Ultra-high Power (180mW), Linearly Polarized DFB Lasers with Narrow Spectral Linewidth (100kHz) for 1550nm WDM +100km Long-haul Transmission

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ABSTRACT

C-band 1550nm DWDM lasers with ultra-high optical power (180mW) operated at 600mA continuous wave (CW) have been successfully developed. The lasers showed linear light vs. current (LI) with little rollover up to 750mA at room temperature. The lasers also showed excellent relative intensity noise (RIN<= –170dB/Hz), narrow linewidth (<=100kHz) as well as excellent polarization extinct ratio (>=21dB) which made it suitable for +100km long-haul transmission. Robust long-term reliability (8800hr) was demonstrated.

Keywords: Distributed feedback (DFB) lasers, 1550nm WDM, high power lasers, relative intensity noise (RIN), polarization extinct ratio (PER), BH lasers, reliability

1. INTRODUCTION

Wavelength division multiplexing (WDM) continues to receive increasing market demand due to its flexibility to increase bandwidth using the existing fiber networks. Using WDM technology, several wavelengths, typically in 1550nm C-band, can simultaneously multiplex signals over the fiber [1,2].

C-band 1550nm lasers are widely used for long-distance optical links due to the benefit of low attenuation. In order to distribute signals from one node to a large number of homes over a long distance (>100km), it is required to have sufficient power budget, narrow spectral linewidth and low relative intensity noise (RIN). Previously we have demonstrated a distributed feedback (DFB) laser with a power of 140mW and RIN-through-fiber of –160dB/Hz [3]. With continued demand for longer transmission and more signal splits, we have recently developed 1550nm DFB lasers that showed ultra-high output power (180mW) and low RIN (<= –170dB/Hz). The DFB laser also has the cost and manufacturability advantages over other solutions such as external cavity lasers (ECL).

2. EXPERIMENT

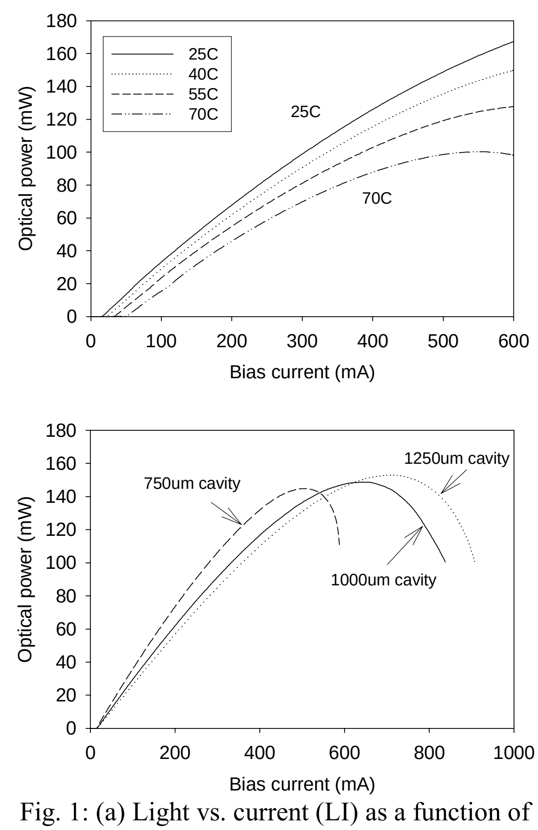


Fig. 1: (a) Light vs. current (LI) as a function of temperature. The current ramp was from 0 to 600mA, taken at temperatures of 25, 40, 55, and 70°C. (b) LI curves of 750, 1000 and 1250μm p-metal-up lasers.

An active region consisting of muliquantum well (MQW) and separate confinement heterostructure (SCH) layers was grown using metal organic chemical vapor deposition (MOCVD). The photoluminescence (PL) of the MQW was in the range of 1520-1555nm depending upon the ITU channel. To form single-mode distributed feedback (DFB) lasers, grating layers were grown and the grating periods were defined by holographic technique.

