Reliability analysis of AlGaInAs lasers at 1.3 μm

V. Vilokkinen, P. Savolainen and P. Sipilä

Long-term reliability of 2.5 and 10 Gbit/s 1.3 μm AlGaInAs lasers has been demonstrated. Analysis of accelerated life test predicts median life of $\geq 1.57 \times 10^6$ h (180 years) at 85°C.

Introduction: Lasers operating at 1.3 μm wavelength are commonly used as transmitters in high-speed optical communication systems owing to low dispersion and a local attenuation minimum of standard singlemode fibre near that wavelength. Slope saturation at high temperatures in conventional InGaAsP lasers emitting at 1.3 μm make them often unsuited for uncooled applications [1]. Replacing InGaAsP by AlGaInAs compound materials in the laser active region improves laser temperature behaviour and enables uncooled operation [2, 3]. However, use of oxidising aluminium in the active region may cause concerns related to laser reliability.

In this Letter, we analyse accelerated life test results for 2.5 and 10 Gbit/s Fabry-Perot (FP) lasers based on an AlGaInAs active region. The analysis predicts excellent reliability for the lasers.

Device structure, fabrication, and characterisation: Laser structures in this study were grown using MBE. In both structures 5 nm thick AlGaInAs quantum wells emitting at 1.3 μm are separated by lattice-matched 10 nm thick $Al_{0.32}Ga_{0.16}In_{0.52}As$ barriers. These layers are sandwiched between AlGaInAs ($E_g = 1.35$ eV) and oppositely-doped AlInAs and InP cladding layers. Both structures have a highly doped *p*-InGaAs layer for contact formation. The lasers were fabricated into ridge waveguide lasers with 2.5 μm wide ridge using standard device processing steps. 2.5 Gbit/s lasers have a cavity length of 300 μm, whereas for 10 Gbit/s lasers the cavity length is 250 μm. Lasers have 70%/30% HR/AR coatings.

The static performance of lasers was characterised (CW) in bar form at 25 and at 85°C. Light power and operating voltage against current (*ILV*) measurements show that 2.5 Gbit/s lasers have a typical threshold current (I_{th}) of 11.3 and 23.8 mA at 25 and 85°C, respectively, resulting in a characteristic temperature (T_0) of 81 K. Measured slope efficiencies are 0.33 mW/mA at 25°C and 0.25 mW/mA at 85°C. Series resistance is below 4.5 Ω. For 10 Gbit/s lasers I_{th} is 12.7 mA and slope efficiency is 0.32 mW/mA. At 85°C, I_{th} is 24.4 mA and slope efficiency is 0.25 mW/mA. T_0 between 25 and 85°C is 92 K and typical series resistance is 4.7 Ω. Emission wavelength at 25°C is 1295–1297 nm for both lasers.

Reliability study: After *ILV* measurements, bars were separated into single laser dies, which were attached with Ag-filled epoxy onto heatsinks for burn-in and accelerated life testing and wire bonded for electrical contacts. Devices for the accelerated aging tests were selected using an automatic current control (ACC) step for screening out unstable devices and for stabilising the selected devices with respect to their performance (burn-in). The ACC burn-in step with 80 mA constant current at 100°C case temperature was run for 96 h for the 2.5 Gbit/s devices and for 24 h for the 10 Gbit/s devices. Selection criteria are based on observed change in threshold current and slope efficiency.

Reliability analysis of the lasers is based on automatic power control (APC) testing at 85°C. During the testing, I_{th} at 85°C is measured every 24 h.

In the evaluation of life test data, we use an end-of-life (EOL) criterion of 50% increase in threshold current from its initial value. Linear model [4] has been used to extrapolate the time-to-failure for each DUT (device under test). A lognormal distribution of failures is assumed [4].

Fig. 1 shows I_{th} at 85°C against aging time for a set of 13 2.5 Gbit/s lasers. Altogether, more than 110 000 device hours with 7 mW constant output power at 85°C have been collected for these lasers. Fig. 2 shows a similar plot for 11 10 Gbit/s lasers. These lasers have been operated at 10 mW output power at 85°C with over 100 000 device hours so far.

Fig. 3 shows expected times-to-failure at 85°C for each device in the form of a lognormal probability plot. Linear fits to the data are also shown. Median life is the time for which 50% of the population have failed. This is obtained from the point where the linear fit intercepts the 50% line in the probability plot. Predicted median life at 85°C for 2.5 Gbit/s lasers is 1.79×10^6 h (204 years) and for 10 Gbit/s lasers it is 1.58×10^6 h (180 years). Only 9 2.5 Gbit/s lasers, out of 13, show a trend of degradation. Only these lasers could be included in the analysis. For the 10 Gbit/s lasers, one laser has not shown consistent increment in I_{th} and thus this device was not included in the analysis.

