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Fabrication of High Speed Single Mode 1.27 μm InGaAs:Sb-GaAsP Quantum Wells Vertical Cavity Surface Emitting Laser

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1. Introduction

Long wavelength vertical cavity surface-emitting lasers (VCSELs) are key devices in the optical fiber metropolitan-area networks (MAN) [1]. To date, the most promising results on low cost long wavelength lasers or VCSELs have been obtained using GaInAsN quantum wells (QWs) grown on GaAs substrates [1-5]. The large conduction band offset leads to the improvement of temperature performance compared to conventional InP-based materials, and the GaAs system provides high performance AlGaAs/GaAs DBR mirrors and allows the use of well established oxide-confined GaAs-based VCSEL manufacturing infrastructure. However, GaInAsN is a very challenging materials system from a growth point of view: (1) it is difficult to incorporate N into the InGaAs QW and the introduction of N into QW increases the non-radiative (monomolecular and Auger) recombination and thus lower the material gain and increase transparency carrier density [6]; (2) During post–growth annealing, the anneal nitrogen diffuses out from the quantum well and blue-shifts optical emission. Recently, highly strained InGaAs VCSELs with photoluminescence (PL) peak at 1.205 μm and laser emission wavelength ~1.26-1.27 μm demonstrated very promising performance and continuous–wave (CW) operation up to 120°C as well as 10 Gb/s operation [7]. However, the emission wavelength of 1.26 μm is barely in compliance with optical communication standards such as IEEE 820.3ae 10Gb/s Ethernet. In addition, the laser has a relatively poor performance at room temperature due to the large negative gain-cavity offset. Antimony (Sb) present during GaInAsN growth has been though to act as a surfactant and improve PL [8]. With the addition of Sb, we have observed a sharp intensity increase with high In samples and found it not only acts as a surfactant but it is a significant alloy constitute further red-shifting the optical emission [8]. In this paper, we present the high performance InGaAs:Sb-GaAsP QWs VCSEL grown by MOCVD.

2. Experiment

The basic VCSEL structure as shown in Fig. 1 consists of an n-type 35.5-period-GaAs/$Al_{0.9}Ga_{0.1}As$ distributed Bragg reflector (DBR) which was grown at 750°C. Then, a double QWs active region $In_{0.42}Ga_{0.58}As$:Sb-GaAs-$GaAs_{0.85}P_{0.15}$ (60Å/10Å/100Å) with the PL emission at 1.214 μm and cladding layer (total 1 . thickness) were grown at 650°C, followed by the growth of a 22-period GaAs/$Al_{0.9}Ga_{0.1}As$ p-type mirror including 30 nm $Al_{0.98}Ga_{0.02}As$ oxidation layer. Finally, a 1 thickness of current spreading layer and thin GaAs contacting layer were grown. The optical properties of QWs were optimized through PL measurement. Fig. 2 shows the comparison of the photoluminescence spectra of InGaAs with different In composition and $In_{0.42}Ga_{0.58}As$ with Sb incorporation (~1.5% measured by SIMS). For the VCSEL structure, the 50 nm negative gain-cavity offset was used for >1.27 μm emission. The VCSELs were fabricated utilizing the high speed VCSEL processing to minimize capacitance while keeping reasonably low resistance [9]. The VCSEL has a 5 μm emitting aperture defined by lateral oxidation and 3.5 μm surface relief structure for single mode operation. Finally, Ti/Pt/Au, AuGe/Ni/Au were used for p-contact and n-metal, respectively.

3. Result

Fig.3 shows temperature-dependent light output and voltage versus current (LIV) curves. Notably the single mode output power is excess of 0.8mW with SMSR >30dB. The threshold current change between 1.8 and 1.1 mA with temperatures between 25°C to 70°C and the slope efficiency drops less than ~30% due to the large gain-cavity offset. Finally, we perform modulation measurement on our VCSELs, the 3dB modulation frequency response (f 3dB) is measured to be 10.1 (8.8) GHz at 25 °C (70°C) and bias current 6 mA (fig. 4).