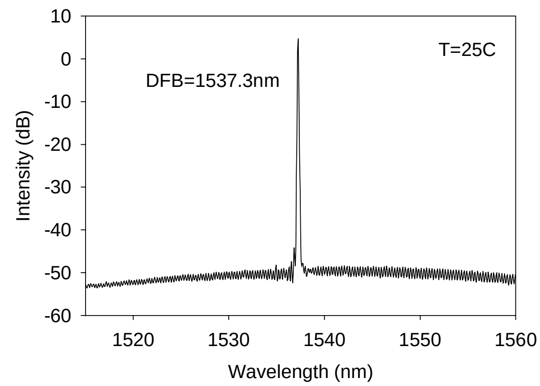
The active region was wet etched to form a mesa structure. Subsequently, p-InP and n-InP blocking layers were grown, followed by p-InP and p-InGaAs layers to form buried heterostructure (BH). For p-metal, Ti/Pt/Au was deposited on the p-InGaAs contact layer and annealed at 420°C [4].

After completion of wafer processing, wafers were cleaved into bars. The bars were coated with anti-reflective (AR) and highly reflective (HR) coatings, screened and diced into chips. To facilitate handling and testing, the chips with p-metal facing up (p-metal-up) were attached and wire bonded to the AlN submounts. The chip-on-submounts were screened for kinks and burned-in to eliminate infant mortality. Laser devices were characterized by LIV, far-field, spectral linewidth and RIN. The linewidth and RIN of the DWDM laser were measured using heterodyne scheme [5-7].

3. RESULTS and DISCUSSIONS

Figure 1(a) shows the light vs. current (LI) as a function of temperature. The laser showed excellent LI characteristics for high power applications. For a current ramp of 0-600mA at 25°C, the LI showed good linearity with little thermal rollover, no kink. For example, the 1250µm laser did not showe rollover up to 750mA. The characteristic temperature (To) of the laser, determined by the change of threshold current over the temperature range of 25-70°C, was estimated to be about 42-51K, which was expected for InGaAsP/InP material. Fig. 1(b) compares the LI curves of 750, 1000 and 1250µm lasers. The peak power and thermal rollover both improved with increasing cavity lengths.

Figure 2(a) and (b) show the optical spectra of a laser at 25 and 85°C where the DFB peaks were located at 1537.3nm and 1542.8nm, equivalent to International Telecommunication Union (ITU) grid channel 50 and 43, respectively. The side-mode-suppression-ratio (SMSR) was excellent, exceeding 50dB.



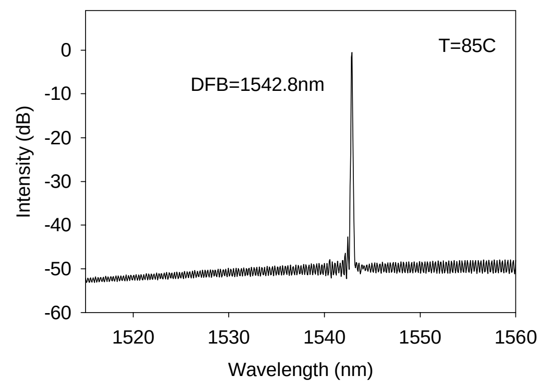


Fig. 2: The optical spectra of a laser at (a) 25°C and (b) 85°C. The DFB peaks were located at 1537.3nm and 1542.8nm, respecitvely.

Figure 3 shows the measured far-field of the high-power laser, taken at 25°C, 300mA. The laser cavity was 1250um, attached to the AlN submount to facilitate probing. The far-field divergence angles in vertical (transverse) and horizontal (in-plane) are about 25 and 20 degrees, respectively. The far-field angles did not change with increasing bias current, from 50 to 500mA.

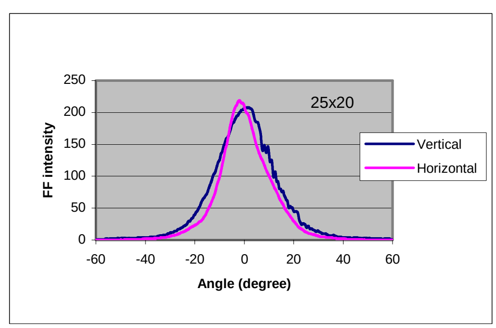


Fig. 3: Far-field of the 1550nm high power laser (laser cavity=1250um).