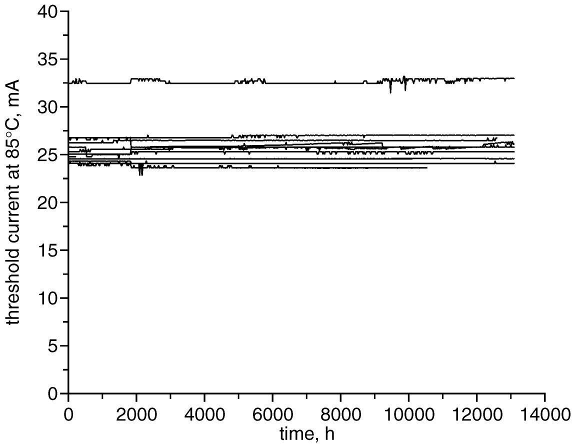

Fig. 1 *I_{th} at 85°C against aging time for 2.5 Gbit/s lasers (13 pcs)*

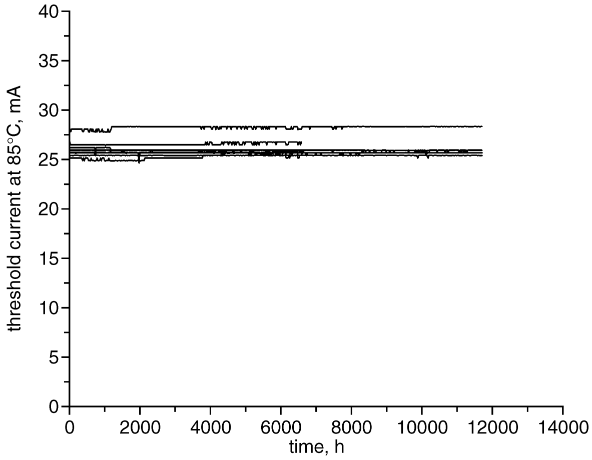

Fig. 2 *I_{th} at 85°C against aging time for 10 Gbit/s lasers (11 pcs)*

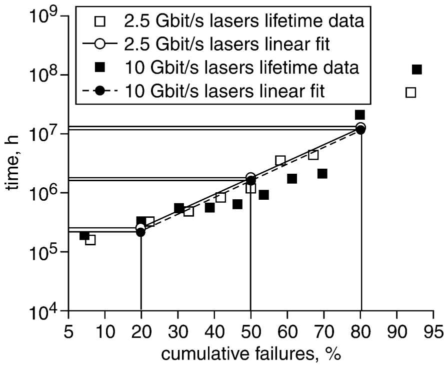

Fig. 3 *Lognormal probability plot for 2.5 and 10 Gbit/s lasers at 85°C*

At other temperatures median life can be estimated using an Arrhenius relationship [4], $ML_2 = ML_1 \times \exp[(1/T_2 - 1/T_1) \times E_a/k]$, where E_a is activation energy and k is Boltzmann's constant. Using Telcordia default activation energy of $E_a = 0.4$ eV [4], expected median life for the 2.5 Gbit/s lasers is 2764 years at 25°C and 1312 years at 40°C. For 10 Gbit/s lasers, median life is 2442 and 1152 years at 25 and 40°C, respectively.

The same lognormal model is used to calculate wear-out failure rates at 40°C for 5, 10 and 20 years of design life. In Table 1, failures per billion device hours after 5, 10 and 20 years of operation are presented for both products.

Table 1: Reliability summary

Reliability summary	2.5 Gbit/s lasers	10 Gbit/s lasers	Unit
Wear-out failure rate at 40°C			
At 5 years	86	111	FIT
At 10 years	109	136	FIT
At 20 years	124	148	FIT
Random failure rate at 40°C with 60% confidence limit	1145	3616	FIT
Random failure rate at 40°C with 90% confidence limit	2862	6963	FIT

Random failure rate represents the number of expected failures, which are not associated with wear-out failure mechanism. Random failure rates can be estimated with failure rate $= 10^9 \times N \times \gamma / t_{tot}$, where N is the number of random failures, t_{tot} is the total number of device-hours and γ is a table constant depending on N [4]. If no random failures are observed as is the case for 2.5 Gbit/s lasers, $N = 1$ is used in the calculation. For 10 Gbit/s lasers the number of observed random failures is 1. Calculated random failure rates with 60 and 90% confidence limits are given in Table 1. Owing to the low amount of test hours (~100 000), calculated random failure rates are relatively high. Even with one million device hours at 85°C and without any observed random failures, calculation still results in 451 FIT at 40°C with 90% confidence limit (1 FIT = 1 failure per billion device operating hours).

To the best of our knowledge, the reliability of 1.3 μm AlGaInAs lasers has not been reported lately in the literature. When compared to mean-life-to-failure obtained in [2], the reliability of the lasers shown in this Letter is significantly better.

Conclusions: Reliability of high-speed lasers fabricated from AlGaInAs structures emitting at 1.3 μm wavelength has been analysed using data collected in accelerated aging tests at 85°C. Analysis predicts that median life for this type of laser is over 180 years at 85°C.

5 August 2004
Electronics Letters online no: 20046314
doi: 10.1049/el:20046314

V. Vilokkinen, P. Savolainen and P. Sipilä (*Modulight, Inc., PO Box 770, FIN-33101 Tampere, Finland*)

E-mail: ville.vilokkinen@modulight.com

References

1 Minch, J., Park, S.H., Keating, T., and Chuang, S.L.: 'Theory and experiment of $In_{1-x}Ga_xAs_yP_{1-y}$ and $In_{1-x-y}Ga_xAl_yAs$ long-wavelength strained quantum-well lasers', *IEEE J. Quantum Electron.*, 1995, **35**, (5), pp. 771–782

2 Zah, C.-E., Bhat, R., Pathak, B.N., Favire, F., Lin, W., Wang, M.C., Andreadakis, N.C., Hwang, D.M., Koza, M.A., Lee, T.-P., Wang, Z., Darby, D., Flanders, D., and Hsieh, J.J.: 'High-performance uncooled 1.3-μm $Al_xGa_yIn_{1-x-y}As$/InP strained-layer quantum-well lasers for subscriber loop applications', *IEEE J. Quantum Electron.*, 1994, **30**, (2), pp. 511–523

3 Kazarinov, R.F., and Belenky, G.L.: 'Novel design of AlGaInAs-InP lasers operating at 1.3 μm', *IEEE J. Quantum Electron.*, 1995, **31**, (3), pp. 423–425

4 Bellcore, 'Generic Requirement GR-468-CORE, Issue 1, 1998