Tunable external cavity laser employing uncooled superluminescent diode

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Abstract: We have fabricated a tunable external cavity laser (T-ECL) based on a superluminescent diode and a polymeric waveguide Bragg reflector, providing a cost-effective solution for wavelength division multiplexing–passive optical network (WDM-PON) systems. The wavelength of the T-ECL is tuned through 100 GHz-spacing 16 channels by the thermo-optic tuning of the refractive index of the polymer waveguide at a low input power of 70 mW. The maximum output power and the slope efficiency of the uncooled diode at 20 (75) °C are 8.83 (3.80) mW and 0.107 (0.061) W/A, respectively. The T-ECL operated successfully in the direct modulation for 1.25 Gbit/s transmissions over 20 km.

OCIS codes: (130.5460) Polymer waveguides; (3600) Tunable lasers; (1480) Bragg reflectors; (3120) Integrated optics devices; (250.5960) Semiconductor lasers.

References and links

1. L. A. Coldren, G. A. Fish, Y. Akulova, J. S. Barton, L. Johansson, and C. W. Coldren, "Tunable semiconductor lasers: A Tutorial," J. Lightwave Technol. **22**(1), 193–202 (2004).
2. Y. Liu, A. R. Davies, J. D. Ingham, R. V. Penty, and I. H. White, "Uncooled DBR laser directly modulated at 3.125Gb/s as athermal transmitter for low-cost WDM systems," IEEE Photon. Technol. Lett. **17**(10), 2026–2028 (2005).
3. H. S. Chung, B. K. Kim, and K. Kim, "Effects of upstream bit rate on a wavelength-remodulated WDM-PON based on manchester or inverse-return-to-zero coding," ETRI J. **30**, 255–260 (2008).
4. H.-C. Ji, I. Yamashita, and K.-I. Kitayama, "Cost-effective colorless WDM-PON delivering up/down-stream data and broadcast services on a single wavelength using mutually injected Fabry-Perot laser diodes," Opt. Express **16**(7), 4520–4528 (2008).
5. J. G. Kim, C.-J. Chae, and M.-H. Kang, "Mini-Slot-Based Transmission Scheme for Local Customer Internetworking in PONs," ETRI J. **30**, 282–289 (2008).
6. B. Lung, "PON architecture 'future proofs' FTTH," Lightwave Mag. **16**, 104–107 (1999).
7. S. H. Oh, D.-H. Lee, K. S. Kim, Y.-S. Baek, and K.-R. Oh, "High-performance 1.55-µm superluminescent diode with butt-coupled spot-size converter," IEEE Photon. Technol. Lett. **20**(11), 894–896 (2008).
8. D.-H. Kim, W.-J. Chin, S.-S. Lee, S.-W. Ahn, and K.-D. Lee, "Tunable polymeric Bragg grating filter using nanoimprint technique," Appl. Phys. Lett. **88**(7), 71120 (2006).
9. K.-J. Kim, J.-K. Seo, and M.-C. Oh, "Strain induced tunable wavelength filters based on flexible polymer waveguide Bragg reflector," Opt. Express **16**(3), 1423–1430 (2008).
10. Y.-O. Noh, H.-J. Lee, J. J. Ju, M.-S. Kim, S. H. Oh, and M. C. Oh, "Continuously tunable compact lasers based on thermo-optic polymer waveguides with Bragg gratings," Opt. Express **16**(22), 18194–18201 (2008).
11. S.-W. Ryu, and S.-B. Kim, J.-S. Sim, and J. Kim, "1.55-µm spot-size converter integrated laser diode with conventional buried-heterostructure laser process," IEEE Photon. Technol. Lett. **15**(1), 12–14 (2003).
12. S. W. Park, J. H. Han, Y. T. Han, S. S. Park, B. Y. Yoon, B. K. Kim, H. K. Sung, and J. I. Song, "Two-step laterally tapered spot-size converter 1.55-mm DFB laser diode having a high slope efficiengy," IEEE Photon. Technol. Lett. **18**(20), 2138–2140 (2006).
13. S. H. Oh, K. S. Kim, O. K. Kwon, and K.-R. Oh, "InGaAaP/InP buried ridge waveguide laser: a new waveguide structure with an improved lateral single mode property," ETRI J. **30**, 480–482 (2008).
14. Y.-O. Noh, C.-H. Lee, J.-M. Kim, W.-Y. Hwang, Y.-H. Won, H.-J. Lee, S.-G. Han, and M.-C. Oh, "Polymer waveguide variable optical attenuator and its reliability," Opt. Commun. **242**(4-6), 533–540 (2004).
15. B. W. Hakki, and T. L. Paoli, "Gain spectra in GaAs double heterostructure injection laser," J. Appl. Phys. **46**(3), 1299–1306 (1975).
16. J.-U. Shin, S. H. Oh, Y.-J. Park, S.-H. Park, Y.-T. Han, H.-K. Sung, and K.-R. Oh, "External Cavity Lasers Composed of High Order Grating and SLD on PLC Platform," ETRI J. **29**, 452–456 (2007).

