InAlGaAs/InP MQW Structures Grown by MOVPE in Nitrogen Atmosphere for 1.55 µm VCSELs

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Abstract

1.55 µm emitting InGaAlAs/InP MQW vertical cavity surface emitting lasers (VCSEL) structures grown by MOVPE under nitrogen atmosphere are presented. Structure design and growth conditions were optimized in order to obtain MQWs with high structural and optical properties. Electrically and optically VCSELs based on these active layers and fused AlGaAs/GaAs mirrors were opbtained. On optically pumped VCSEL a single mode CW emission power of 3 mW at 24^{o}C and 1.2 mW at 73^{o}C were measured. An output power of more than 1.5 mW at 20^{o}C and 0.2 mW at 70^{o}C were achieved for single mode electrically pumped VCSEL.

1. Introduction

Long−wavelength VCSELs are among most promising low−cost light sources for local−area and long−haul fiber−based optical communication systems and optical interconnection. The main limitation to realizing commercial devices has been high−temperature performance. The most commonly used active material system for 1.55−µm emission is InP–InGaAsP, which is limited in VCSEL applications by poor temperature characteristics. In contrast, InAlGaAs/InP material system is very attractive for long wavelength emitting lasers due to superior high temperature performance compared with standard InGaAsP quantum well lasers. This advantage is due to the conduction band offset in InAlGaAs system, $dE_c = 0.72 dE_g$, is considerably larger than in InGaAsP system ($dE_c = 0.40 dE_g$) [1]. This larger conduction band offset has been predicted to result in better electron confinement in the conduction band and, therefore, higher temperature stability.

We describe here the MOVPE growth of strain−compensated InGaAlAs/InP MQW vertical−cavity 1.55 µm emitting structures in nitrogen atmosphere. The use of nitrogen as carrier gas in the MOVPE of III/V−based materials was proved to be effective in obtaining highly homogeneous and high purity layers and a reduction of carbon and oxygen incorporation in Ga(Al)As layers has been demonstrated [2]. To our knowledge, there are no publications on the growth of InAlGaAs/InP using nitrogen as a carrier gas. Results on high power and high−temperature operation VCSEL devices based on these structures, with both optical and electrical pumping, are presented.

2. Experimental procedure

InAlGaAs structures were grown by low pressure MOVPE under nitrogen atmosphere in an AIXTRON 200/4 reactor. The source materials were trimethylindium, trimethylgallium, trimethylaluminium, arsine and phosphine. Disilane and carbon tetrabromide were used as dopant sources. The V/III ratio was close to 100 and the growth rate was 1−2 µm/h. The MQW structure consists of 6 $In_{0.7}Ga_{0.2}Al_{0.1}As$ quantum wells (~1.2% compressively strained) surrounded by 7 $In_{0.41}Ga_{0.4}Al_{0.19}As$ barriers (~0.8% tensile strained) and InP cap and buffer layers. The QWs composition was tuned for a photoluminescence emission at ~1.53−1.55 µm with barriers with band gap at ~1.25 µm. Epitaxy was performed on (001) exactly oriented and 2 degree misoriented InP substrates at different growth temperatures in order to optimize the uniformity, as well as the optical and structural quality of the material. Grown structures were studied by standard room temperature photoluminescence (PL) measurement, Nomarski microscopy, Atomic Force Microscopy (AFM), Transmission Electron Microscopy (TEM) and high resolution X−Ray Diffraction (XRD).

3. Growth results

Figure 1a shows the dependence of the room temperature PL intensity on the growth temperature.

