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Research Article

Burn-In Aging Behavior and Analytical Modeling of Wavelength-Division Multiplexing Semiconductor Lasers: Is the Swift Burn-In Feasible for Long-Term Reliability Assurance?

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Effective and economical burn-in screening is important for technology development and manufacture of semiconductor lasers. We study the burn-in degradation behavior of wavelength-division multiplexing semiconductor lasers to determine the feasibility of short burn-in. The burn-in is characterized by the sublinear model and correlated with long-term reliability.

1. Introduction

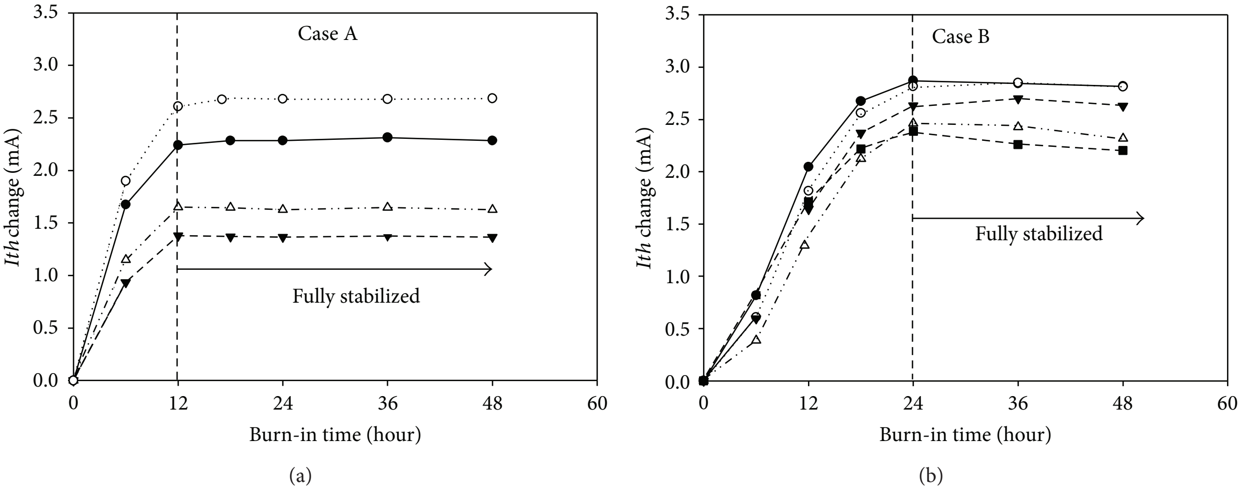
As the demand of data, voice, and video play grows, the bandwidth requirement for downstream and upstream transmissions continues to increase. Recently, there has been accelerated growth in bandwidth demand due to the introduction of mobile smart phones and portable touch screen tablets (iPhone, iPad, etc.). Wavelength-division multiplexing has been the enabling technology for higher bandwidth. To meet the WDM applications where a high density of channels is in service, each channel requires superior reliability and wavelength stability. Some network and cable operators have tightened up their wavelength stability from 0.1 nm to 0.03–0.09 nm [1–4]. On the other hand, there has been an ongoing driver to reduce the manufacturing cost and cycle time of the laser components. One way to achieve the lower cost is by means of qualification improvement.

In this paper, we study the burn-in behavior of the WDM distributed feedback (DFB) lasers and correlate it with long-term reliability. We characterize the burn-in behavior using sublinear model and determine the burn-in times. We also correlate the burn-in with the long-term life test. We demonstrate that swift burn-in screen of BH lasers is feasible while meeting the long-term WDM reliability requirement.

2. Experimental

The buried heterostructure (BH) DFB lasers with C-band (1550 nm and vicinity) lasing wavelength were used for the study. Epitaxial layers were grown on n-type InP substrate using metal organic chemical vapor deposition (MOCVD) technique. First, n-doped InP buffer layer was grown. An active layer consisting of multiquantum well structures and grating layers were grown sequentially. The composition of the active region was InGaAsP. A mesa structure was formed by wet etch. Subsequently, p-InP and n-InP burying layers were grown to form current blocking. The final regrowth layer was grown, etched into mesa structure, and covered with SiN_x/SiO_2 dielectric layers. The contact opening in the dielectric was created by reactive ion etching (RIE), and the p-metallization stack of Ti/Pt/Au/Cr/Au was deposited to make ohmic contact. On the n-side, the wafer was thinned by lapping and deposited with AuGe/Ni/Au to form n-contact. Finally, wafers were cleaved into bars to form facets, and the bars were coated with antireflective (AR) and highly reflective (HR) coatings. The laser cavities of 550 and 1000 micrometer were prepared for burn-in and life test studies.

