Effect of Temperature on Reliability and Degradation of 0.63µm Laser Diode

Saman Q. Mawlud*

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Abstract:

The reliability of optical sources is strongly dependent on the degradation and device characteristics are critically dependent on temperature. The degradation behaviours and reliability test results for the laser diode device (Sony-DL3148-025) will be presented .These devices are usually highly reliable. The degradation behaviour was exhibited in several aging tests, and device lifetimes were then estimated. The temperature dependence of 0.63µm lasers was studied. An aging test with constant light power operation of 5mW was carried out at 10, 25, 50 and 70°C for 100hours. Lifetimes of the optical sources have greatly improved, and these optical sources can be applied to various types of transmission systems. Within this degradation range, the device life for system application is estimated to be more than 100 h at 70 ºC at a constant power of 5mW.

Key words: LD reliability, lifetime test, temperature characteristics, semiconductor laser.

Introduction:

In General, laser diode reliability may be defined as the ability to operate the device satisfactorily in a defined environment for a specified period of time. The development of economical fiber optic transmission systems, such as access network systems and local area networks (LAN's), is urgently needed in order to construct an infrastructure for the information networks of the near future. Laser diodes are key components in such systems and they strongly influence the performance and total cost of system equipment. Consequently, it is important to reduce the cost of the laser diodes and their modules while maintaining their high performance and high reliability [1]. The most reliable laser diode with high performance at the present includes buried heterostructure InGaAsP LD's with a 1.3µm wavelength, such as Buried Heterostructure (BH), Double-Channel-Planar-Buried-Heterostructure (DC-PBH), and V-grooved Substrate Buried Heterostructure (VSB) LD's. These laser diodes have successfully achieved low threshold current, high efficiency, high stability, and long lifetime and are expected to be also highly reliable [2].

Despite nearly 40 years of field service, the reliability of photonics devices is still an unresolved issue for the fiber optic data communications industry. Since the invention of the semiconductor laser in 1962, photonics devices have evolved into indispensable components in virtually every data communication market including long-haul terrestrial, submarine, and metro applications [3]. As public acceptance and use of optical data communications increases, end users have come to expect a very high level of network availability. This expectation translates into equally

*Dept. of Physics, Science Education Collage, Salahaddin University

stringent requirements for the long-term reliability of individual photonics devices [4]. In comparison to other electronic devices, laser diode testing is complicated by the requirement to accurately measure both optical and electrical parameters and by the diverse package styles and power levels found in currently available laser diodes. Laser diode life testing is used for part qualification during product development as well as for lot testing throughout the production life of the laser. Life tests generally consist of high temperature accelerated aging of a sample group of lasers under carefully controlled conditions. [5].

Degradation in laser diodes is substantially different from that in other electronic devices due to the radiative recombination process of electron-hole pairs and the presence of high optical power densities within the active region and at the output facets of the laser [1]. The primary degradation modes in laser diodes arise from (1) defects in the active inner region of the laser due to the growth of dislocations, (2) facet degradation due to oxidation, (3) electrode degradation due to metal diffusion into the inner region, (4) bond degradation, and (5) heat sink degradation. Degradation may be enhanced by increased current, temperature, light output, and moisture. Additionally, laser lifetimes may be shortened by electrical surges [6]. The experimental part and the used components were discussed in section II. The basic characteristics of the (Sony-DL3148-025) LD's and the temperature effect on the reliability and life time are described in Section III, the results and discussion obtained are summarized in Section IV and conclusion is presented in section V.

Materials and Methods:

In this study laser diode (Sony-DL3148-025) was used, it was obtained from Thorlabs company, at temperature 25ºC the laser diode (LD) has a characteristics of wavelength 0.63µm, output power 5mW and threshold current around 20mA. A laser chip is mounted on a thermoelectric cooler (TEC) for stabilizing the temperature; the temperature control can be a critical issue in laser diode design, due to the strong temperature dependence of threshold current, quantum efficiency and device lifetime [7]. The laser diode and TEC were mounted on a heatsink for absorbing the heat pump from the TEC. The experimental work was a two-step test. In the first step, the laser diodes were operated at a constant driving current 20mA at 25ºC for 100 hours. The main characteristics (threshold current, differential quantum efficiency and device temperature) were calculated and the relation between lifetime and the output power was obtained. In the second step the laser diode was operated at different temperature (15, 25, 40, 55, and 70) ºC for 100 hours. The screening criterion for this step is to study the effect of temperature on the life time of the laser diode.

