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Reliability studies of 0.85 μm vertical cavity surface emitting lasers: 50000 h MTTF at 25°C

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Indexing terms: Semiconductor lasers, Reliability

Reliability studies of gain-guided 0.85μm GaAs/AlGaAs quantum well surface emitting lasers were performed on 45 randomly selected lasers operated at 25, 50 or 90°C with biased currents up to 15 mA (about four times the threshold values). At 25°C, no noticeable degradation was seen after 5000h of operation. A 14% reduction of power was seen at 50°C after 2700h. A faster degradation on power output was seen at 90°C, though the lasers are still functional after 1000h. The mean time toward failure (MTTF) of these lasers operated at 25°C and 15mA is extrapolated to be ~5 × 10^4h.

Vertical cavity surface emitting lasers (VCSELs) emit normal to the wafer. Owing to their unique vertical emitting geometry, VCSELs have many advantages over conventional edge emitting lasers, such as circular light output mode, high two-dimensional packing density for arrays and wafer scale testing ability. They are attractive light sources for optical recording, communication, interconnect and computing applications. Thus far, the most successful device structures have been gain-guided 0.8 – 1μm InGaAs/GaAs/AlGaAs or GaAs/AlGaAs quantum well VCSELs prepared by one-step molecular beam epitaxy and proton implantation [1–3]. Reliability ultimately determines the usefulness of these lasers for various applications. Previously we reported [4] that the gain-guided 0.85 μm GaAs/AlGaAs quantum well VCSELs showed no noticeable power reduction at 25°C after 3000h of continuous operation. In this Letter we report the results of reliability studies on 45 randomly selected 0.85μm VCSELs with operating temperature ranging from 25 to 90°C. From these data, the mean time toward failure (MTTF) [5] at 25°C is extrapolated, based on the commonly used accelerating aging model for a wide variety of electronic and optoelectronic devices, to be ~5 × 10^4h. To the best our knowledge, this is the first MTTF value reported to date for the novel class of vertical cavity surface emitting lasers.

The inset of Fig. 1 shows the cross-sectional view of the structure studied here. It consists of four 100Å-thick GaAs quantum wells embedded within a λ-thick graded AlGaAs spacer and sandwiched between two similar AlAs/AlGaAs distributed Bragg reflectors. Laser processing consists of the deposition of 15 μm inner diameter annular ring metal ohmic contacts and 350 keV proton implantation at a dosage of 3 × 10^{14}cm^2. 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 through the preferred top surface. The details on the layer structure and device processing were described in [3].

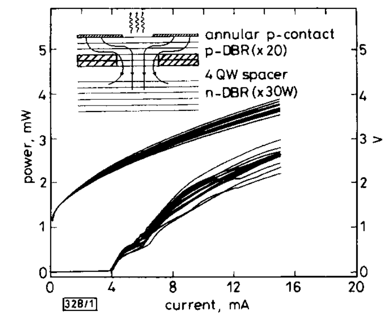

Fig. 1 *L-I and V-I characteristics of gain-guided surface emitting lasers*

Inset: cross-sectional view, in which dotted region is made highly resistive by proton implantation

The 45 lasers were divided into four groups. The first group of eight lasers, VCSELs 1–8, was operated at an ambient temperature of 25°C and biased at 7mA to allow ~1mW output. The second group, VCSELs 9–16, was also operated at 25°C. The biased currents were set at 7mA for the first 200h and then raised to a higher value of 15mA, about four times the threshold values. The output powers under this operating condition vary from 2 to 3mW. The third group, VCSELs 17–32, was operated inside an oven at a temperature of 50°C and biased at 13mA. The output powers at 50°C are in the range 1.4 – 2.1mW. The fourth group, VCSELs 33–45, was operated at 90°C and 15mA.

Room temperature CW light output and voltage against injection current characteristics for VCSELs 17–32 are plotted in Fig. 1. The threshold currents vary from 3.8 to 4mA. The biased voltages at the threshold vary from 2.2 to 2.3V. The output powers at 15mA vary from 2.1 to 3mW. The low bias voltage allows the maximum CW operating temperature of the lasers to exceed 100°C. The light and voltage against current characteristics of the rest of the lasers are similar to those in Fig. 1.

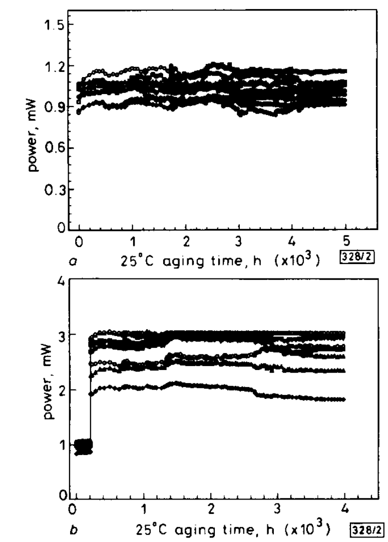

Fig. 2 *Output powers of VCSELs 1–8 (7mA) and 9–16 (15mA) against aging time at 25°C*

a VCSELs 1–8
b VCSELs 9–16

Fig. 2 shows the temporal plot of output powers of the first and second groups of the lasers. It is evident that at 25°C the output powers remain essentially unchanged after 5000 (7mA) and 4000 (15mA) hours of continuous operation. The slight fluctuations in these curves are due to the ambient temperature variation of ±3°C. Fig. 3 shows the temporal plot of output powers of the

