Ring-resonator-integrated tunable external cavity laser employing EAM and SOA

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Abstract: We propose and demonstrate a tunable external cavity laser (ECL) composed of a polymer Bragg reflector (PBR) and integrated gain chip with gain, a ring resonator, an electro-absorption modulator (EAM), and a semiconductor optical amplifier (SOA). The cavity of the laser is composed of the PBR, gain, and ring resonator. The ring resonator reflects the predetermined wavelengths into the gain region and transmits the output signal into integrated devices such as the EAM and SOA. The output wavelength of the tunable laser is discretely tuned in steps of about 0.8 nm through the thermal-optic effect of the PBR and predetermined mode spacing of the ring resonator.

OCIS codes: (140.3600) Lasers, tunable; (130.3120) Integrated optics devices; (250.5960) Semiconductor lasers.

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#153589 - $15.00 USD Received 31 Aug 2011; revised 11 Nov 2011; accepted 11 Nov 2011; published 29 Nov 2011

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1. Introduction

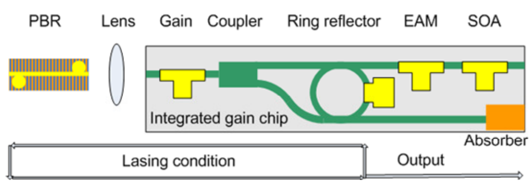
There has been great interest in tunable semiconductor lasers for wavelength division multiplexing-passive optical network (WDM-PON)-based fiber-to-the-home (FTTH), as they can flexibly allocate wavelengths to many subscribers [1–8]. Attention has been focused on monolithically integrated tunable lasers using sampled grating distributed Bragg reflectors (SG-DBRs) or double ring resonators for wavelength selection as well as wide wavelength tuning [9–14], and a hybridly-integrated tunable external cavity laser (ECL) using a superluminescent diode (SLD) and a PBR [15–18]. The monolithically integrated tunable lasers use the Vernier effect and electro-optic effect to obtain a wide wavelength tuning range as InP-based semiconductor lasers have a small electro-optic effect. Although tunable SG-DBR lasers have been commercially successful, and tunable lasers using double ring resonators have a high Q factor and are compact in size, they have a complicated fabrication process, low fabrication yield, and high-cost requirement since they require the complex control for wavelength tuning and stability. A hybridly-integrated ECL using a superluminescent diode (SLD) and a PBR is a good solution for a WDM-PON system since it has a wide wavelength tuning range and easy control for wavelength tuning due to the large thermo-optic effect of the polymer waveguide. We previously reported the transmission characteristics of a 2.5 Gbps directly modulated tunable ECL [19-20]. However, the directly modulated ECL has a limited modulation speed and limited transmission distance. To obtain an ECL with higher performance and higher modulation speed, a gain chip integrated with optical devices such as an EAM and SOA is needed. An optical device with a reflection port for laser cavity and a transmission port for the laser output is required to obtain a highly-integrated gain chip, as the cavity mode of the directly-modulated ECL is composed of the facet reflection of the gain chip and reflection of the tunable reflector.

In this paper, we propose a tunable ECL composed of a PBR and highly-integrated gain chip with gain, a ring resonator, an EAM, and an SOA. The ring resonator is a good candidate for a highly-integrated gain chip in a tunable ECL, as its drop port re-injects the predetermined wavelengths into the gain region and its through-port transmits the output signal into the integrated devices such as the EAM and SOA. Moreover, the output wavelength of the laser is more stabilized by the ring resonator because the ring resonator acts as comb reflector. The cavity of the laser is composed of the PBG, gain and ring resonator. The output wavelength of the tunable laser is discretely tuned through the continuous wavelength tuning of the PBR and the predetermined mode spacing of the ring resonator. Thus the proposed tunable ECL is suitable for an optical source of a DWDM-PON system as it easily satisfies the ITU grid channel spacing through the free spectral range (FSR) design of the ring resonator.