Temperature effect on the reliability and life time

The lifetime of a laser diode can be approximated by the following relationship. Given an initial power output of the device *Po* and the exponential lifetime τ, the power output over time *t*, can be extrapolated as in equation (1) [8]:

$$P_{out}(t) = P_o e^{-t/\tau} \quad \text{........... (1)}$$

Assume that for a given time *t*, the power output of the device has dropped to a percentage from the initial power level such that Power ratio, *PR* = *Pout/Po* and solve for *t* such that,

$$\tau = \frac{-t}{\ln(P_R)} \quad \text{............ (2)}$$

For determining the relationship between temperatures of the device to predict lifetime an Arrhenius relationship can be expressed as [8]:

$$t = ce^{Ea/kT} \quad \text{.......... (3)}$$

Where:

Ea is the activation energy for the device in units of eV, k is Boltzmann's constant = 1.38 * 10^{-23} joules/Kelvin, T is absolute temperature, (273.2+°C) in units of Kelvin, and c is the device constant.

Given known activation energy *Ea*, operating temperature T_o and lifetime of the device t_o, the constant can be calculated by:

$$c = t_o e^{-\frac{Ea}{kT_o}} \quad \text{........... (4)}$$

Or as a ratio, t_1 can be solved in terms of T_1 given T_o and t_o such that:

$$\frac{t_o}{t_1} = \frac{e^{\frac{Ea}{kT_o}}}{e^{\frac{Ea}{kT_1}}} \quad \text{............. (5)}$$

Simplifying the above equation in order to solve for t_1 as a function of the temperature for accelerated life testing, we get [9]:

$$t_1 = t_o e^{-\frac{Ea}{k}\left[\frac{1}{T_o} - \frac{1}{T_1}\right]} \quad \text{.......... (6)}$$

Changes in temperature must be taken into account during the operation of a laser diode. A relatively small temperature change can easily destroy the device by allowing too much current to flow through the pn junction because any increase in current causes an increase in optical output. If this optical output increases beyond its maximum permitted value, the facets on the ends of the Fabry-Perot cavity will burn out causing the unit to be destroyed. Optical and electrical properties of these LD's such as light output versus current *(I-P)* and voltage versus current *(I-V)* curves before, during, and after constant current aging were measured. The operation current of these LD's biased above threshold under a constant optical output power (5 mW) was measured as a function of aging time at various temperatures. Fig.(1), shows typical light power and current characteristics of (Sony-DL3148-025) before the aging test. The threshold current is about 20 mA and threshold voltages 1.88V at 25ºC. The output power is more than 5mW at 21.5mA, and power saturation does not occur at driving current of less than 21.5mA. The typical temperature dependence of the current-light output power characteristics is shown in Fig.(2). The threshold current and the slope efficiency were respectively 19.8 mA and 0.42W/A at 25ºC. The degradation of laser diode is usually caused by an increase in the nonradiative recombination, where the threshold current increases and the slope efficiency scarcely changes from the initial value at the same current bias after lasing. This is due to the fact that the injected carrier lifetime and threshold carrier density remain constant during degradation, although the threshold current increases [6].

As shown in Fig. (3), however, the slope efficiency gradually decreases and the threshold current increases when the device is operating at higher temperature. This decrease in the slope efficiency indicates that degradation of the laser cavity, that is, an increase in optical absorption loss is generated.

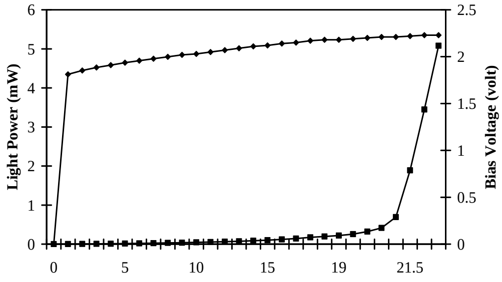


Fig.(1): Typical I-P and I-V characteristics of the (Sony-DL3148-025) before aging tests at 25 ºC.

