RELIABILITY CULTURE OF COST EFFECTIVE 980 NM SUBMARINE PUMPS

Stefan Mohrdiek, Mark Ives, Hans-Ulrich Pfeiffer, Rainer Bättig, Nadhum Zayer, Shaun Quinlan, Tomas Pliska, Robert Cann, Nicolai Matuschek, Jeffrey Greatrex, Norbert Lichtenstein

Stefan.Mohrdiek@Bookham.com

Bookham (Switzerland) AG, Binzstrasse 17, CH-8045 Zürich, Switzerland

Abstract: We describe a methodology to maintain performance, quality, and reliability of undersea components and reveal a design for cost effective pump laser modules at 980 nm. Further we present our advanced submarine 980 nm pump module, consisting of an eight pin, hermetically sealed, ceramic Mini-DIL package housing without thermo-electric cooler.

1 INTRODUCTION

Inevitably, undersea system manufacturers have to face longer periods of time between installation projects, which may exceed a common storage time for critical components. The challenge for active component manufacturers is to either maintain a dedicated submarine line, or to re-launch manufacturing, including all necessary re-qualifications, once business resumes. By adopting a high reliability methodology as standard, we can take advantage of materials and processes used in high volume manufacturing, in our case for 980 nm pump lasers for terrestrial applications, to offer "always on" high reliability manufacturing for submarine systems. This approach is made possible as a result of Bookham's experience with 350,000 devices shipped, accumulating 14 billion device hours, with less than 28 FIT in the field at a confidence level of 95 %. Our products use industry standard MiniDIL packages and proprietary high reliability laser diode design.

The small form factor MiniDIL pump module complies with multi-source agreements between JDSU, Alcatel and Nortel Networks Optical Components (now Bookham) for use in uncooled Telecom applications. A robust alignment technology in plane with the diode laser with a wedged fiber lens exhibits negligible drift of alignment over life.

The design of our G08 (generation 8) 980 nm laser diode is a continuation of successfully introduced improvements in previous undersea qualified generations [1], using the same MBE grown InGaAlAs material system, E2 facet-passivated COMD-free, ridge waveguide manufacturing technology. The capability exceeds 500 mW for wavelength stabilized optical powers in the fiber at operating temperatures from 0 °C – 45 °C and a failure rate of less than 100 FIT.

The MiniDIL package, the fiber alignment technology and the G08 laser being used in our submarine 980 nm pump module have seen refined manufacturing practice for several years, resulting in a major benefit for reliability and guaranteeing delivery of high quality parts.

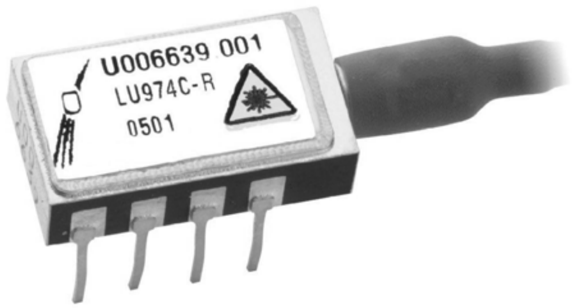

Figure 1 Eight pin DIL package with 13.2 mm x 7.4 mm housing size

2 SEMICONDUCTOR LASER TECHNOLOGY

The major differences of the G08 laser to previous laser generations are a change of the epitaxial structure in the non-active region to reduce waveguide losses and to decrease the series resistance, and further, improved waveguiding properties along the laser cavity. As a result the chip length can be increased in conjunction with lowered front facet reflectivity. All these measures increase the kink free light output power. This and in particular the E2 facet passivation [2] enables to meet the stringent reliability requirements for undersea applications.

In early days, AlGaAs lasers failed frequently, suddenly and unpredictably due to COMD and dark-line defect propagation. However, the suppression of dark lines through optimized crystal growth, and the development of mirror passivation procedures in Bookham's laser diodes have eliminated this major sudden fail mechanism. The principal problem concerning the reliability models of semiconductor laser diodes is the difficulty to generate an accurate acceleration model for failures at various power levels.