#109664 - $15.00 USD Received 9 Apr 2009; revised 22 May 2009; accepted 29 May 2009; published 3 Jun 2009

17. D. Van Thourhout, A. Van Hove, T. Van Caenegem, I. Moerman, P. Van Daele, R. Baets, X. J. M. Leijtens, and M. K. Smit, "Packaged hybrid integrated phased-array multi-wavelength laser," Electron. Lett. **36**(5), 434–436 (2000).
18. S. H. Oh, J.-U. Shin, Y.-J. Park, S.-B. Kim, S. Park, H.-K. Sung, and K.-R. Oh, "Multi-Wavelength Lasers for WDM-PON Optical Line Terminal Source by Silica Planar Lightwave Circuit Hybrid Integration," IEEE Photon. Technol. Lett. **19**(20), 1622–1624 (2007).

1. Introduction

Tunable lasers are important devices in the wavelength division multiplexing (WDM) transmission systems [1,2]. Since the wavelength division multiplexing–passive optical network (WDM-PON) system [3,4] has required wider bandwidth than other PON systems [5,6], there have been strong demands on widely and rapidly tunable compact laser diodes that can be easily fabricated in mass production. One of the big technical challenges in employing the tunable lasers as a colorless transmitter in the WDM-PON systems is the initialization of the wavelength without any intervention of operation.

The superluminescent laser diode (SLD) is one of the promising candidates for the source of tunable external cavity lasers (T-ECL) because the 3dB spectral width of the emission spectrum can cover the full band at the operating system and a stable reflectivity of less than 0.1% maintains for the full band of the WDM systems [7]. SLDs with a spot size converter (SSC) are suitable light sources for the implementation of planar lightwave circuit (PLC) optical modules since they have narrow far-field patterns (FFP) (less than 15°). On the other hand, polymer waveguides have merits of a large thermo-optic effect as well as a good efficiency for heat insulation, resulting in large refractive index tuning with consumption of a low power. With the advance of nano-imprinting processes, polymers have a large potential for low-cost manufacturing of waveguide devices [8]. Flexible polymer grating devices can extend the wavelength-tuning capability beyond the limit of thermo-optic effect [9]. In the previous report [10] we reported a compact T-ECL based on SLD and polymeric waveguide Bragg reflector aligned actively with a transistor outline (TO) can, increasing the coupling efficiency of the module and the yield of fabrication.

In this paper, we discuss the characteristics of a T-ECL with an uncooled SLD and a polymeric tunable Bragg reflector. The temperature characteristics of the T-ECL are better than that of the SLD because the carrier density in the SLD active region is reduced by inserting the reflecting beam into the SLD from the grating region of ECL. The T-ECL can operate at the high temperature of 75°C. This device operated successfully with a total throughput of 1.25-Gbit/s over 20km transmission, demonstrating its possibility of application to WDM-PON systems.

