Reliability Studies of Gain-Guided 0.85 μm GaAs/AlGaAs Quantum Well Surface Emitting Lasers

C. C. Wu, *Member, IEEE*, K. Tai, T. C. Huang and K. F. Huang

***Abstract*—A reliability study of gain-guided 0.85 μm GaAs/AlGaAs quantum well surface emitting lasers is reported for the first time. 32 lasers were randomly selected to operate at 25 or 50 C with bias currents up to 15 mA, about 4 times the threshold values. The power outputs of the 32 lasers showed no noticeable degradation after 2000-3000 hours of operation.**

I. INTRODUCTION

VERTICAL-CAVITY surface-emitting lasers (VCSELs) consist of a double heterostructure diode sandwiched between two highly reflective distributed Bragg reflectors (DBRs) and emit normal to the wafer. Due to the unique vertical emitting geometry, VCSELs have many advantages over the conventional edge emitting lasers, such as a circular light output mode, high 2-dimensional packing density for arrays, single longitudinal mode emission due to the inherent short cavity length, and wafer scale testing ability. Therefore VCSELs are attractive light sources for optical recording, communication, interconnect and computing applications. Thus far the most successful device structures have been the gain-guided In GaAs/GaAs/AlGaAs or GaAs/AlGaAs quantum well VCSEL using one-step MBE grown wafers emitting in the 0.8–1μm wavelength range [1]–[5]. In these devices, lateral gain and current confinement are facilitated by a simple processing step of proton implantation. The one-step growth and few process steps are important for low cost mass production of these devices. Previously, Ibaraki et al[6] reported a 500 hour aging test on surface emitting lasers with GaAs active region and TiO_2/and SiO_2 DBRs. In this paper we report the reliability study of fully MBE grown 0.85 μm vertical cavity surface emitting lasers. In the experiments, 32 lasers were randomly selected to operate at 25 or 50 C with bias currents up to 15 mA, about 4 times the threshold values. The power outputs of the 32 lasers show no noticeable degradation after 2000-3000 hours of operation till the time of preparation of the manuscript.

The inset of Fig. 1 shows the cross-sectional view of the structure studied here. The wafer was grown by molecular beam epitaxy (MBE). It consists of four GaAs(100 Å)/ $Al_{0.7}Ga_{0.3}As$(60 Å) quantum wells embedded within a λ-thick graded AlGaAs spacer and sandwiched between two similar stair-case DBRs.[7] The top (bottom) stair-case DBR is Be (Si) doped and has 20 (30) periods of DBR stacks. Each stair-case DBR period consists of $Al_{0.15}Ga_{0.85}As$ /$Al_{0.4}Ga_{0.6}As$/$Al_{0.7}Ga_{0.3}$ As/AlAs/$Al_{0.7}$ $Ga_{0.3}$ As/$Al_{0.4}$ $Ga_{0.6}As$ layers, with nominal layer thicknesses of 500, 100, 100, 640, 100 and 100 Å, respectively. The 100 Å thick intermediate bandgap $Al_{0.4}Ga_{0.6}As$ and $Al_{0.7}Ga_{0.3}As$ layers are introduced to grade the otherwise abrupt hetero-junctions between the $Al_{0.15}Ga_{0.85}As$ and AlAs layers to reduce the series resistance of p-type DBR.[7] VCSEL device processing steps are very simple and include deposition of annular ring p-type semiconductor-metal ohmic contacts, and proton implantation. Proton implantation is done at an energy of 350 keV and a dosage of 3×10^{14} cm^{-2}. Proton implantation facilitates lateral gain and current confinement in these devices. As indicated by the arrows in the inset of Fig. 1, the electrical current starts from the annular contacts and funnels through the central 15 μm diameter active region as defined by proton implantation. The laser light emits upward and outputs through the preferred top surface. We thinned the wafer down and diced it into 500 μm square chips to ease the power monitoring of each individual laser.