Figure 4 shows the 2-D plot of RIN-through-fiber and power of various wafers where the lasers were biased at 600mA at 25°C. Lasers of cavity lengths of 750, 1000 and 1250µm were included to study the effect of kL. The RIN-through-fiber was measured through a 65km fiber spool. It was shown that the RIN improved with increasing cavity length. The power of both 1000 and 1250µm lasers were excellent while that of 750µm lasers was limited by thermal rollover. For 1250µm lasers, a minimum RIN-through-fiber of –162dB/Hz, measured at a frequency of 870MHz, was achieved. Majority of population showed RIN better than –158dB/Hz and power greater than 130mW. The optical power was as high as 180mW, equivalent to a fiber-coupled output power of 108mW assuming 60% coupling efficiency. It was noted that the optical was improved with improved die attach. The group "1250um-G2" showed higher power than that of the group "1250um". The latter had smaller area (1000um x 250um) of die attach, while the former had larger area (1250um x 250um).

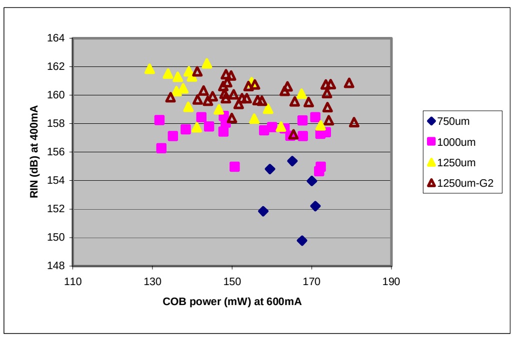


Fig. 4: RIN-through-fiber vs. power plot of 1550nm DWDM long-haul lasers.

Figure 5 shows the spectral linewidth as a function of RIN-through-fiber based on Eq. (1). Since it was difficult to measure narrow linewidth (<1MHz) with accuracy, the RIN-through-fiber was measured instead for linewidth estimation.

$$\Delta\nu = \Delta RIN(f)\{4\pi (D\lambda^2 L/c)^2 f^2\}^{-1} \quad (1)$$

where $\Delta\nu$ is the spectral linewidth, $\Delta RIN(f)$ is the measured RIN-through-fiber, f is the measurement frequency (860 MHz), D is the fiber dispersion (assumed 17 ps/nm/km), L is the fiber length (65km), c is the velocity of light in free space and λ is the center wavelength of DWDM channel. For example, the RIN-through-fiber of 1250µm lasers was <= –162.2dB/Hz; the spectral linewidth was <=82kHz based on Equation (1).

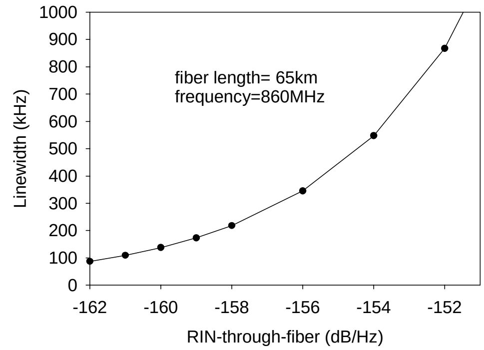


Fig. 5: Linewidth as a function of current.

Figure 6 shows the RIN over a frequency range of 1-20GHz at room temperature. The plot shows the RIN curves at different bias currents. At 150mA, the RIN curve peaked around 7GHz, which was corresponding to the resonance frequency. At higher bias current, the resonace frequency increased. The RIN relaxation oscillation peak was also greatly suppressed at high bias (500mA). The RIN was better than –170dB/Hz over the entire frequency range of 1-20GHz. The noise beyond –175dB/Hz was attributed to shot noise.

The laser also exhibited excellent polarization extinct ratio (PER), suggesting that the laser offered a good quality of linearly-polarized light source. The typical PER was in the range of 21-28dB, exceeding the 17dB specification for the modulators. Figure 7 shows the polarization angles as a function of bias current and temperature. The polarization angles were close to the slow axis (0 degree) of the polarization-maintaining (PM) fiber. The polarization angle was measured at PER=16dB.