In order to obtain good reliability data, laser diodes are tested under stress conditions, with elevated temperatures and injection currents as compared to typical operating conditions. The G08 laser sudden failure rate is predictable by an acceleration model derived from an extensive set of lifetime tests performed under various stress conditions. Less than 100 FIT is estimated for undersea operating conditions. In the case of Bookham's 980 nm laser diodes wear out is hardly observed and an average lifetime due to gradual degradation of more than 100 years under operating conditions is predicted.

The figure below shows the operating current over 16 years of continuous operation for first generation 980 nm lasers with E2-facet passivation. The current is adjusted to maintain a constant diode light output power. The noise in the data is not due to laser instability but due to test set instability caused by power outages, temperature variations and moves into new locations during the last 16 years. More than one million device hours are accumulated at various stress conditions. Based on the standard reliability model [1] and data of these 9 devices the "only" fail gives an estimate of less than 32 FIT failure rate at operating conditions for these first generation 980 nm pump lasers. Today's 980 nm pump laser diodes have inherited the advantages of all previous design optimizations and show lower failure rates at much higher power levels.

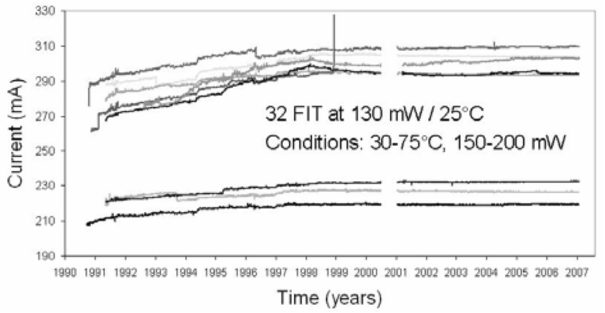

Figure 2 Nine first generation of E2-lasers under test for 16 years at various stress conditions

3 MINIDIL PACKAGING TECHNOLOGY

The laser diode is mounted onto an aluminum nitride (AlN) carrier in plane with the fiber fixture. The AlN carrier is hard soldered to the CuW base of the MiniDIL housing and thus yields a lower thermal resistance as compared to earlier designs with Al_2O_3 carriers [3]. The wedged lens on the fiber tip matches the ellipticity of the laser beam for maximum coupling efficiencies in excess of 80 % into single-mode fibers. A PIN back facet monitor photodiode (BFM) is included for diagnostics and alarm purposes, and optionally a thermistor may also be provided. The external fiber Bragg grating (FBG) in a polarization-maintaining pigtail provides excellent wavelength stability over the entire operating temperature range. Part of the product design is the incorporation of oxygen in the gas fill. This is to eliminate potential package-induced failures (PIF) [4]. A getter is fitted to absorb any resultant water vapor. It is recommended that oxygen remains part of packages environment during the product's lifetime.

The photo in Figure 3 shows the top view of the carrier including laser, back facet monitor diode (BFM), thermistor and the lensed fiber tip fixed close to the laser.

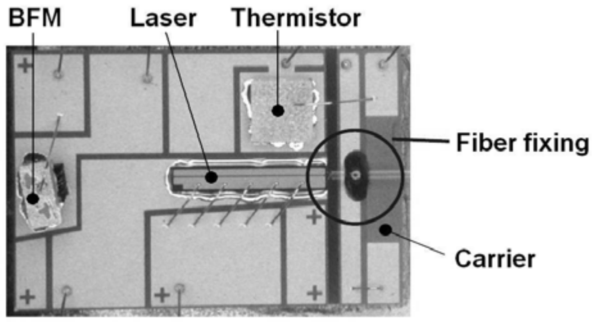

Figure 3 Laser carrier with fiber lens fixing

The alignment technology inside a MiniDIL has a number of advantages over conventional Butterfly type housings with weld clip or bulk optics fiber alignment schemes. The less complex, fully planar assembly with fewer parts along with the stiff package housing is designed for low mechanical wear-out and well-adapted to cost effective automation.

Figure 4 shows MiniDIL lifetest data recorded over more than 25,000 hours (3 years) at an operating condition of 200 mW ex-fiber power and 70 °C ambient temperature with FBG stabilized laser diodes. The changes in coupling are minimal, demonstrating the robustness of the fiber fixing technology as well as the package as a whole.

