APPLICATION NOTE

10Gb Oxide Isolated VCSEL Reliability Report

SUMMARY

Advanced Optical Components (AOC) has performed extensive reliability evaluation of its multi-mode oxide-isolated VCSEL product family, including 17μm (2Gb), 14μm (4Gb), and 10μm (10Gb) aperture diameter versions. The 10Gb VCSEL product incorporates a 10μm diameter aperture with design features aimed at high-speed performance. The same basic epitaxial structure is used for 4Gb applications, and this product utilizes the AOC patented STABILAZE technology. This report provides an update on the 10Gb oxide isolated VCSEL chip level reliability improvements over the past year. The 10Gb oxide isolated VCSEL reliability model improvement in operating lifetime is described.

INTRODUCTION

For ten years AOC has been intensively studying and improving VCSEL reliability. The earliest reliability studies on commercially available VCSELs were published by AOC (Honeywell at that time) starting in 1995 on proton-implanted devices. Oxide-isolated VCSEL technology began development and reliability study a few years later. During this time we have generated many millions of actual device-hours of life test data supporting the derivation and updating of the reliability models we have published for the AOC oxide-isolated and proton-implanted VCSEL.

AOC has generated over 3 million actual device-hours of burn-in data for 10Gb oxide isolated VCSEL, which completed qualification in mid-2004, using the reliability testing and analysis methodology developed for the earlier generation oxide and proton VCSEL products. The 10Gb multi-mode oxide VCSEL was designed to incorporate earlier generation oxide and proton VCSEL design features, where appropriate, in terms of both performance and reliability. Likewise, most of the device fabrication processes are identical or similar for the earlier generation oxide and proton VCSEL, including factory, equipment, and personnel.

Continuous improvement work over the past year, including process learning with increased 10Gb volume, tightened wafer probe limits, plus more stringent wafer evaluation reliability acceptance criteria, has resulted in the reliability model improvements described in this report. Wafer level evaluation burn-in data provides several million additional device-hours for random failure rate estimates.

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RELIABILITY TESTING AND ANALYSIS METHODOLOGY

The reliability testing methodology for the 10Gbps oxide VCSEL is essentially identical to that used and described in numerous previous reliability reports for the proton and larger diameter oxide VCSEL. Chips that pass the STABILAZE wafer level stabilization process and probe-level testing are packaged as TO-style components, typically with the VCSEL chip mounted directly onto the header. Following successful completion of parametric testing used for AOC production devices, the components are subjected to life testing. The life test protocol consists of burn-in at constant temperature and a fixed current, with the devices periodically removed from the oven and tested at room temperature. The testing interval depends upon the particular temperature/current condition (shorter intervals for higher stress). Failure is defined as a 2 dB reduction in total output power at a standard operating current. Failures are not based on extrapolation to presumed failure time but instead only actual failures are utilized in the analysis. Typical 10Gb oxide VCSEL device wear out failures, just as proton and larger-diameter oxide VCSEL, exhibit a shift upward in threshold current, with minimal change in the slope efficiency. In average power control applications the monitor current will adjust for small threshold shifts, extending the actual time to failure.

Reliability analysis is also identical as for proton and larger diameter oxide VCSEL devices. Reliasoft's Weibull ++ software is used to model the failure distribution -- for both the proton and oxide VCSEL the lognormal distribution consistently provides the best fit. For this distribution the natural logarithm of the failure times are distributed normally, and the distribution can be described with two parameters: the median lifetime ($e\mu$) and a slope parameter (σ), which is the standard deviation of the logarithms of failure times. For σ in our range this distribution indicates a wear-out failure mechanism predominates. A large median lifetime implies a long mean-time-to-failure (MTTF), although those figures are not the same. A small σ indicates a narrow range of failure times and implies few early failures will occur, making this parameter the most important one for users, who are generally more interested in the early failure rate than the mean-time-to-failure (or if they are not they should be!).

The acceleration model used is the Arrhenius model, which depends on the junction temperature, with an additional current squared dependence. This additional factor is used to account for the effect of device current on reliability, above its effect on junction temperature alone.

