Record Single-Mode Power of 1300 nm-Wavelength VCSELs

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***Abstract* — Record-high fundamental mode output power of 6.8 mW at 20 ºC achieved with wafer-fused VCSELs emitting at 1300 nm is reported in this paper. VCSEL contains an InAlGaAs-InP active with buried tunnel junction and undoped AlGaAs/GaAs Distributed Bragg Reflectors. This performance positions wafer-fused VCSELs as prime candidates for many applications in low power consumption, "green" photonics.**

Key words – **Wafer fusion, long wavelength, VCSEL**

I. INTRODUCTION

Vertical cavity surface emitting lasers (VCSELs) have important advantages compare with edge emitting semiconductor lasers such as low beam divergence, high fiber coupling efficiency due to circular output beam, low threshold current, low power consumption, single longitudinal mode emission, simple integration into one or two dimensional arrays and on-wafer testing capability. VCSELs operating at <1µm wavelengths have established themselves as the ultimate low-power-consumption lasers for an increasing number of applications in data communications, active optical cables, laser mouse and sensing.

There are currently increasing needs for similar low-power-consumption laser technology at longer wavelengths, especially for 1310 nm and 1550 nm optical communications networks, where the huge expansion in data traffic is facing severe limitations due to thermal management problems [1]. There are different approaches for near-infrared VCSEL fabrication: using InGaAsN active and GaAs/AlGaAs Distributed Bragg Reflectors (DBR) grown monolithically on GaAs substrate; using InGaAsP or InAlGaAs in combination with InP based or dielectric DBRs grown on InP substrate and Wafer Fusion approach. Wafer fusion [2] has an advantage allowing combining high quality InP-based active and high reflectivity, low absorption GaAs-based DBRs.

However, long wavelength (LW) VCSELs emitting in this spectral range have suffered so far from limited single-mode power outputs, putting them in a disadvantage in comparison with corresponding high power consumption edge emitting lasers. Developing such LW-VCSELs with single mode (SM) output power well in excess of 1mW simultaneously with high modulation speed capabilities and accurate emission wavelength setting would allow their incorporation in low-power consumption, high performance modules for broadband optical communications, optical absorption spectroscopy and Bragg-grating sensor applications. Up to now, the best reported results in terms of SM emission power are 8 mW for the 1500 nm range [3] and 5.4 mW for 1300 nm VCSELs at ambient temperature [4].

One way to increase the emission power is to increase the tunnel junction (TJ) diameter, but this may compromise the side mode suppression ratio (SMSR). Experimentally has found that the optimal TJ diameter for wafer fused VCSELs ranges between 5 and 7 μm. SM power is sensitive to output coupling and detuning between the photoluminescence pick (PL) and the cavity mode. Through the optimization of these parameters, along with improving the active region quality, we have achieved before higher performance LW-VCSELs emitting near 1500 nm with 8 mW SM power at 0°C [5]. In this paper, the results on VCSELs emitting near 1310 nm with SM power of 6.8 mW at room temperature are presented.

II. DEVICE FABRICATION AND OPTIMIZATION

The VCSEL device structure comprises an InP-based 5/2 λ-active cavity, fused on both sides to undoped AlGaAs/GaAs DBRs, as schematically is shown in figure 1.

The active cavity includes an InAlGaAs/InP multi-QW region with 5 compressively strained quantum wells and a p++/n++ InAlGaAs tunnel junction. PL spectra at room temperature are shown in fig. 2 and peak position is shifted from designed cavity wavelength by 40 nm in order to have acceptable performances in large temperature range.

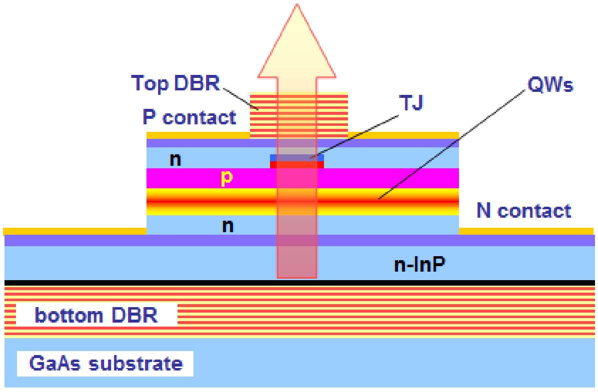

Fig. 1. Cross-section of double wafer fused VCSEL.