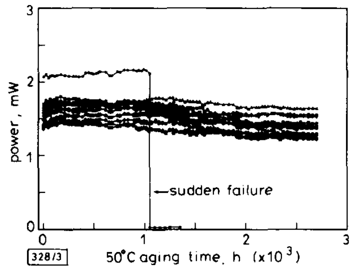

Fig. 3 *Output powers of VCSELs 17–32 against aging time at 50°C and 13mA bias*

third group (17-32) at 5°C and 13mA bias. One laser failed suddenly at the 1100th hour. The power of the rest of the 15 lasers reduced by about 14% after 2700h operations until the time of manuscript preparation. The average power degradation rate is ~5% per 1000h. The cause of the sudden failure of the one laser is to be determined and is not believed to be intrinsic to the device structure. [4] shows the temporal plot of output powers of the fourth group (33-45) at 9°C and 15mA bias. The powers were not monitored at 90°C. From time to time we lowered the temperature to 25°C and performed the power measurements. The lasers have therefore also gone through many thermal cycles. The curves show that the power of one of the lasers remains unchanged after 1000 h and the power of the rest of the group drops to 30 to 60% of the original values. All the lasers are functional after 1000h of 90°C and 15mA burning. We note that the actual junction temperature of the lasers is about 120°C, which is 30°C higher than the 9°C substrate temperature due to ohmic heating, estimated from the thermal resistance (800K/W) of the lasers.

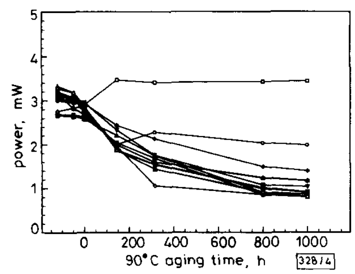

Fig. 4 *Output powers (measured at 25°C) of VCSELs 33–45 against aging time at 90°C and 15mA bias*

To access the MTTF for these lasers, we define failure as being when the laser output power drops to half of the original value at a fixed bias current. Under this definition, the MTTF for the 90°C and 15mA bias condition is ~1000h. The MTTF for the 50°C and 13mA bias condition is ~10000h. From the two high-temperature MTTF values, the MTTF at 25°C and 15mA can be extrapolated to be ~5 × 10^4h.

In conclusion we have reported 25, 50 and 90°C aging data for 45 randomly selected 0.85μm GaAs quantum well surface emitting lasers. At 25°C, no noticeable degradation was seen after 4000 - 5000h of continuous operation for current up to four times the threshold values. The MTTF at 25°C is extrapolated from the high-temperature accelerated aging process to be ~5 × 10^4h.

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Up to 15dB improvement in second harmonic distortion in complex-coupled DFB semiconductor lasers

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Indexing terms: Distributed feedback lasers, Harmonic distortion

The Letter numerically demonstrates that a pure gain-coupled distributed feedback (GC-DFB) laser exhibits more than 12dB lower second harmonic distortion than an equivalent index-coupled DFB laser at a modulation frequency of 1GHz. Furthermore, the addition of index coupling to the gain-coupled device can give a further 3dB reduction in the distortion level.

Introduction: Analogue lightwave transmission systems such as multichannel CATV systems and the transmission of microwave signals for phased-array radars require low harmonic distortion semiconductor lasers at frequencies up to several gigahertz [1]. It is known [2] that an increase in the laser resonance frequency should also lead to a reduction in the distortion characteristics of the device over a high frequency range giving improved performance in such systems. Recently we demonstrated the possibility of tripling the maximum intrinsic modulation bandwidth of gain-coupled distributed feedback (GC-DFB) lasers (which incorporate a periodic modulation of the optical gain along the length of the laser cavity) by incorporating index coupling [3]. This has also been recently confirmed independently [4]. Therefore GC-DFB lasers should exhibit improved distortion characteristics. Furthermore, GC-DFB lasers have been shown to exhibit high singlemode yield [4], high sidemode suppression ratios [5,6] and low chirp [7].

In this Letter, we show that GC-DFB lasers can give an improvement of up to 12dB in the second harmonic distortion level at 1GHz over a purely index-coupled DFB laser fabricated from the same material using numerical simulations. Also, with an optimised addition of index coupling the second harmonic distortion in a complex-coupled laser can be further reduced by more than 3dB, giving a total improvement of up to 15dB over the equivalent index-coupled structure.

Numerical model: A transmission-line laser model (TLLM) [8] was used to calculate the harmonic distortion levels in the DFB lasers. The TLLM is a time-domain model, however by taking the Fourier transform of the laser output in response to an applied sinu-