm. The composition of Ga decreases in the well by approximately the same amount. This result is in qualitative agreement with the short diffusion length of In (a typical value of ***D/k*** is about 30 µm) and the longer diffusion length of Ga (***D/k*** is about 120 µm). The composition of Al stays practically unchanged at a level between 0.15 and 0.16 suggesting a significantly longer diffusion length for the Al precursor compared to that for In and Ga.

In conclusion, we believe that the systematic studies presented in this paper will provide important experimental background for the SAG modeling and will stimulate the progress in design of integrated optoelectronic components based on InGaAlAs material system.

References

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