2. Design and fabrication

The SLD is fabricated in a double-waveguide-core structure: an active waveguide in a planar buried heterostructure (PBH) and a passive waveguide in a ridge shape [11,12]. The cavity length of the SLD is 800μm, which has four sections; a straight active, a bending active, a SSC, and a passive waveguide with the length of 400 μm, 60 μm, 300 μm, and 40μm, respectively. For the formation of a mesa structure, the reactive ion etching (RIE) followed by the chemical wet etching is used to form a submicron taper tip. The width of the taper tip is less than 0.2 μm at the SSC section. And, active stripe is 1.5 μm and the SSC region is tapered from 1.5 μm down to less than 0.2 μm. The two methods are applied to reduce the reflectivity and to obtain the ripple less than 3dB. First, the waveguide is tilted by 7-degree with respect to the cleaved facet. Second, the front facets are AR-coated with a two-layer of SiO_2/TiO_2. Our SLD is designed to have the lasing beam in a circular shape at the front facet and is fabricated in the ridge waveguide (RWG) type which is better than the buried RWG [13] in making a circular-shaped laser beam. To improve the temperature characteristics of the SSC SLD, regrowth of the current blocking layer formed by a 2nd p-InP, a 3rd n-InP, and a 4th p-InP layer is optimized. The current blocking layer plays the role of concentrating the injection current in the active region. The high temperature operation of this device is dependent on the effectiveness of the current blocking layer. In the previous report [12], the current blocking

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layer was optimized having PBH mesa height of 1μm when the thickness of the 2nd p-InP layer is 0.8μm in a double-waveguide-core structure. In this study, however, we adopt a PBH mesa height of 0.6μm to improve the high-coupling efficiency between active and passive waveguides [7]. And, in order to optimize the blocking layer, we controlled the mesa shape, the thickness of the 2nd p-InP layer and the growth temperature. The 2nd p-InP layer is overgrown on the edge region of the active area, the thickness of this layer is ~0.85μm which is similar to that in Ref [12]. The thickness of the 3rd n-InP layer is about 0.7μm.

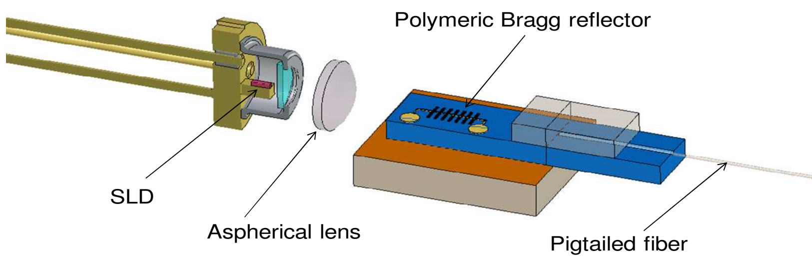

Fig. 1. a schematic diagram of the hybrid integrated tunable laser consisting of a SLD, an aspheric microlens, and a polymeric tunable Bragg reflector.

Figure 1 shows a schematic diagram of the T-ECL consisting of a SLD, an aspheric microlens, and a polymeric tunable Bragg reflector. The SLD is hermetically packaged in a TO can whose structure and fabrication process are described elsewhere [7]. The polymer waveguide device can be operated in air and does not need a costly hermetic packaging as is employed in Ref [14]. The output beam emitting from the spot size converter SLD is coupled to the polymer waveguide through the microlens with a typical coupling efficiency of 40%. Since the polymeric Bragg reflector is actively aligned with the TO can, the coupling efficiency and yield of the fabricated module are higher than those of other hybrid structures. The wavelength of the laser reflected from the Brag reflector can be controlled by applying a current on the integrated heater of the polymer device. In this study, the tuning range of the polymer device is designed and fabricated to cover 15 nm from 1532 nm to 1547 nm. The index contrast and the physical dimension of the polymer waveguide are 0.005 and 6×6 μm^2, respectively. The fabrication procedure and the performance of the polymeric tunable Bragg reflector are detailed elsewhere [10].

3. Result and discusssion

Figure 2(a) shows some output spectra of the SLD at an output power of 3 mW by controlling the SLD injection current. As the chip temperature increased, the 3dB spectral width broadened. They varied from 40 nm at 20 °C to 89 nm at 75 °C. The center wavelength is about 1.53μm at whole temperatures. The gain spectra for these devices are obtained by using a well known Hakki-Paoli method [15]. The peak of the net modal gain for the SSC SLD as the function of temperature is shown in Fig. 2(b). The peak gain is nearly constant up to 40 °C, but rapidly decreased over 50 °C. The peak gain at 75 °C is 15 dB lower than that of 20 °C. The SLD chips are highly sensitive to the temperature which is a high of the carrier density in the active region of SLD because of the spontaneous emission.