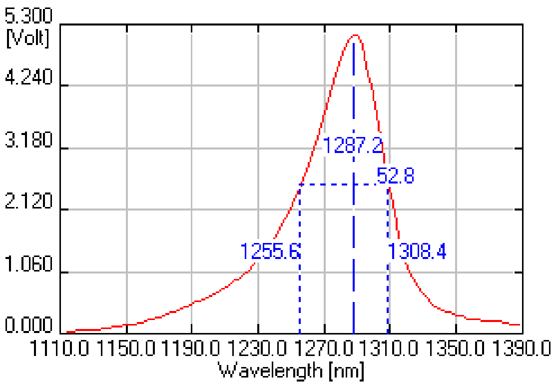

Fig.2. Photoluminescence spectra of QWs at 20°C.

Top and bottom DBRs comprises 20.5 and 35 pairs respectively. Intracavity contacting and undoped DBRs help to reduce the free currier absorption and to avoid current flow through fused interfaces. Both the InP-based active cavity and the GaAs-based DBRs were grown by low-pressure metal-organic vapor phase epitaxy (LP-MOVPE) on 2” (100) wafers. Prior to wafer fusion, tunnel junction mesas of 6 μm diameter were defined by photolithography and wet etching and were subsequently re-grown with n-type InP and this buried tunnel junction realize lateral carrier and photon confinement. InGaAsP cavity adjustment layers, grown on both sides of the active cavity, allow controlling the cavity length and hence the emission wavelength with nanometer range accuracy on the two-inch wafer level using a simple and effective procedure. In order to determine the effect of changing the output coupling on the 1.3-μm VCSEL characteristics, two different samples from the same double-fused VCSEL wafer were processed and analyzed. One sample contained a standard top Al0.92Ga0.08As/GaAs DBR with 20.5 pairs (sample A). On the second sample, the 3 top pairs were removed by selective etching using solutions of H_2O_2-Citric acid for the GaAs and HCl-H_2O for the AlGaAs layers, respectively (sample B). Both structures have been processed using standard lithography, wet and dry etching steps, Si_3N_4 passivation layer and Ti/Pt/Au metal contacts.

III. VCSEL CHARACTERISTICS

Light-current (LI) characteristics of processed VCSELs batches were measured by a directly coupled photodiode at different temperatures. Figure 3(A) depicts LI characteristics of sample A, measured in the temperature range of 0÷100 °C and on figure 3(B) LI characteristics of sample B in temperature range 0÷90 °C are shown. As expected, reducing reflectivity of the top DBR increases the maximal power but the penalty is in increasing of threshold current and in reducing of maximum temperature operation. If sample A still have good performances at 100 °C, sample B doesn’t generate at temperatures higher 100°C.

Threshold current versus temperature for both structures are plotted on figure 4. Minimum threshold current is around 40 °C for samples A and B and for sample B values are higher by 1.5 to more than 2 mA compare with A. Maximum emission power is close to 10 mW at 0° C (B) and more than 1 mW at 100°C (A), but maximum SM power is limited for temperatures less than 50°C and is SM up to roll-over for temperatures higher than 50°C (Fig. 5).

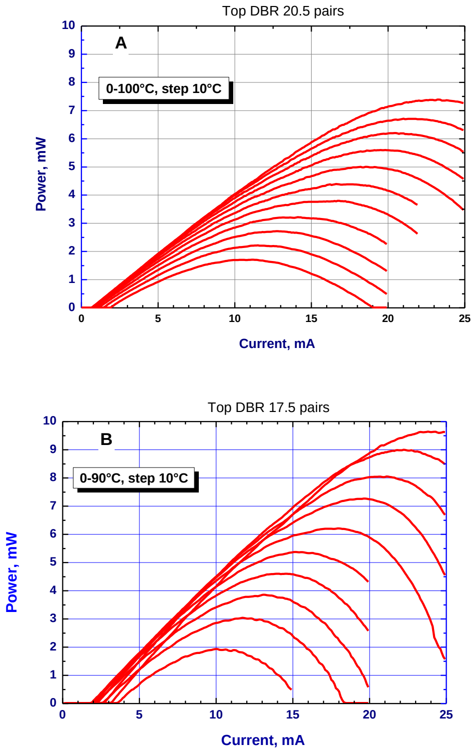

Fig. 3. LI characteristics in temperature range of structures A and B.