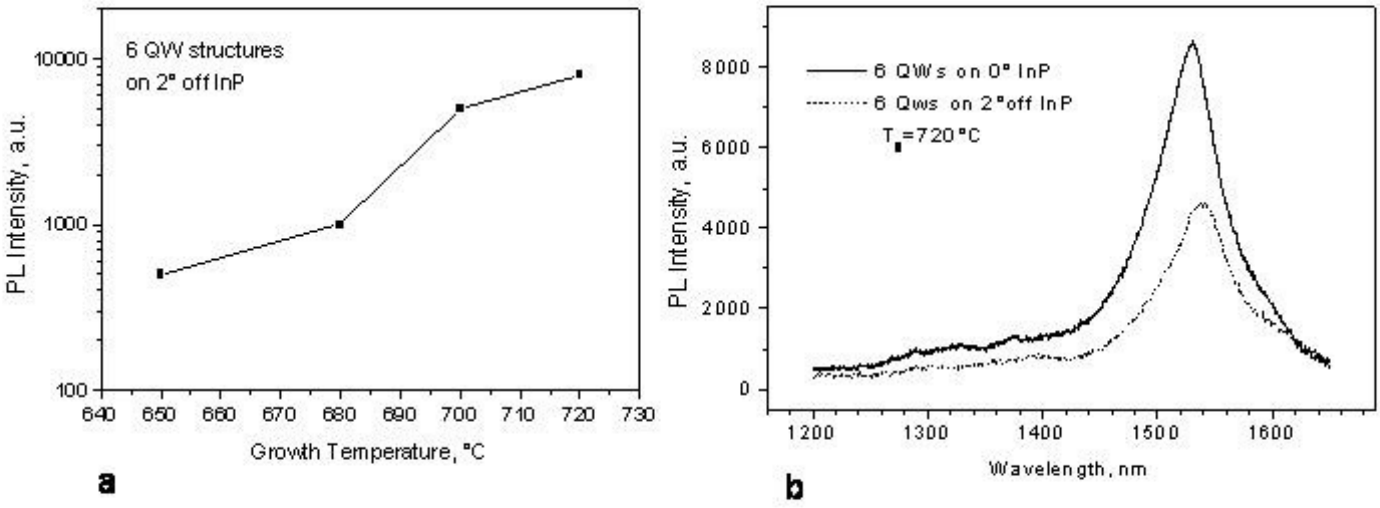

Fig.1. *PL intensity of InAlGaAs QW structures grown at different temperatures (a) and substrate orientation (b).*

The PL peak wavelength is ~1.53 µm. The PL intensity of InAlGaAs MQWs increases with the growth temperature (as indicated by the reactor thermocouple), a tendency similar to that of other Al−containing materials.

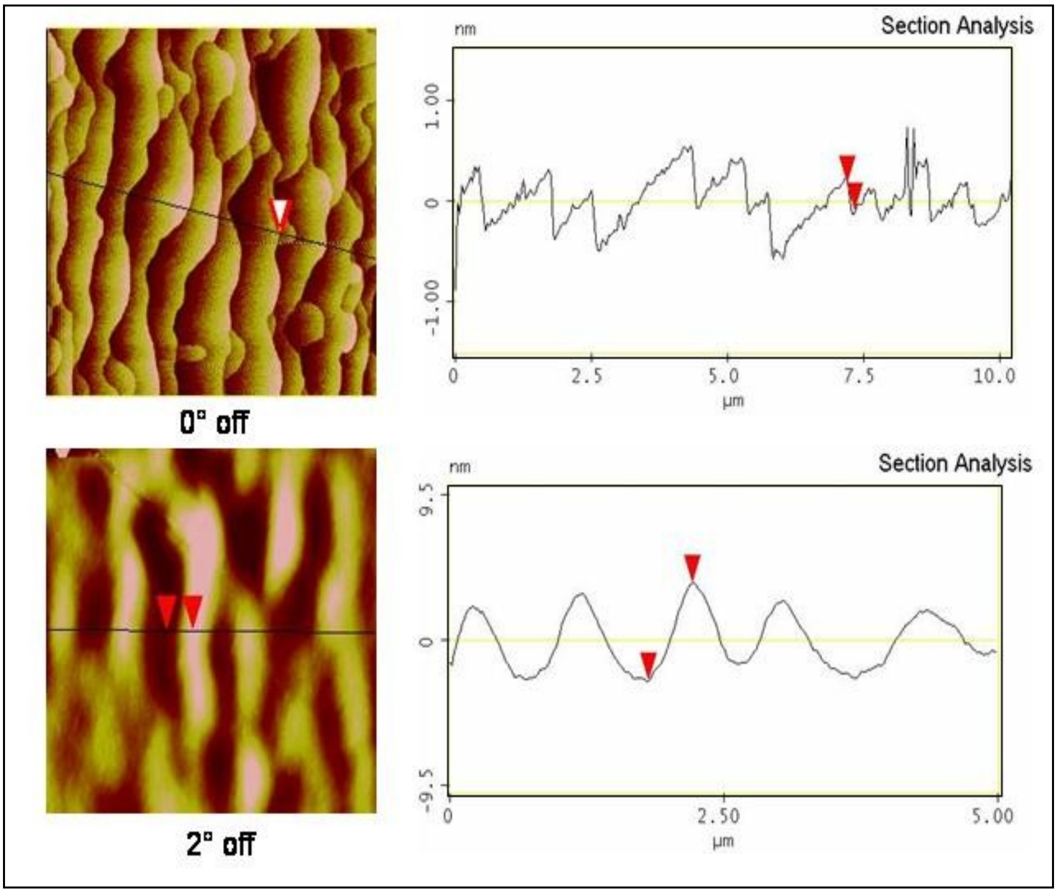

Fig.2. *AFM images and section analysis of InAlGaAs/InP QW structures grown on 0° (001)and 2° misoriented InP substrates*

At 720°C the PL intensity is comparable to or higher than for the best similar InGaAsP or InGaAlAs MQW structures grown and optimized in a hydrogen atmosphere. It was also observed that the use of 2° misoriented InP substrates resulted in a lower PL intensity (Fig.1b) for all growth conditions that were covered in this study.