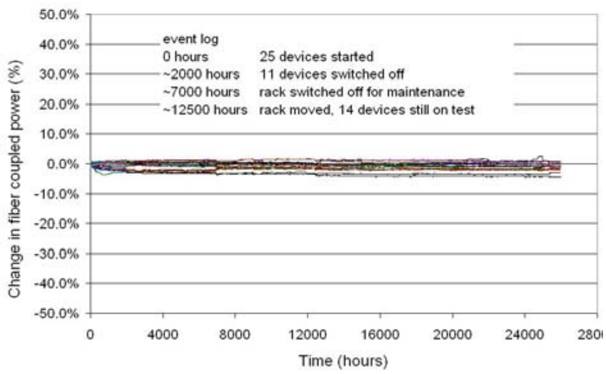

Figure 4 Lifetest data over 3 years (200 mW ex-fiber power at 70 °C ambient temperature)

4 DEVICE RELIABILITY

The described package platform is used in both in Butterfly-type and MiniDIL packages for three laser generations (G06-G08) and has seen a number of qualifications and re-qualifications according to the generic requirements described in Telcordia GR-468-CORE standards for use in Central Office environments and beyond. More than 165 devices have been exposed to mechanical integrity tests against MIL-STD-883 standards for mechanical shock, vibration and thermal shock. Endurance tests, such as accelerated ageing for 2000 and 5000 hours, high temperature storage, temperature cycling and damp heat were performed with more than 280 devices. A number of other tests were dedicated to prove the effectiveness of the getter for water adsorption and the remaining oxygen content.

As a result, the package wear out related failure rate is estimated to be less than 10 FIT.

Thus, the majority of failures are random failures due to sudden chip failure.

After qualification of a laser diode, it is important to maintain or improve reliability of shipped parts manufactured in regular production mode by appropriate lot selection as well as individual testing and screening. In our case a lot consists of a wafer with hundreds of laser diodes from which a sample of devices is tested at an accelerated condition and screened against a failure rate consistent with the reliability model. Once a lot passes this lot validation procedure, each individual laser diode from this lot is fully characterized and screened for electro-optical performance. Every laser is burnt-in on carrier together with BFM and thermistor to eliminate infant mortality from the population of shipped devices.

The handling of large quantities of test data in a cost effective manner is being made possible by a high degree of automation in testing and data collection, as well as by introduction of efficient data analysis tools. Our continuous process improvement (CPI) methodology enables us to fine tune our pump modules towards optimal parameters for reliability and performance, thereby reducing the need for intensive and time consuming pedigree type of reviews.

Since 1996 a known number of 980 nm pump modules have been shipped into the field by Bookham (formerly Nortel Networks Optical Components) with the same basic laser diode technology. This can be used to estimate cumulative field hours. Then together with the cumulative number of field failures it allows for the calculation of a field failure rate. The summary in figure 5 shows a reducing trend towards failure rates below 28 FIT at 95% confidence level with increasing statistics.

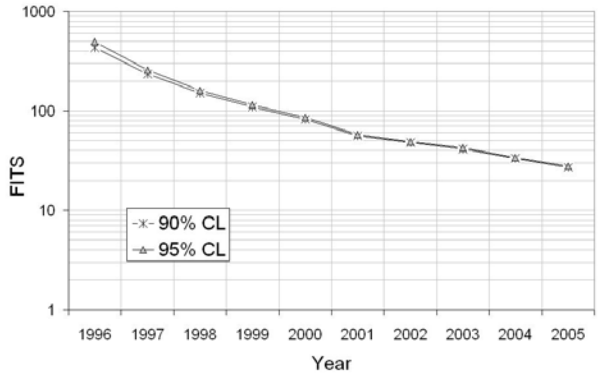

Figure 5 Module failure rates versus year from field returns at 90% and 95% confidence level

5 MINIDIL PERFORMANCE DATA

Temperature variations over 45 K in case of undersea applications cause a wavelength shift of 13.5 nm due to the natural bandgap narrowing of around 0.3 nm/K of the pump laser diode. In addition, varying the laser output power over several hundreds of mW also yields a wavelength shift on the order of several nanometers, depending on thermal resistance of the laser chip and heatsink, and further the series resistance. Since the EDFA absorption spectrum is sharply peaked at 980 nm wavelength, it is vital to efficient amplifier operation to prevent wavelength drift. Fiber Bragg gratings (FBG) are used as standard in Bookham’s uncooled and cooled pump modules to lock the pump laser wavelength over a wide operating range.