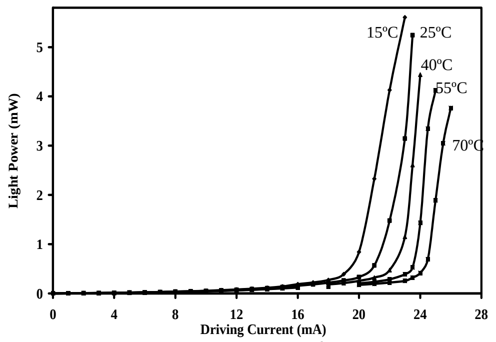


Fig.(2): Temperature Dependence of Light vs Current

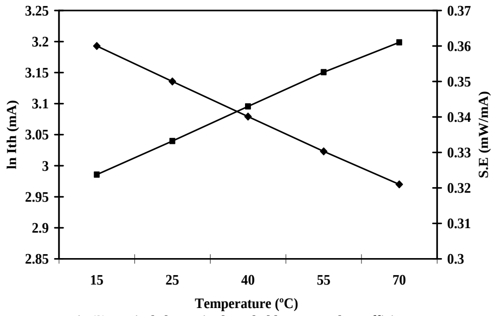


Fig.(3):Typical change in threeshold current- slope efficiency characteristics with temperature

Results and Discussion:

Fig.(4) shows the light-output power and the driving-current characteristics for several high-stress test times. The degradation of light power at less than about 100 h is mainly due to the threshold-current increase and the slope-efficiency decrease which led to an increase in the driving current at power saturation.

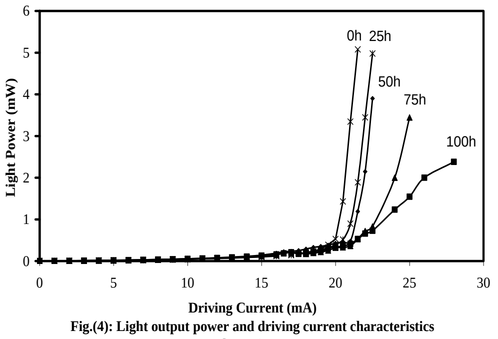


Fig.(4): Light output power and driving current characteristics at several test times at 25 ºC.

The change in light output power with high test time is shown in Fig.(5). The light power gradually decreases for about 25 h, and it decreases more at around 100 h. The large increase in the driving current is mainly due to the light-power saturation caused by the device temperature rise, and the maximum power due to light-power saturation limits the device lifetime.

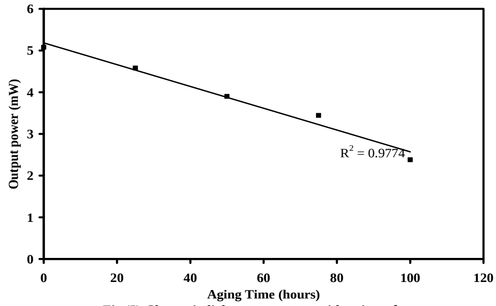


Fig.(5):Change in light output power with a time of test.

The rate of degradation was examined as a function of the injected current. For LD's operating under the constant optical output power aging condition, the operation current is measured as a function of the aging time to determine the lifetime of the LD's. Fig.(6) shows the dependence of the threshold current increase on the aging time. The threshold current increased in proportion to the aging time. This degradation behaviour, in which the threshold current increased and the slope efficiency decreased, is influenced mainly by the increase in internal optical loss in the cavity and in nonradiative recombination process. The main cause of degradation in the inner region is directionally dependent on the crystal structure as well as dependent on the material used for the source [9].

A digital camera, to take an image of the output beam, was used to reveal the degradation of the laser diode. The images of the laser diode obtained after aging times are shown in Fig.(7).