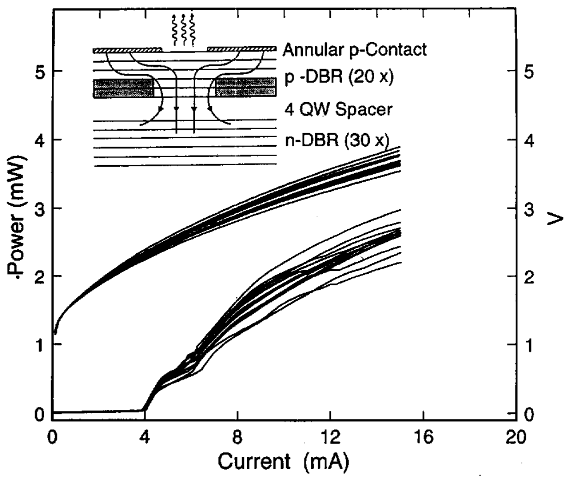

Fig. 1. L-I and V-I characteristics of the gain-guided surface emitting lasers. The inset shows the cross-sectional view, in which the dotted region is made highly resistive by proton implantation.

Manuscript received August 16, 1993; revised October 18, 1993.

C. C. Wu and K. Tai are with the Institute of Electro-Optical Engineering, Chiao Tung University, Hsinchu, Taiwan.

T. C. Huang and K. F. Huang are with the Department of Electro-Physics, Chiao Tung University, Hsinchu, Taiwan.

IEEE Log Number 9214966

In the experiment, the randomly selected 32 lasers are labelled as VCSEL #1 to #32 from a quarter of a two inch diameter wafer. Figure 1 shows the room temperature cw light output and voltage vs injection current characteristics (L-I and V-I) of the VCSEL #17 to #32. The threshold currents vary from 3.8 to 4 mA. The bias voltages at threshold vary from 2.2 to 2.3 V. The output powers at 15 mA vary from 2.1 to 3 mW. The L-I and V-I characteristics of the VCSEL #1 to #16 are similar to those in Fig. 1. The variations in the L-I and V-I characteristics are rather small among the lasers, indicating that good uniformity in MBE growth and in device processing was achieved. The low bias voltage allows the maximum cw operating temperature of the lasers to exceed 100 C. The overall sub-linear characteristic in the L-I curve is caused by the ohmic heating in p-DBR as analyzed in detail previously.[5] The kinks in the L-I characteristics result directly from the excitation of higher order transverse modes, which is inevitable in the gain-guided laser structure.[3,8] The VCSEL devices have a thermal resistance of about 800 C/W, which is about one order of magnitude higher than the edge emitting lasers.

The 32 lasers were divided into three groups. The first group of 8 lasers, VCSEL #1 to #8, was operated at an ambient temperature of 25 C and biased at 7 mA to allow about 1 mW output. The second group of 8 lasers, VCSEL #9 to #16, was also operated at 25 C. The bias currents were set at 7 mA for the first 200 hours and then raised to a higher value of 15 mA afterwards, about 4 times the threshold current values. The output powers under this operating condition vary from 2 to 3 mW. The third group of 16 lasers, VCSEL #17 to #32, was operated inside an oven at a temperature of 50 C and biased at 13 mA. The output powers at 50 C are in the range of 1.6 to 2.1 mW.

In the experiment, we used one constant voltage source to drive each individual group of lasers (the lasers were connected in parallel). To reduce the current variation and allow a near constant current operation condition, an external resistor of 1.5 kΩ was added in series with each individual laser. For the first and second groups, only the output powers were monitored and recorded by a computer via a 16 channel analog-to-digital convertor. For the third group, bias currents, bias voltages and output powers were monitored, simultaneously by two 16 channel multiplexer and a second analog-to-digital convertor.

Figure 2 show the plot of output powers of the VCSEL #1 to #8 versus aging time at 25 C. It is evident after 3,000 hours of continuous operation till the time of manuscript preparation, the output powers remain essentially unchanged. The slight fluctuations in these curves are due to the ambient temperature variation of ±3 C. Figure 3 shows the plot of power outputs of VCSEL #9 to #16 versus aging time at 25 C. It is also evident that the lasers powers are essentially unchanged after 2,000 hours operation till the time of manuscript preparation, even when operated at high currents of near 4 times the threshold values. To accelerate the aging process, the operating temperature of VCSEL #17 to #32 was raised to 50 C after 200 hours aging at 30 C. Figure 4(a) shows the plot of power outputs VCSEL # 17 to #32 versus accelerated aging time at 13 mA, 50 C. Figure 4 (b) shows the plot of corresponding bias voltage of the same lasers. It is evident that the output powers and bias voltages of the lasers are essentially the same after 700 hours high temperature aging till the time of manuscript preparation.