LIFE-TESTING

This section summarizes the reliability testing on the 10Gb oxide VCSEL, for devices built and tested in the 2002-2004 time period. The table below summarizes life test conditions. The results are for multiple test groups and wafers, representing more than 25 different epitaxy runs. Many of the groups continue on burn-in. Two groups were subjected to –65^{o}C ambient to check for mechanical stress that may cause failures at low temperature operation—no issues have been found. Additional life test data was collected for this new product at wafer reliability acceptance testing, where 3 separate stress conditions (low, medium, high stress) were run to 800 hours for each wafer, providing careful wafer selection for reliability and a large reliability information database of this new product for learning. A total of 19 burn-in conditions, with 8 different temperature and 5 current conditions, totaling over 3 million device-hours, were utilized to verify the reliability model parameters. Many of the groups have been driven to 50+% failures to provide model data. The most recent vintage wafer groups, which had the key continuous improvement features for reliability, totaling almost 1500 units, were utilized for the model update.

ACCELERATION MODEL

As described earlier, the acceleration model used is the Arrhenius model, which depends on the junction temperature, with an additional current squared dependence. This additional factor is used to account for the effect of device current on reliability, above its effect on junction temperature alone. The reliability data has been analyzed on an Arrhenius plot, with a good regression fit to the 0.70eV and current squared model factors.

FAILURE RATE DISTRIBUTION

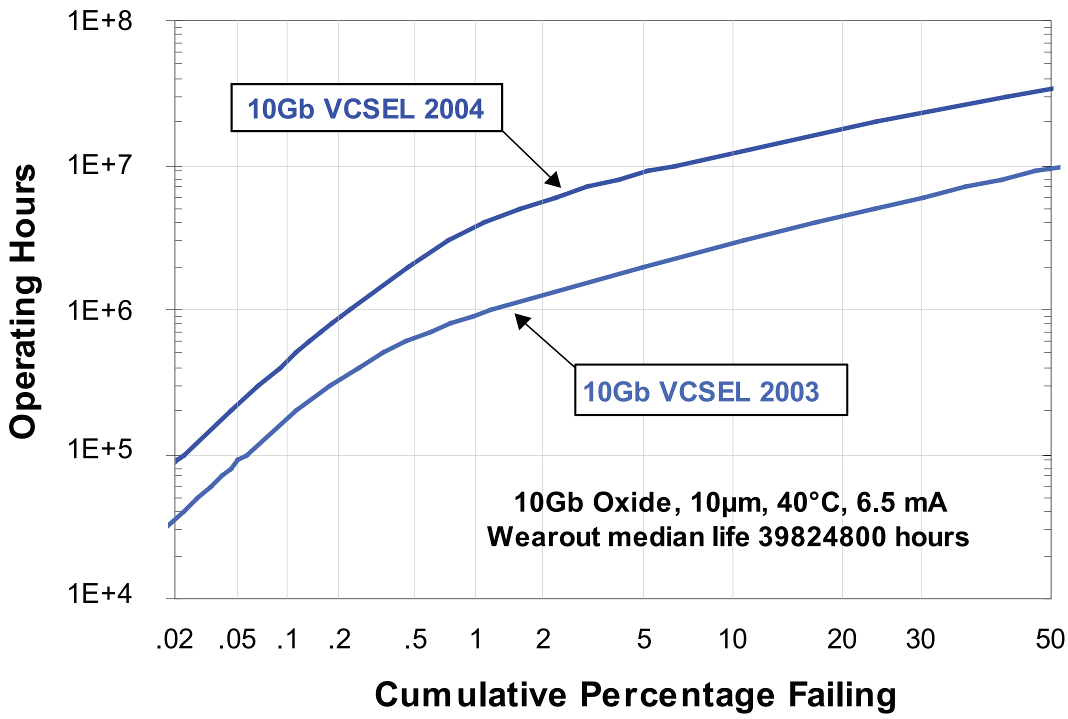
A meta-analysis was done for the selected reliability groups to verify the 0.70eV activation energy and current squared factors, and to determine the model mu and sigma values. Each group and each failure in the group was calculated for the equivalent hours at a standard operating condition (40^{O}C, 6.5mA for the 10Gb oxide VCSEL device) and the composite data analyzed as a log-normal distribution. The distribution plot has a sigma of 0.80, indicating the data is a good fit to the log-normal, 0.70eV, current squared model. The mu value results in approximately a 3.2X improvement in model reliability lifetime for most operating conditions versus the previous model developed in 2003. The sigma value is a reduced variation from the 2003 model analysis, indicating process control improvement. The good fit to the log-normal distribution model even at low failure rates indicated that there is not a significant early failure (infant mortality) factor.