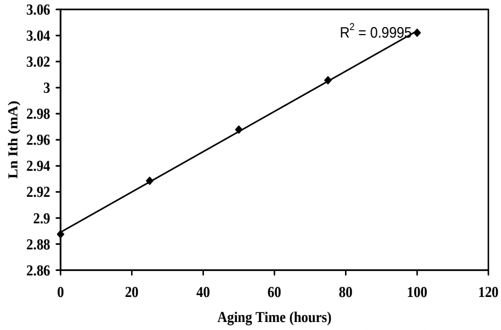
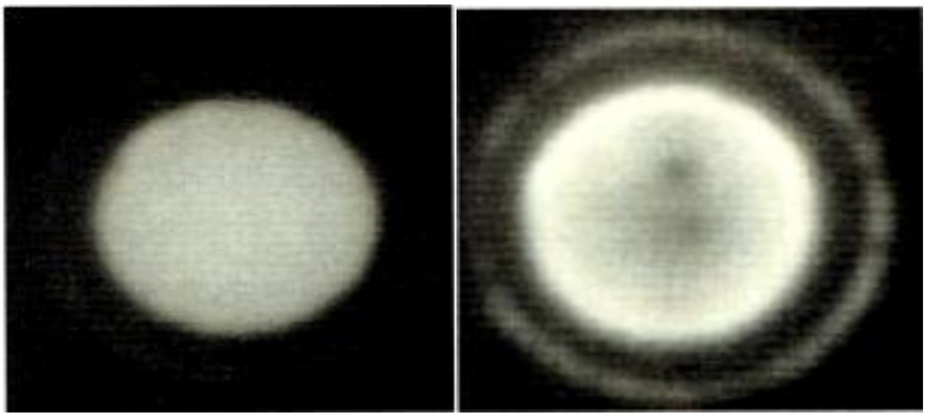


Fig.(6): Relative threshold current changes as a function of aging time.

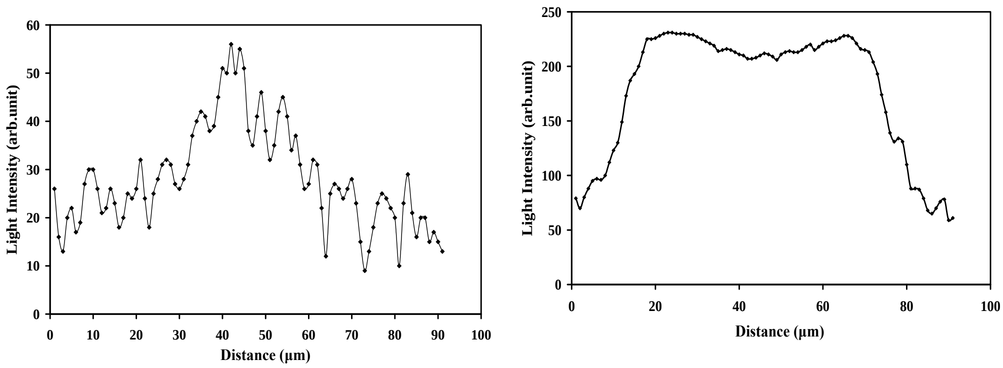
Fig.(7a) shows the image of the laser diode, which was taken at 0h. It contains neither a dark line nor a dark spots. Any dark line might appear in the image of the laser before any operation will fail to operate properly [10]. The light power linearly increased as the driving current was increased to about 20 mA and saturated at more than 20 mA. This saturation is attributed to the fact that the temperature rise of the laser diode due to driving current affects the light power characteristic. As shown in Fig. (7b), a dark spot appeared after 100 h aging, even though the driving current was less than 20 mA. A dark spot is observed at the centre of the image at a driving current of more than 20 mA. Because the intensity decreases with aging time, the degradation is attributed to an increase in nonradiative defect density [1].



(a) (b)

Fig.(7): Images of the (Sony-DL3148-025) at T=25ºC.
(a) Undegraded device at driving current of 20 mA and aging time 0 h.
(b) Degraded device at driving current of 20 mA and aging time 100 h.