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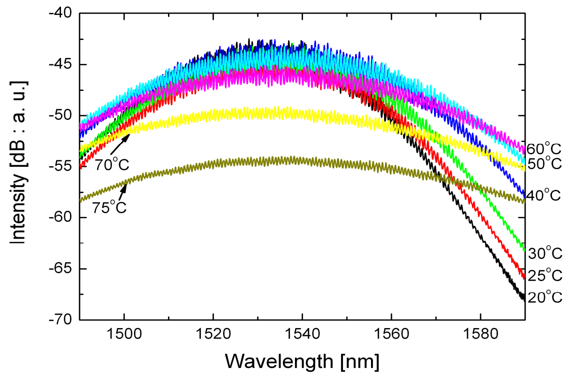
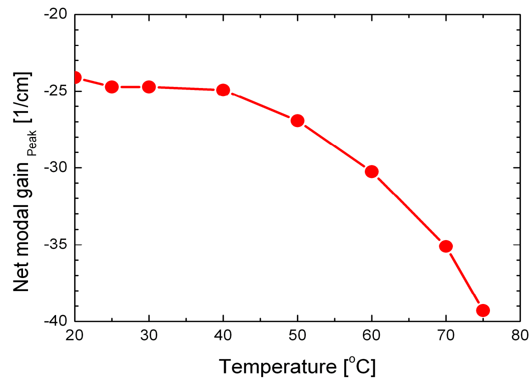


(a)



(b)

Fig. 2. (a) Light output power characteristics versus injection current at various temperatures of the SLD, (b) the peak of net modal gain for SSC SLD

The L-I curves of T-ECL at five different temperatures are shown in Fig. 3. The temperature of the polymer Bragg grating is fixed at 25 °C, while that of T-ECL is changed from 20 to 75 °C. The L-I curves of the present T-ECL show large sharp kinks due to mode hopping at high-current levels over 75 mA depending on various temperature. The large sharp kinks are due to a phase mismatch between the SLD and the polymer grating in the cavity. This result has been observed from the lasers having a long cavity [16–18]. We measured a mode hopping of 0.09 nm which is good agreement with the calculated result of 0.08 nm. The measured static characteristics are summarized in Table 1. The maximum output power and the slope efficiency are measured at the same condition as those in Fig. 2. At 20 °C, the maximum output power and the slope efficiency are 8.83 mW and 0.107 mW/mA, respectively. In particular, at 75 °C, the device showed a maximum output power and a slope efficiency of 3.80 mW and 0.061 W/A, respectively. The T-ECL is not shown a rapid decrease in output gain over 50 °C differently that of the SLD. For the reason of this result, the temperature characteristics of the T-ECL are better than that of the SLD since the carrier density in the SLD active region is reduced by inserting the reflecting beam into the SLD from the grating region of ECL. This result implies that the proposed T-ECL is definitely useful for the WDM-PON systems at the high temperature of 75 °C. We find that the temperature characteristics of ECL are largely affected by the structure characteristics of ECL rather than uncoold SLD due to reduction of the carrier density in the inside of the ECL.

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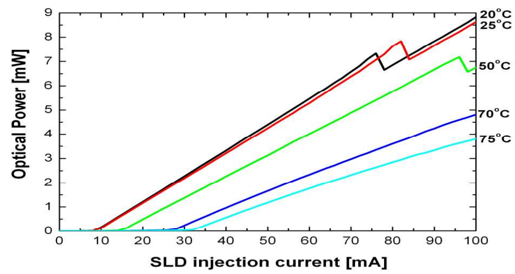

Fig. 3. Output power of T-ECL as a function of the injection current at five different temperatures.

Table 1. Static characteristics of T-ECL at various temperatures.