Figures 6 and 7 demonstrate the capability to obtain powers well in excess of 500 mW at currents of less than 1 A, while the MiniDIL is wavelength stabilized by an FBG even over an extended temperature range of 70 K. A side lobe suppression ratio greater than 30 dB over all operating conditions reveals that more than 98% of power remains within the useful pump band with a wavelength shift of less than 0.4 nm.

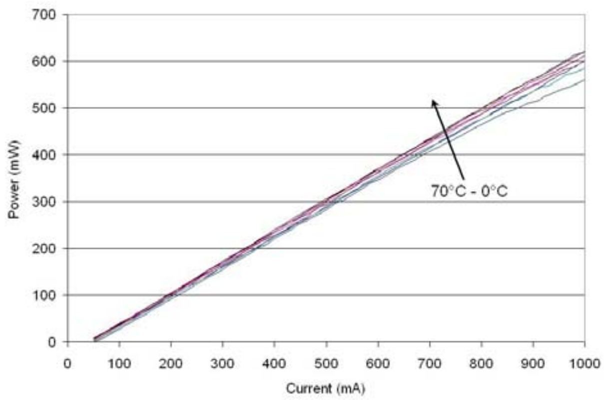

Figure 6 Power versus current characteristics for various temperatures demonstrates up to 600 mW ex-fiber at 1 A

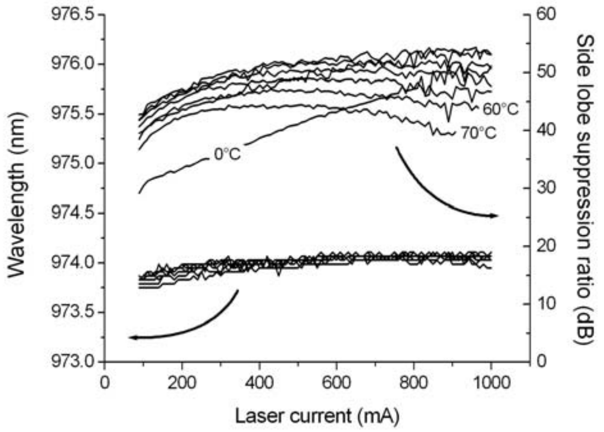

Figure 7 Peak wavelength and side lobe suppression ratio versus current reveals proper wavelength stabilization over 70 K temperature range in steps of 10 K

6 CONCLUSION

We have presented an approach to heavily utilize cost effective 980 nm pump module technology in high reliability undersea applications, taking advantage of volume production for terrestrial applications. Key enabling elements are the use of a common robust packaging platform along with procedures for appropriate laser diode screening and field proven manufacturing processes. The submarine 980 nm pump module in MiniDIL packaging format incorporates our G08 laser and is very well suited for 500 mW wavelength stabilized power in the fiber at operating temperatures from 0 °C – 45 °C and a reliability of less than 100 FIT.

7 REFERENCES

[1] B.Schmidt, S.Mohrdiek, and C.Harder, “Chapter: Pump Laser Diodes” in Optical Fiber Telecommunications IVA, Editors: Kaminov & Li, Academic Press, ISBN 0-12-395172-0, 2002

[2] A. Oosenbrug, "Reliability Aspects of 980-nm Pump Lasers in EDFA Applications", Proc. of SPIE, pp. 20-27, San Jose, California, USA, 1998

[3] Mohrdiek, S. Pliska, T. Bättig, R. Matuschek, N. Valk, B. Troger, J. Mauron, P. Schmidt, B. E. Jung, I. D. Harder, C. Enochs, S. “400 mW uncooled MiniDIL pump modules”, IEE Electronics Letters, vol.39, pp. 1105-1107, 2003

[4] J.A.Sharps “Reliability of hermetically packaged 980nm diode lasers”, LEOS 94’, Boston, paper DL1, pp.35-37, 1994.