All samples show a mirror like surface under optical microscope, but layers grown on misoriented substrates show large terraces (~1 µm wide and 5−10 nm high) under AFM observation (Fig.2) for our growth range. The terrace height decreases with increasing growth temperature. At 720°, terraces are 1 µm wide with ~5 nm high steps, a factor of two smaller compared to samples grown at 680°C. Structures grown on exactly oriented substrates have a smoother morphology showing monolayer steps.

TEM and X−Ray diffraction on exactly oriented substrates show no undulations. The TEM picture presented in figure 3a shows perfect well/barrier thickness and composition uniformity and abrupt well/barrier interfaces of the structure. The measured XRD spectrum reported in Figure 3b shows very sharp and intense satellite peaks. Simulation (dashed line) fits very well with measured XRD spectrum of the MQW structure with 6 QWs and 7 barriers with the above mentioned alloy compositions.

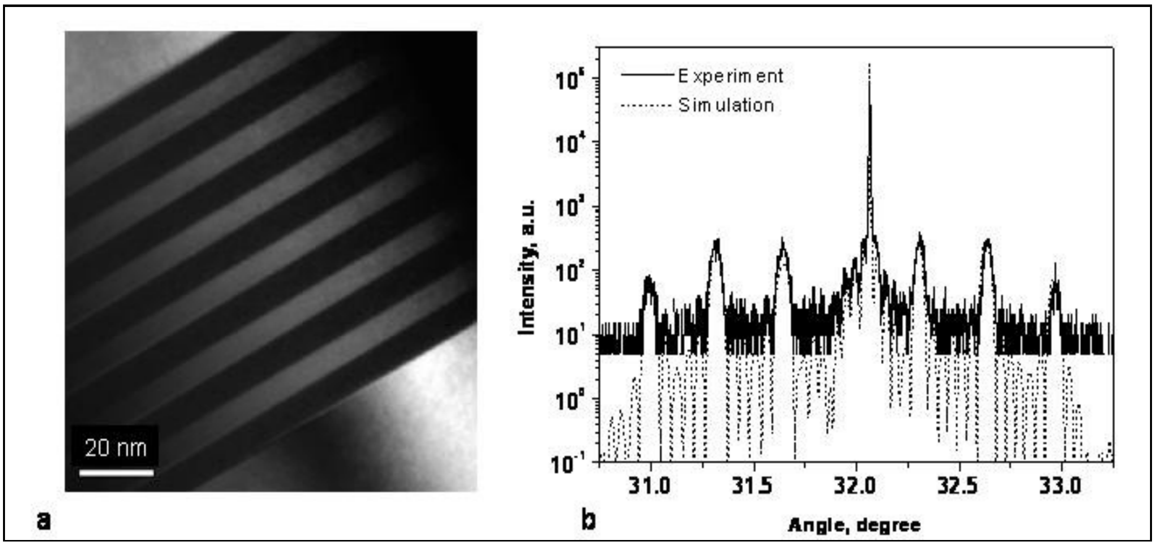

Fig.3. *TEM picture (a) and high−resolution X−ray diffraction spectra (b) of InGaAlAs MQW strain compensated structure*

4. Devices

We have used such InAlGaAs strain compensated MQW structures as active regions of optically and electrically pumped 1.5 µm single wavelength VCSELs. Both optically and electrically pumped devices were realized including InGaAlAs/InP MQW active cavity between bottom and top AlGaAs/GaAs DBRs using the localized wafer fusion technique [3, 4]. This approach combines advantages of high emission properties of the InAlGaAs MQW with the high reflectivity and superior thermal conduction properties of AlGaAs/GaAs based DBRs. Lateral refractive index variation for mode confinement is obtained in−situ during the localized fusion process.

The active structure of optically pumped VCSEL contains 3 groups of 6 InAlGaAs QWs wich are inserted in a 5/2 lambda cavity. Light−Light characteriscics of an opticaly pumped VCSEL are presented in Fig.4a.The 980 nm pump light is focused on the top of the VCSEL active region and the 1.55 µm output light is collected through the GaAs substrate into a single mode optical fiber. Single mode CW emission power of 3 mW at 24^{o}C and 1.2 mW at 73^{o}C have been obtained under 90 mW of 980 nm pumping light, which represent the best result among published so far for any 1.5 µm VCSEL. At 35^{o}C clear roll−over effects are observed. At maximum output power about 6% of the absorbed power is transformed into 1.55 µm emission.