T (°C)	I_{th} (mA)	η (W/A-@3mW)	P_{max} (mW-@100 mA)
20	9	0.107	8.83
25	9	0.103	8.63
50	15	0.088	6.75
70	28	0.068	4.81
75	32	0.061	3.80

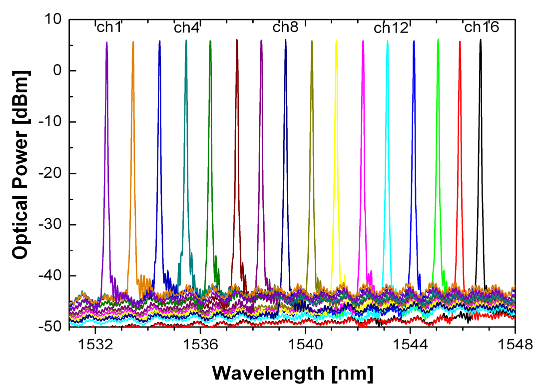

Fig. 4. The wavelength tuning characteristics of the polymer Bragg grating tunable laser for 16 channels from 1546.6nm to 1532.4nm with a 0.8 nm spacing.

Figure 4 shows superimposed CW spectra of 16 channels spaced by 0.8 nm within a tuning range of 15nm from 1546.6 to 1532.4 nm. These spectra are obtained by applying the electrical heating power on the micro-heater of the device at an injection current of 50mA of the SLD. The output wavelength is tuned to the 16 channels by applying an electrical power of 70 mW for maximum tuning. This result is very excellent performance due to wide tuning range of 15 nm by using the low power consumption. During the tuning, the output power varied from 6.18 to 5.65 dBm with a small variation of 0.6dB. The linewidth of the lasing spectrum is less than 0.1 nm at 20 dB from the peak. From this result, we obtained the tuning range of 15 nm by reducing 50% of the index contrast compared to the previous report [10].

Figure 5 shows the eye diagrams of ch1, ch6, ch11, and ch16 among the 16 channels of T-ECL with 20-km transmission when the SLD is operated at 1.25 Gbit/s with a pseudo random bit sequence (PRBS) of 2^{23}-1 (non-return-to-zero) at a bias current of 30 mA and an amplitude of 20 mA (± 10 mA). A clear eye patterns are obtained with a mask margin of 10% and the extinction ratio is larger than of 9dB.

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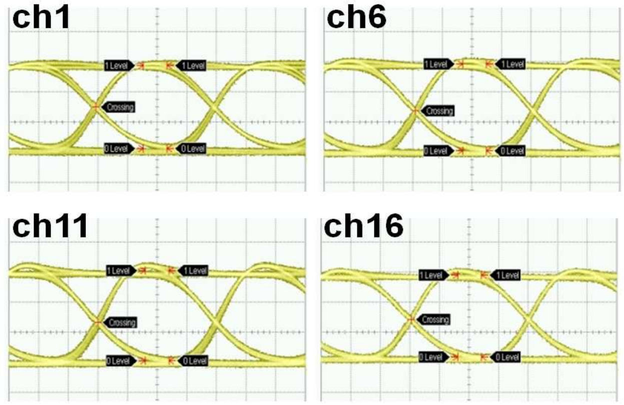

Fig. 5. Eye diagram of optical signals generated from 1.25 Gbit/s direct modulations of the ch1, ch6, ch11, and ch16 among the 16 channels of T-ECL.

4. Conclusion

Employing uncooled SLD, we have developed a T-ECL that can operate at the high temperature over 70°C by decreasing the carrier density in the active region. We show that the temperature characteristics of ECL are largely affected by the structure characteristics of ECL rather than uncoold SLD. The maximum output power and the slope efficiency are 8.83 mW and 0.16 mW/mA at 20°C, respectively. In particular, at an operation temperature of 75°C, the device shows a maximum output power of 3.80 mW and a slope efficiency of 0.06 W/A. The output wavelength is tuned to the 16 channels by using a low power consumption of 70 mW for maximum tuning. We also demonstrate that the module operates successfully with a total throughput of 1.25-Gbit/s over 20Km transmission. This result implies that the proposed T-ECL is useful for WDM-PON systems.

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