The LD emits more light as the forward current is increased. This analysis indicates that the dominant failure mechanism for these LDs is significantly different from one of the major failure mechanisms causing degradation in 630 nm LEDs [8]. Using MathCAD 14 package, the real image of the spot in Fig.(7) a,b can be converted to a greyscale image; the logical analysis was then performed to study the change in the characteristics of the laser diode spot [11]. Fig.(8) shows the intensity distribution of the laser diode as a function of distance for 2 aging times.



(b) (a)

Fig.(8): Intensity distribution of (Sony-DL3148-025) at T=25 ºC.
(a) Aging time 0 h.
(b) Aging time 100 h.

The lognormal distribution used to model failure times is probably the most commonly used distributions in reliability applications [12]. Fig.(9) represents the lognormal distribution for a failure time to a cumulative failure probability of a laser diode at a specific condition, 70 ºC and 6 hours time of operation. The resulting plots (below) shows that line up approximately on a straight line indicate a good fit to a lognormal.

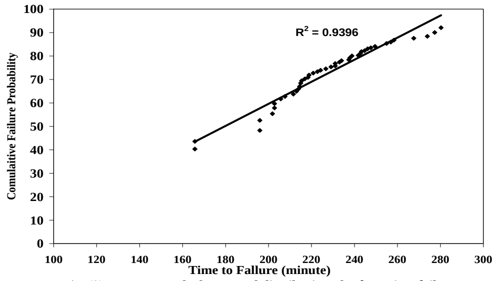


Fig. (9): Represents the lognormal distribution plot for a time failure data at a condition, 70 °C junction temperature.

Conclusion:

Degradation characteristics of (Sony-DL3148-025) were studied. Lifetimes of the optical sources have been greatly improved by several tests of laser diode under different temperature and aging time.

At 25ºC the threshold current and the slope efficiency respectively 19.8 mA and 0.42W/A at 25ºC were obtained. No evidence of dark lines or dark spots were observed at 0h, but a dark spots was generated after 100 h aging. The increased current causes the device temperature to rise, and finally bring about the large current increase due to the temperature rise and the light power saturation. Thermal effects play an important role in accelerating the device degradation. The laser diodes continued to operate over a wide range of temperatures. The lifetime of the laser diode under test had been confirmed to be more than 6380 h by using Arrhenius relationship at 25 °C at 5 mW and 200 h at 70 °C at 2.38 mW.

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تأثير الحرارة على الموثوقية والتقادم الثنائي ليزر 0,63مايكروميتر

سامان قادر مولود*

*قسم الفيزياء – كلية التربية الاقسام العلمية – جامعة صلاحالدين-اقليم كردستان/العراق

الخلاصة:

إنّ الموثوقيةَ في المصادر الضوئية تعتمد بشكل كبير على التقادم و إنّ خصائص ثنائي الليزر تعتمد بشكل حرج على درجةِ الحرارة. تمت دراسة نَتائِجَ إختبار سلوكيات التقادم و الموثوقية لثنائي الليزر (Sony-DL3148-025)، وتبين بأن هذه الليزرات تكون عادة ذات موثوقية عالية، وسلوك التقادم قد تم تعرضه في عِدّة إختبارات عمرية، وتم من خلالها تقدير العمر الزمني لهذه الثنائيات، وأجريت دراسة إعتمادية الليزر دايود ذات الطول الموجي 0.63 مايكروميتر على درجة الحرارة. تم أجراء الاختبار العمري لقدرة ضوئية ثابتة 5 ملي واط عند درجات حرارة مختلفة 10و25و50و70 م° و لمدة 100 ساعة. فقد تم تحسن العمر الزمني لهذه المصادر الضوئية بشكل، ويُمْكِنُ لهذه المصادرِ الضوئية تطبيقها في الأنواعِ المُخْتَلِفةِ مِنْ أنظمةِ الإرسال. وضمن هذا المدى من التقادم فقد تم تقدير العمر الزمني لهذه الليزرات فوجد أنه أكثر من 100 ساعة عند درجة حرارة 70 م° وعند قدرة ثابتة مقدارها 5 ملي واط.