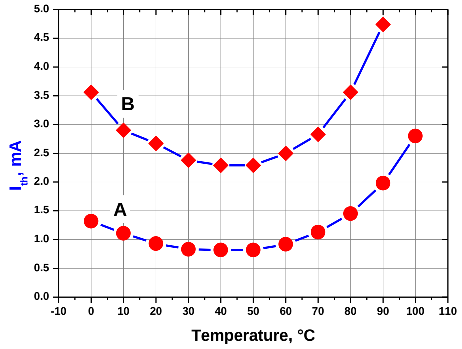

Fig. 4. Threshold current versus temperature for samples A and B.

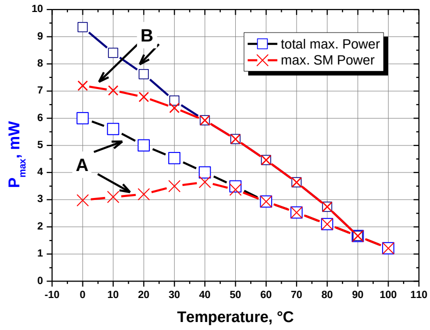

Fig. 5. Total power (squares) and maximum SM power (crosses) versus temperature for samples A and B.

Spectral characteristics were measured using Spectral Analyzer HP70951B with a resolution of 0.1 nm at 20°C and different pumping currents. (Fig.6). Device with higher top-DBR reflectivity shows SM emission with SMSR more than 30dB up to 8 mA of pumping current. Increase in output coupling also influence the SM performances clearly seen on sample B, where SM emission is maintained up to 15 mA at 20 °C. At this pump current, the highest value of 6.8 mW SM output power is achieved at room temperature, to our knowledge the highest value reported so far for any 13xx VCSELs.

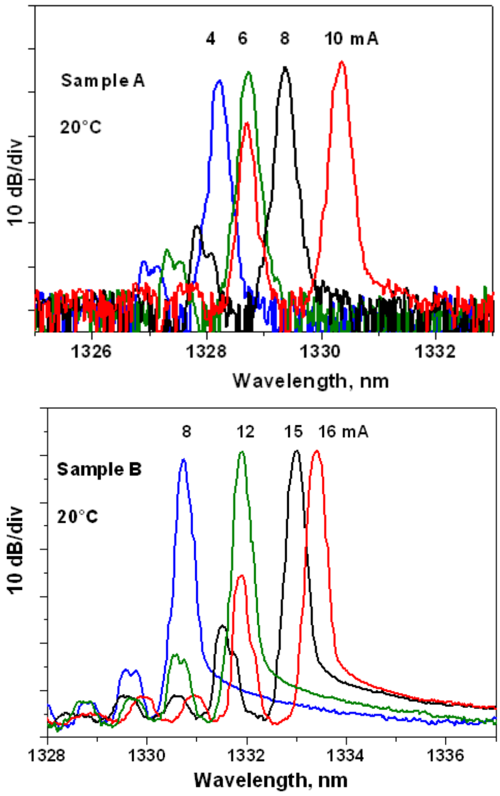

Fig. 6. Room temperature spectra at different pumping currents for devices from samples A and B.

IV. CONCLUSIONS

In this work, we report on the enhancement of the emission of single-mode 1.3-μm VCSELs by reducing the reflectivity of the top GaAs-based DBR for output coupling optimization. Devices with record SM power of 6.8 mW at room temperature and 2.8 mW at 80°C, with more than 30 dB SMSR, have been obtained. Achieving this output coupling optimization with a post-processing adjustment of the number of Bragg periods in the output coupler is compatible with full wafer industrial production of these devices, and should also increase yield and eventually reduce device costs. The steady progress in increasing the SM output power of long wavelength VCSELs has brought their performance in this respect close to that achievable with their short wavelength (850-980nm) counterparts that are based on simpler and more mature technologies. Further increase of the SM power of long wavelength VCSLEs to the 10 mW range is expected with additional improvements in transverse carrier and optical confinement, e.g., using intra-cavity refractive index patterning [6].

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