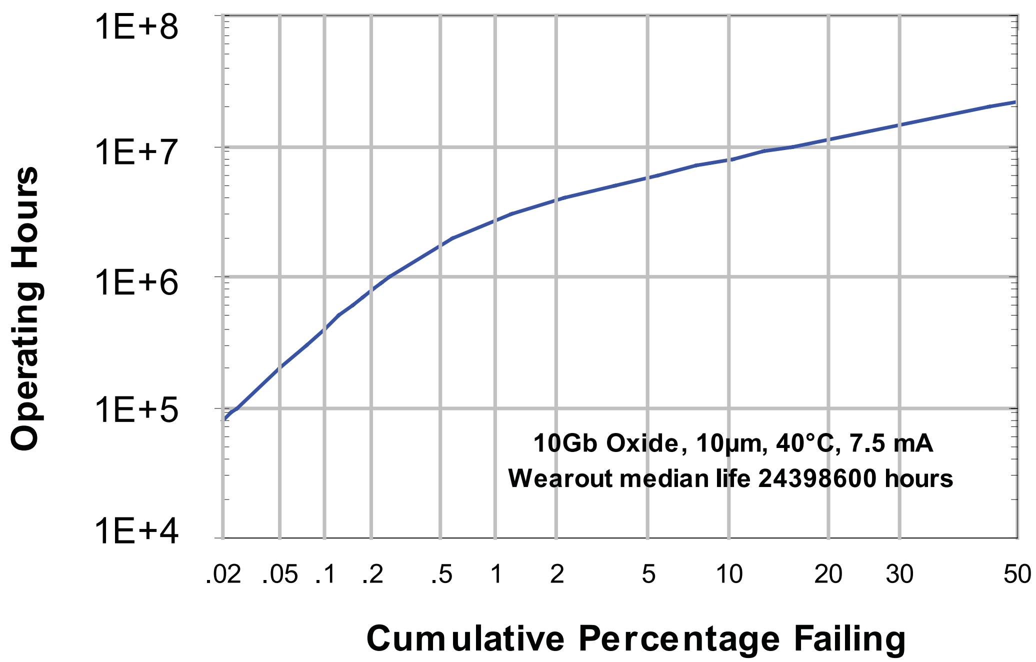
RELIABILITY IMPROVEMENT

The updated 10Gb oxide VCSEL reliability model results, with 3.2X nominal operating lifetime improvement, reduced sigma variation, and reduced random failure rate is shown graphically below. The "curvature" at low total failure rates is due to the model random failure rate that dominates at low cumulative failure rates.

RELIABILITY MODEL GRAPH

The updated reliability model is plotted below for the nominal operating condition of 40^{O}C, 7.5mA. The model includes a random failure rate (discussed in a later report section), a constant ppm/year value based on actual field return history, to cover various factors in product assemblies that are not directly device reliability related. This results in the "curving" of the reliability model line in the low failure rate region.





ESD TESTING

The 10Gb oxide isolated VCSEL device has been characterized for Electro-static discharge (ESD) sensitivity per the Human Body Model. Damage threshold voltage range is 200 to 275 volts with median sensitivity of 260 volts. This designates the 10Gb oxide VCSEL as a Class 1 (<2000V) ESD device. Reliability tests have shown no latent degradation in a burn-in study of units exposed up to 200 volts ESD levels (Human Body Model). Handling of the device must be under ESD controlled conditions to achieve the reliability ratings defined in this report. ESD controls and discipline that achieve <100 volt Human Body Models levels as defined ANSI/ESD standard S20.20 are recommended. In addition constant vigilance for exposure to other ESD/EOS sources must be maintained. Experience has shown that ESD handling and EOS (Electrical Over Stress) at testing causes most customer failures.

AGING THRESHOLD/SLOPE EFFECTS

Analysis has been done of the effects of threshold and slope changes during 10Gb oxide VCSEL aging. Threshold change is the dominant effect in aging, with slope change a lesser effect. Median data for a highly accelerated stress burn-in condition has been analyzed, and the equivalent years of operation at nominal operating condition of 55C, 8mA has been calculated. At this specific condition, when extrapolated to aging end-of-life at delta PO = -2dB, threshold change is estimated to be 81% (1.62dB) and slope change to be 19% (0.38dB) of the total power output change.