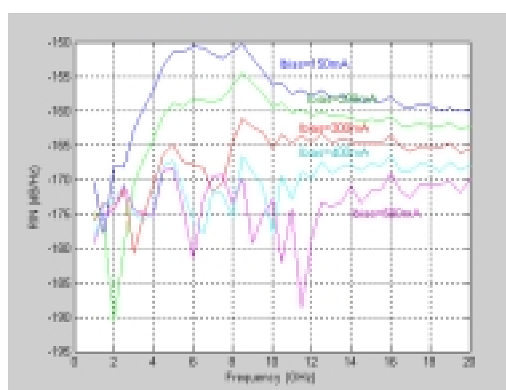


Fig. 6: RIN as a function of bias current of 1550nm DWDM long-haul lasers.

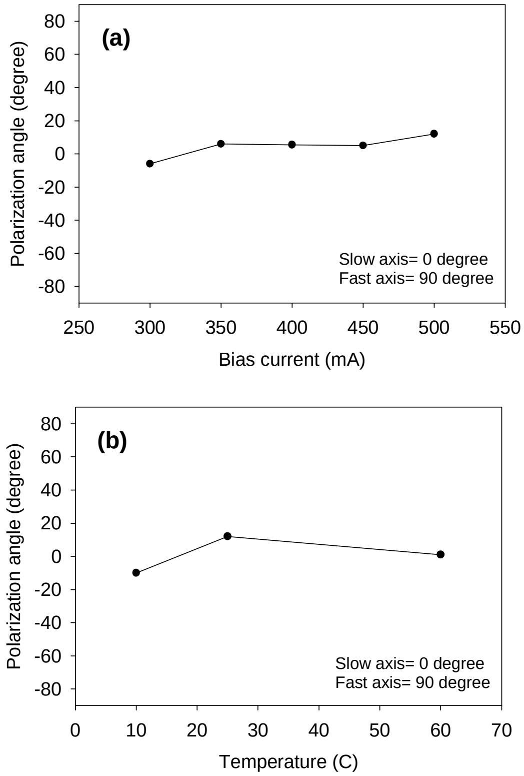


Fig. 7: Polarization angles as a function of (a) bias current and (b) temperature.

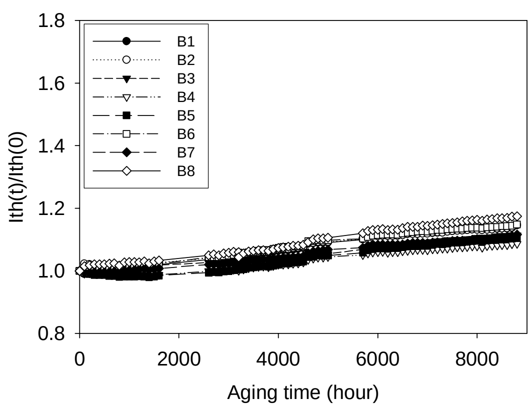


Fig. 8: Relative threshold current trend chart during life test aging. All lasers showed robust long-term reliability performance.

Figure 8 shows the relative threshold current trend chart during life test aging. All lasers showed excellent reliability performance after 8800hr. The laser devices were aged with a constant stress current of 500mA at ambient temperature of 100°C. The average threshold current shift was only about 13% compared to 50% failure criterion. Based on our previous reliability study on buried heterostructure DFB lasers, the activation energy determined by sublinear model was about 0.8eV [8-10]. Using the activation energy of 0.8eV, the extrapolated device median lifetimes at 25°C operation were estimated to be 28.3k years, well exceeding the 20 year lifetime requirement recommended by Telcordia. The temperature rise between junction temperature and ambient temperature was not included in the lifetime calculations. The acceleration factor and the resultant device operating lifetime would increase using the junction temperature.

4. CONCLUSIONS

We have shown that our 1550nm DWDM lasers achieved excellent power and RIN performance for +100km long-haul application, as an industry leading solution. The RIN of <= –170dB/Hz and output power of 180mW were obtained. The spectral linewidth of <=100kHz and RIN-through-fiber of <= –162dB/Hz were obtained at output power of 180mW for a 1250μm long p-up MQW-DFB lasers. The PER was in the range of 21-28dB, excellent for PM fiber transmission.

Lasers exhibited robust reliability performance with no failure. The median threshold current shift was less than 10% after 8800hr. Based on the activation energy of 0.8eV, the extrapolated device median lifetimes at 25°C operation were estimated to be 28.3k years, well exceeding 20-year lifetime requirement.

5. ACKNOWLEDGMENTS

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