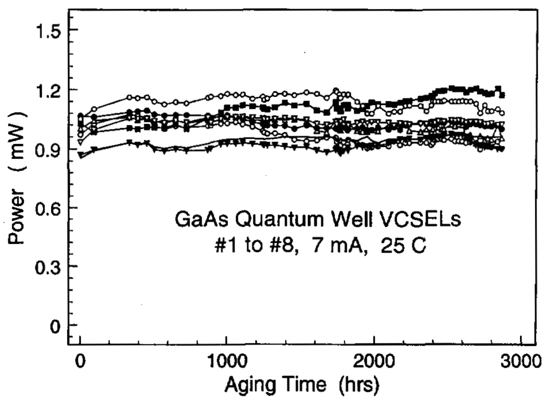

Fig. 2. Plot of output powers of VCSEL #1 to #8 versus aging time at 25 C.

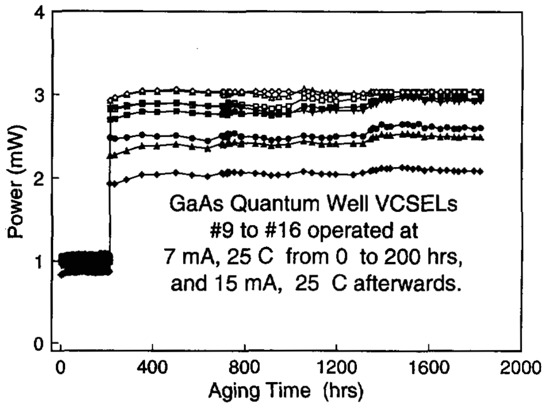

Fig. 3. Plot of output powers of VCSEL #9 to #16 versus aging time at 25 C.

It is well known that GaAs/AlGaAs edge emitting lasers emitting in the 0. 78–0. 88 μm wavelength region are much less reliable than the 1.3–1.55 μm InGaAsP/InP counterparts. The former are also vulnerable to a thermal runway catastrophic optical damage (COD) process when operated at high currents/powers. The notorious reliability probelms of the GaAs/AlGaAs lasers are caused by the high surface recombination velocity of GaAs/AlGaAs and the oxidation of AlGaAs when exposed to air. These cause carrier depletion on the facets and, consequently, excess thermal heating and damage on the facets. Applying dielectric coatings on the facets will ease the problem but not eliminate it. Unlike the edge emitting lasers, the active region of the gain-guided GaAs/AlGaAs quantum well surface emitting lasers studied here is embedded between two DBR layers during the ultra high vacuum MBE growth process. The device processing steps of the lasers do not involve etching, or regrowth. There is no cleaved facet or etched sidewall for the lasers. Thus

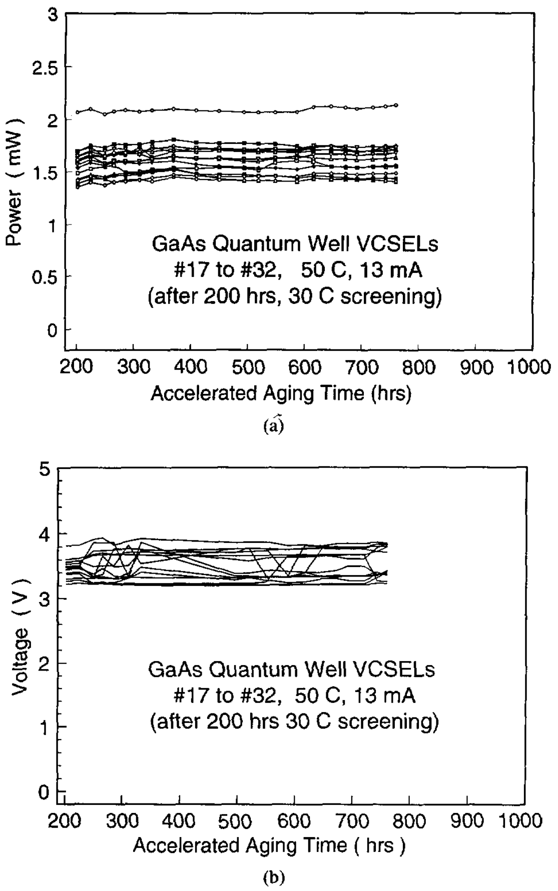

Fig. 4. (a) Plot of output powers and (b) bias voltage of VCSEL #17 to #32 versus accelerated aging time.