RANDOM FAILURE RATE ESTIMATES

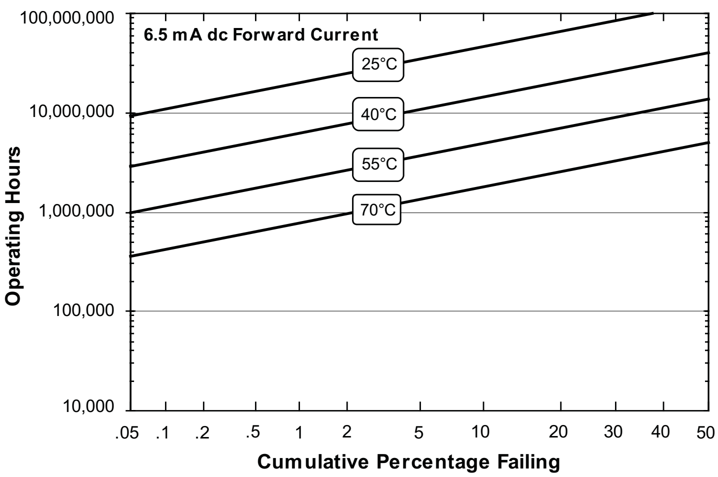
The focus of this reliability report is end-of-life wear out lifetime estimates, however also important in the reliability "bathtub curve" is the early (infant) mortality rates and the useful lifetime random failure rates. Since the median lifetime at 40^{O}C, 7.5mA nominal operating condition is 2700 years, most customer interest will concern the initial failures. Two sources provide data to estimate these parameters, the wafer evaluation burn-in done at a highly accelerated condition for a small sample from each 10Gb VCSEL production wafer, and the actual field return history for earlier generation oxide VCSEL products.

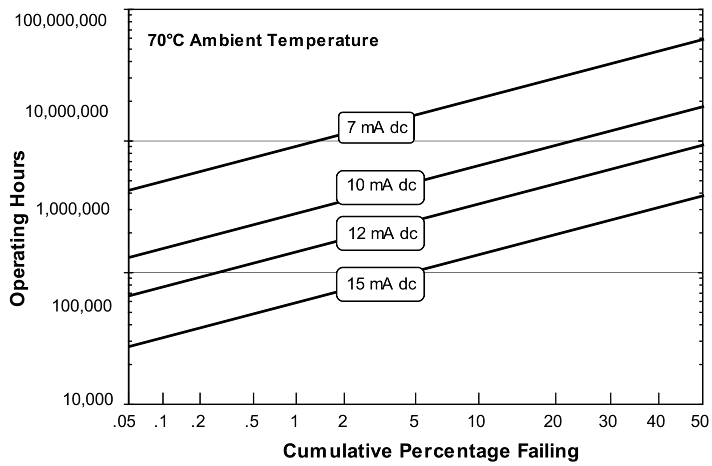
The wafer evaluation data in 2004 and a number of low stress level reliability study groups have been tabulated for cumulative device-hours and failures. In all cases there were no short-term failures. The lack of short-term failures is consistent with the near zero level of early (infant) failures observed for AOC oxide VCSEL devices. The Telcordia GR-468 standard recommends 0.35eV activation energy, with no current dependence factor, for random failure extrapolations unless otherwise justified. This low activation energy, and lack of failures, makes meaningful random failure rates from the wafer evaluation data difficult. The upper bound estimate is 29.6 FIT at 40°C, 60% C.L. and 73.9 FIT at 40°C, 90% C.L. If a 0.70eV activation energy and N=2 current acceleration factor are assumed, the upper bound estimate is 1.3 FIT at 40C, 8mA, 90% C.L. The updated reliability model predicts a point estimate wear out failure rate in 25 years of 40°C, 6.5mA nominal operation of 2.3 FIT.