The VCSEL active region for electrical pumping incorporates 6 QWs in 3/2 lambda InP−based cavity which terminates with a p++/n++ InGaAs tunnel junction and an InP−spacer layer. Optical and electrical transverse confinement were built by selective etching of mesas with ~7 µm in diameter through the InP spacer layer and the tunnel junction. The structured surface of the InP−based wafer is fused to an undoped AlGaAs/GaAs DBR (top DBR). As bottom mirror, an n−doped DBR was used.

Fig.4b shows single mode CW Light−Current−Voltage characteristics for an electrically pumped VCSEL at different ambient temperatures from 20 to 70°C. An output power of more than 1.5 mW with a threshold voltage of 1.87 V is obtained at 20°C and 0.2 mW is achieved for 70°C.

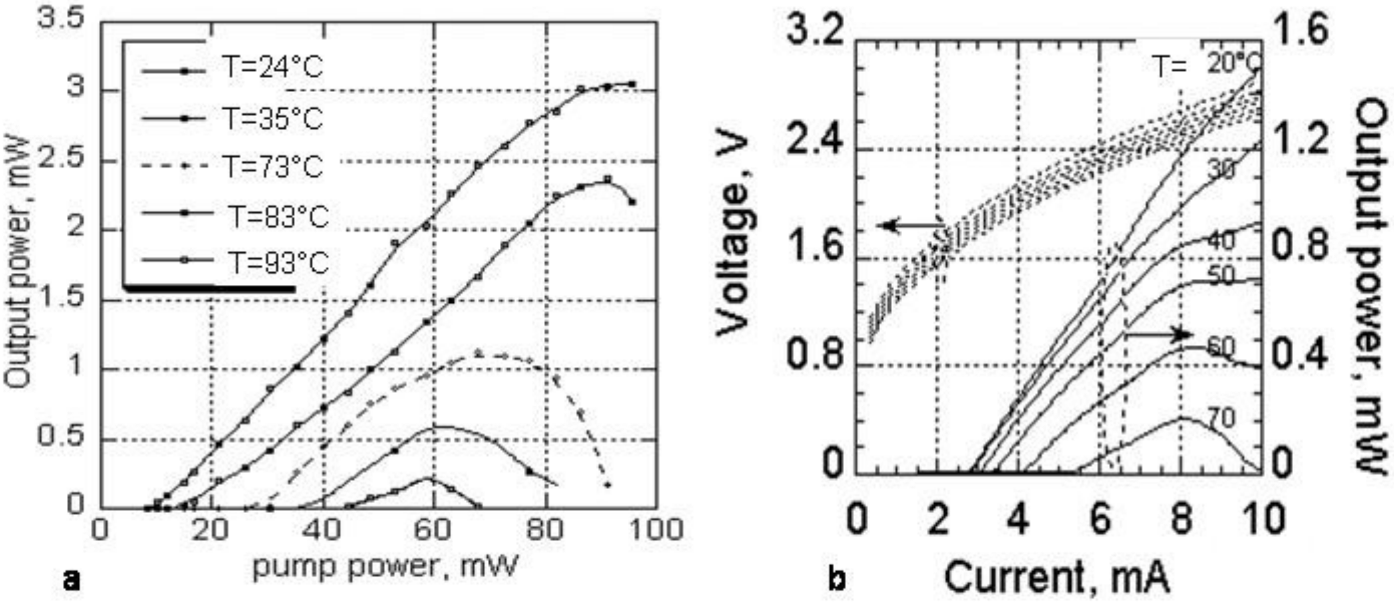

Fig. 4. *Light−Light characteristics for opticaly pumped (a) and Light−Current curves for electricaly pumped VCSELs (b) at different temperatures*

Conclusions

In summary, we have investigated MOVPE growth of InAlGaAs MQW structures in nitrogen atmosphere. After optimisation of growth conditions, structures of high optical and structural quality were obtained. With VCSELs based on these active layers and fused AlGaAs/GaAs mirrors, single mode CW emission power of 3 mW at 24°C and 1.2 mW at 73°C were obtained under optical pumping, which represent the best result published so far for any 1.5 µm VCSEL. An output power of more than 1.5 mW at 20°C and 0.2 mW at 70°C were achieved for single mode electrically pumped VCSELs.

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