the gain-guided GaAs/AlGaAs quantum well surface emitting lasers studied here are inherently free from the notorious facet related complications that trouble the edge emitting lasers. Besides, due to the large emitting windows, the threshold carrier densities in VCSELs are about the same as those of the edge emitting lasers. Therefore VCSELs should be inherently more reliable. However it is known that the high energy beam of the implanted protons can create damages in the lattice. In fact we found the output powers can increase by 5–10% in the initial 24–48 hour period. Much larger increases were observed in similarly prepared devices studied previously. We also found this initial power enhancement period can be reduced to a few minutes or less by injecting higher currents into the devices. Presumably this phenomenon can be regarded as a current-induced self-healing or self-annealing process of the devices. That is the damage in the neighborhood of the annular rings caused by straggling of protons during the implantation was annealed by the effect of injection current. The detailed annealing mechanism and dynamics are beyond the scope of the present study. We note that higher temperature (e.g. 100 C) aging and the investigation of other parameters such as spectral and spatial emission characteristics are required in order to determine the mean time to failure of the lasers operating near room temperature and the failure mechanism.

In conclusion we have studied the reliability of gain-guided 0. 85 μm GaAs/AlGaAs quantum well surface emitting lasers fabricated by one-step MBE grwoth and proton implantation. 32 randomly selected lasers were operated at 25 or 50 C with biased currents up to 15 mA, about 4 times the threshold values. The power outputs of the 32 lasers show no noticeable degradation after 2000–3000 hours of operation. Combined with the many previously reported nice features of VCSELs by many groups$^{1-5}$ and the preliminary reliability data reported here, we are optimistic about practical applications of VCSELs, especially the large volume compact optical memory and optical interconnect, in the near term.

ACKNOWLEDGMENT

We wish to acknowledge National Science Counsil, Republic of China for the grant, NSC82-0417-E-0090178, in support of this work.

REFERENCES

[1] Y. H. Lee, B. Tell, K. F. Brown-Goebeler, J. L. Jewell and J. V. Hove, *Electron. Lett.*, vol. 26, pp. 710–711, 1990.
[2] C. J. Chang-Hasnain, M. Orenstein, A. Von Lehmen, L. T. Florez, J. P. Harbison and N. G. Stoffel, *Appl. Phys. Lett.*, vol. 57, pp. 218–220, 1990.
[3] R. S. Geels, S. W. Corzine, J. W. Scott, D. B. Young and L. A. Coldren, *IEEE Photon. Tech. Lett.*, vol. 2, pp. 234–236, 1990.
[4] K. Tai, G. Hasnain, J. D. Wynn, R. J. Fischer, Y. H. Wang, B. E. Weir, J. Gamelin and A. Y. Cho, *Electron. Lett.*, vol. 26, pp. 1628–1629, 1990.
[5] G. Hasnain, K. Tai, L. Yang, Y. H. Wang, R. J. Fischer, J. D. Wynn, B. E. Weir, N. K. Dutta and A. Y. Cho, *IEEE Quantum Electron.*, vol. 27, pp. 1377–1385, 1991.
[6] A. Ibaraki, K. Kawashima, K. Furusawa, T. Ishikawa, T. Yamaguchi and T. Niina, ECOC 1990.
[7] K. Tai, L. Yang, Y. H. Wang, J. D. Wynn and A. Y. Cho, *Appl. Phys. Lett.*, vol. 56, pp. 2496–2498, 1990.
[8] K. Tai, Y. Lai, K. F. Huang, T. C. Huang, T. D. Lee and C. C. Wu, 1993 Annual Meeting of Optical Society of America, paper MLL3, Oct. 3, Toronto, Canada.