Chips were die attached and wire bonded to the AlN submounts to facilitate burn-in and life test [5]. The burn-in and



(a)

(b)

Figure 1: (a) Case A burn-in behavior of WDM lasers. The laser cavity is 550 micrometer from wafers A and B. (b) Case B burn-in behavior of WDM lasers. The laser cavity is 550 micrometer from wafer C.

life test were monitored with high-resolution measurements on the threshold current, optical output power, and forward voltage. The burn-in and life test aging was conducted at 100°C, while the LIV (light versus current, voltage) data was taken at 25°C at every interval. The LIV was measured *in situ* throughout the aging test in order to minimize the noises introduced from external handling. At each interval, the laser submounts were cooled down to 25°C by the thermoelectric cooler (TEC) and stayed at 25°C for 5 minutes to allow full temperature stabilization before LIV data was taken.

Table 1: Sub-linear model fitting extrapolation of burn-in curves for cases A and B.

	Case A	Case B
Fitting exponent	$m = 0.2$	$m = 0.4$
Fitting-correlation factor	$f = 0.961$	$f = 0.865$
*I*th stabilization	At 12 hr	At 24 hr
R square	0.967	0.874
Sample size	4	5

3. Results and Discussions

The lasers of 550-micron cavity were subjected to the burn-in stress current of 210 mA at 100°C. To determine the time for lasers to stabilize, the LI was taken at every 6 hours. The typical burn-in behaviors are shown in Figures 1(a) and 1(b). For case A, the lasers showed gradual increases in the threshold current (*Ith*) during 0–12 hours and became fully stabilized after 12 hrs. For case B, the lasers showed gradual *Ith* increases during 0–24 hours and became fully stabilized after 24 hrs. The burn-in behavior showed dependence upon the wafer. The processing was nominally the same. Case A behavior came from the samples of wafers A and B, while case B was from wafer C.

The burn-in curves in Figure 1 were also characterized by the sublinear fitting. The sublinear model was based on polynomial function expression recommended by Telcordia [6]. In the sublinear model, an experimental burn-in curve was fitted by $y = 1 + at^m$ where y is the ratio of the threshold current at time (t) after burn-in and the initial threshold current, t is the burn-in time, and the constant (a) and the exponent (m) are the free parameters for the curve fitting [7–10]. Table 1 shows the fitting exponent and fitting-correlation factor of the two groups. For case A, the smaller fitting exponent suggests a greater saturation of threshold current. This is consistent with the earlier time (12 hours) of *Ith* stabilization in case A compared to the 24 hr in case B. The statistical uncertainties are estimated by *R* squares.

An analytical simulation by Lam et al. [11] showed that the sublinear model was accurate in describing the saturation of degradation in aging curves. It was assumed that the change in threshold current was given by the change in the nonradiative recombination current that was proportional to the defect density. It was further assumed that the source to supply the creation and growth of defects was finite. Figure 2 shows the example of simulated degradation curves as a function of curve fitting exponent (m). As m increases, the aging curve becomes more linear with less degree of saturation. On the other hand, the saturation becomes more pronounced when m is smaller, as shown in case A.

Figure 3 shows the threshold current (*Ith*) change as a function of stress current density. The current density is defined as the current divided by the cavity length. The *Ith* change generally increases with increasing current density. The higher current density would accelerate the aging rate likely due to the enhanced defect formation and propagation. The *Ith* change follows the linear regression line, suggesting the same degradation mechanism without inducing new failure modes. For a given burn-in current density, the *Ith* change is higher for the 1000 micrometer long lasers, likely due to the long cavity and mechanical stress [12–16]. For the long cavity, the number of defects within the laser cavity is likely to be higher. In addition, the mechanical stress

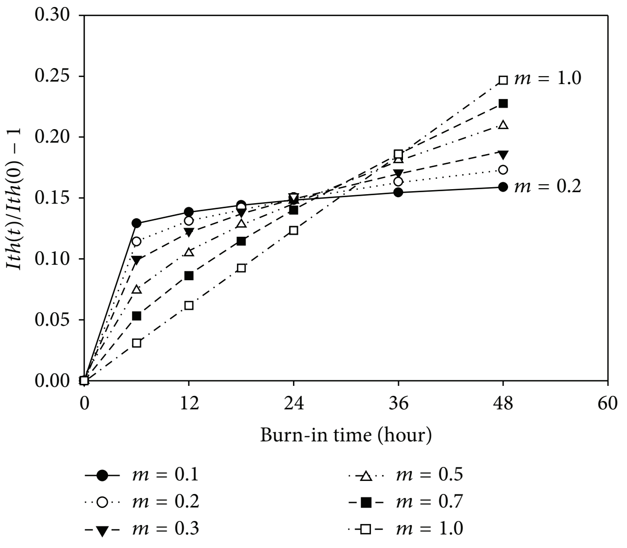


FIGURE 2: The sublinear fitting curve as a function of fitting exponent (m). The saturation is more pronounced when m is smaller.