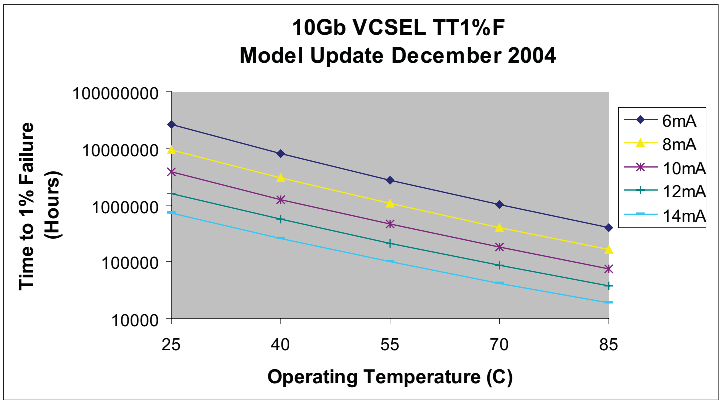
APPLICATION RELIABILITY GRAPHS

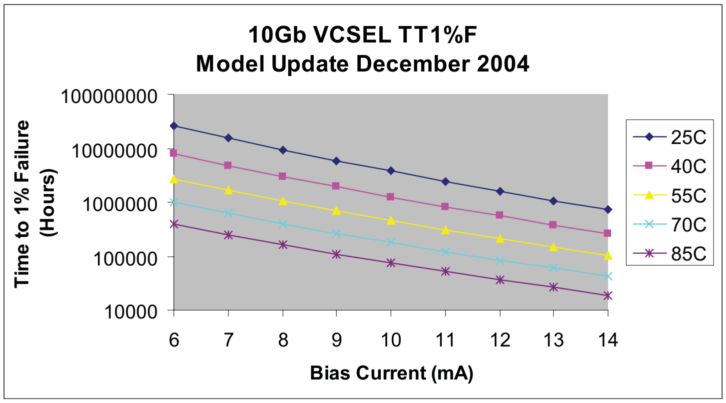
Based on the reliability model, the curves below can be used to predict the operating time to attain any particular cumulative failure percentage, for various application ambient temperatures and currents. The random failure estimate is not included in the first two graphs, but is included for the second two graphs. Note that for high-speed applications the average current can be taken to be the dc current. Also note that the model accounts for the junction temperature rise above ambient temperature. Keep in mind that, as for all models---especially reliability models, there are bands of uncertainty around each of these curves.

The graphs below are reliability graphs of the 10Gb oxide VCSEL over a range of operating temperatures and currents. The top two graphs depict operation time to a particular cumulative failure percentage using the lognormal distribution. The bottom two graphs depict operation time to the specific cumulative failure of one percent for a range of temperatures and currents.









ADVANCED OPTICAL COMPONENTS

Finisar's ADVANCED OPTICAL COMPONENTS division was formed through strategic acquisition of key optical component suppliers. The company has led the industry in high volume Vertical Cavity Surface Emitting Laser (VCSEL) and associated detector technology since 1996. VCSELs have become the primary laser source for optical data communication, and are rapidly expanding into a wide variety of sensor applications. VCSELs' superior reliability, low drive current, high coupled power, narrow and circularly symmetric beam and versatile packaging options (including arrays) are enabling solutions not possible with other optical technologies. ADVANCED OPTICAL COMPONENTS is also a key supplier of Fabrey-Perot (FP) and Distributed Feedback (DFB) Lasers, and Optical Isolators (OI) for use in single mode fiber data and telecommunications networks

LOCATION

- Allen, TX - Business unit headquarters, VCSEL wafer growth, wafer fabrication and TO package assembly.
- Fremont, CA – Wafer growth and fabrication of 1310 to 1550nm FP and DFB lasers.
- Shanghai, PRC – Optical passives assembly, including optical isolators and splitters.

SALES AND SERVICE

Finisar's ADVANCED OPTICAL COMPONENTS division serves its customers through a worldwide network of sales offices and distributors. For application assistance, current specifications, pricing or name of the nearest Authorized Distributor, contact a nearby sales office or call the number listed below.

AOC CAPABILITIES

ADVANCED OPTICAL COMPONENTS' advanced capabilities include:

- 1, 2, 4, 8, and 10Gbps serial VCSEL solutions
- 1, 2, 4, 8, and 10Gbps serial SW DETECTOR solutions
- VCSEL and detector arrays
- 1, 2, 4, 8, and 10Gbps FP and DFB solutions at 1310 and 1550nm
- 1, 2, 4, 8, and 10Gbps serial LW DETECTOR solutions
- Optical Isolators from 1260 to 1600nm range
- Laser packaging in TO46, TO56, and Optical subassemblies with SC, LC, and MU interfaces for communication networks
- VCSELs operating at 670nm, 780nm, 980nm, and 1310nm in development
- Sensor packages include surface mount, various plastics, chip on board, chipscale packages, etc.
- Custom packaging options

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