4. Conclusion

High performance 1.27 μm InGaAs:Sb-GaAsP vertical cavity surface emitting lasers (VCSELs) are demonstrated with superior performance and temperature stability. The threshold current changes between 1.8 and 1.1 mA and the slope efficiency drops less than ~30% when the temperature raised from room temperature to 70°C. High modulation bandwidth of 10.1 (8.8) GHz at 25 °C (70°C) and bias current 6 mA are demonstrated. The results of InGaAs:Sb VCSELs can reach a performance level comparable to GaInAsN VCSELs with better thermal stability and should be considered as a very promising candidate for 1.3 μm commercial applications.

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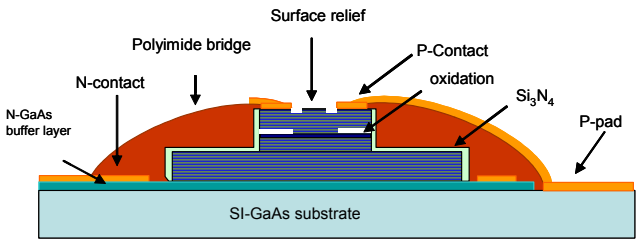

Fig. 1. Schematic cross section of high speed single mode VCSEL structure. The oxide-confined aperture is 5 µm with a Shallow Surface Relief size of 3.5 µm.

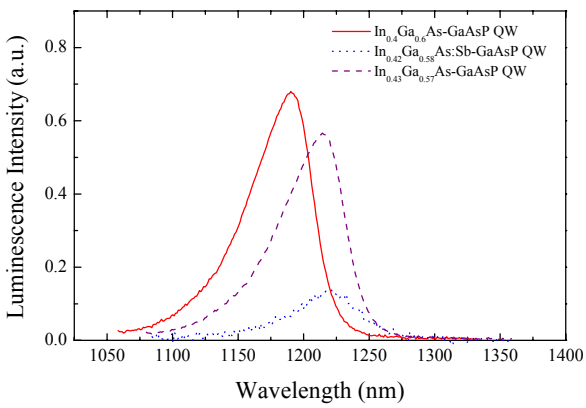

Fig. 2 Comparison of the photoluminescence spectra of InGaAs with different In composition and In0.42Ga0.58As with Sb incorporation (~1.5% measured by SIMS).

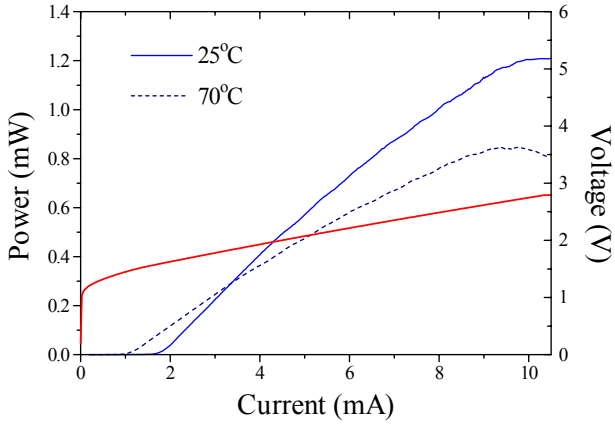

Fig.3 Temperature-dependent light output and voltage versus current (LIV) curves.

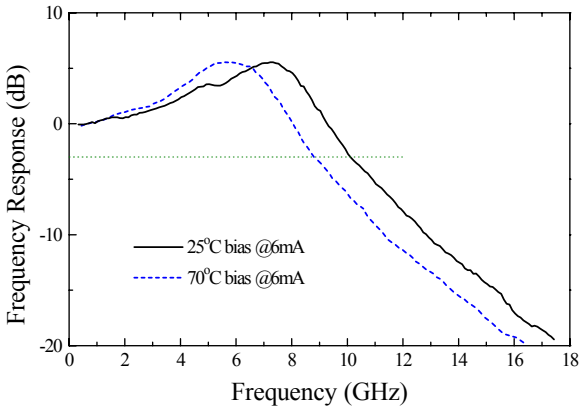

Fig. 4 High speed modulation measurement on VCSELs, the 3dB modulation frequency response (f 3dB) is measured to be 10.1 (8.8) GHz at 25 °C (70°C) and bias current 6 mA.