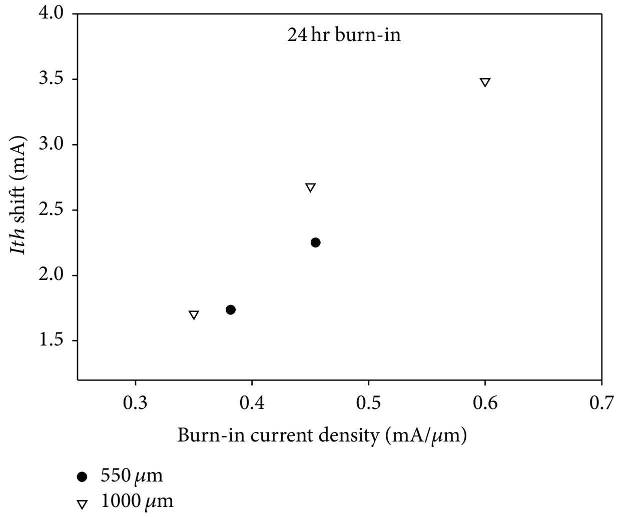


FIGURE 3: *Ith* change versus stress current density of WDM lasers of 550- and 1000-micron lengths.

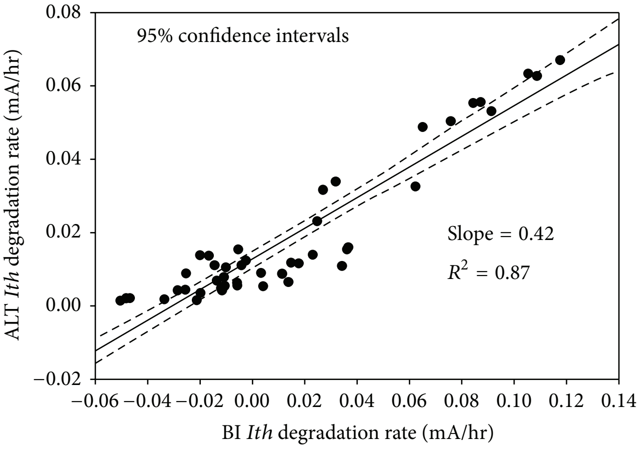


FIGURE 4: Correlation of burn-in and life test aging. The burn-in and subsequent life test degradation rates are correlated. The degradation rate is decreased over time. The solid and dash lines indicate the linear regression and 95% confidence intervals, respectively.

caused by the mismatch of the thermal expansion coefficients between the InP laser chip and AlN submount becomes more important as the laser cavity increases [13]. Hence, the degradation rate is expected to be higher.

We also correlated the burn-in behavior and long-term life test aging. In order to complete the life test study in a reasonable time frame, we used the first 300-hour life test data for the correlation analysis. Figure 4 shows the correlation of the threshold current changes between the burn-in and life test aging where the linear regression line and the 95% confidence intervals are shown by the solid line and dash lines, respectively. The coefficient of determination, denoted as R squared, was 0.87. The burn-in (BI) degradation rate was defined as the ratio of the *Ith* change and burn-in time. The accelerated life test (ALT) degradation rate was defined as the ratio of the *Ith* change and ALT aging time. The *Ith* change of ALT was generally proportional to the *Ith* change of BI. Based on the fitting regression, the slope was 0.42, suggesting that the degradation was slower during life test aging. This was consistent with the sublinear model where the degradation rate was expected to decrease over time.

4. Conclusion

We studied the burn-in behavior of the WDM semiconductor lasers by using the sublinear model. case A group showed *Ith* stabilization at 12 hr, while case B group stabilized at 24 hr. The former showed a greater saturation in degradation rate, leading to a smaller fitting exponent (m). The life test *Ith* change also showed correlation with the burn-in *Ith* change. The ratio was determined to be 0.42, indicating that the degradation was saturating over time. We have demonstrated that swift burn-in screen (<48 hr) may be feasible.

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