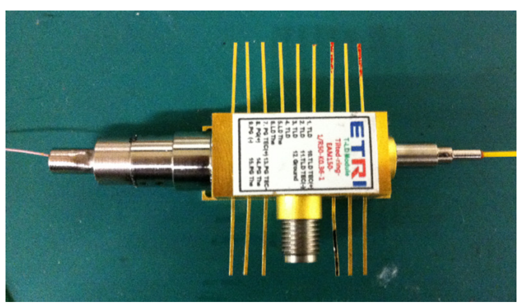
#153589 - $15.00 USD Received 31 Aug 2011; revised 11 Nov 2011; accepted 11 Nov 2011; published 29 Nov 2011

2. Design and fabrication

Figure 1 shows a 10 Gbps tunable ECL for a laser source in a WDM-PON system. The tunable laser is made by actively aligning the highly-integrated gain chip and PBR through an aspherical microlens. The integrated gain chip is composed of an active gain region, passive ring resonator region, EAM region, and active SOA region. The ring resonator has four ports. Two ports of the ring resonator are connected with an optical coupler to feedback the lasing lights with a predetermined wavelength interval into the gain and PBR. One of the ports is connected with the EAM to modulate and output the lasing light. And the last port is used to absorb the reflected light from the EAM and SOA. The PBR acts as a wavelength selection reflector and continuously tunes the wavelength of the reflected light through its thermo-optic effect. Single-mode laser oscillation occurs when the reflected wavelength from the PBR agrees with one of feedback wavelengths of the ring resonator (λ_1), as shown in Fig. 2. If the reflected wavelength of the PBR is changed from λ_1 to λ_2, the lasing mode changes from λ_1 to λ_2. The ring resonator is designed to have a resonant mode with an FSR of about 0.8 nm ($d\lambda$) to obtain a tuning spectral spacing of 100 GHz. The phase shift region of the ring resonator is used to fine tune the lasing wavelength by changing the effective index through a carrier injection.



(a)



(b)

Fig. 1. A 10-Gbps tunable ECL (a) schematic diagram and (b) a Photograph.

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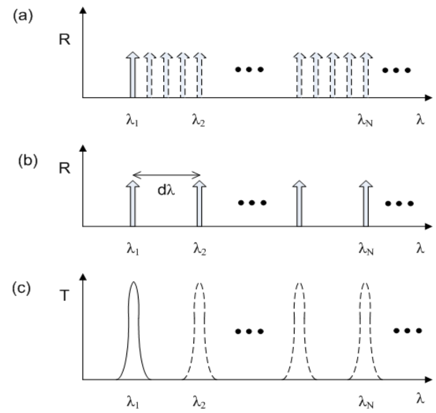

Fig. 2. Operation principle of the tunable ECL (a) reflection of the PBR, (b) reflection of the ring resonator, and (c) the transmission of the laser.

The active regions have a planar buried heterostructure (PBH) with a multiple quantum well (MQW) composed of nine wells and ten InGaAsP barriers [21]. Separate confinement heterostructure layers are above and below the MQWs of the active regions. The width of the active waveguide is set 1.5 µm. The EAM region has a deeply-etched waveguide with a multiple quantum well (MQW) composed of eight wells and nine InGaAsP barriers. The deeply-etched waveguide of the EAM has a width of 2 µm and is buried with Polymide (PI2723) for planarization and electrical passivation. Electrical isolation between the active and EAM regions is achieved using oxygen implantation. The passive region consists of an optical coupler and a ring resonator with a deeply-etched waveguide. The ring resonator is composed of two 3 dB-MMI couplers with a width of 6 µm and length of 158 µm, a phase shift region with a length of 40 µm, and curved waveguides with a radius of 60 µm [13]. To reduce the sidewall roughness of the waveguide, the straight and curved passive waveguides are deeply etched using an etching mask made of 300-nm-thick SiO2 and an ICP (inductive coupled plasma) dry etching system (Unaxis SLR 770). The active gain and SOA have an SSC for higher coupling efficiency with the PBR and output fiber, respectively. The SSC has a double-waveguide-core structure with a lateral tapered upper core with a thickness of 0.35 µm and lower core with a thickness of 0.1 µm [20]. The optical waves emitted from the gain and SOA are expanded by gradually reducing the width of the tapered upper core of the SSC from 1.5 µm down to less than 0.3 µm and the waves are confined by the lower core and passive ridge waveguide of the SSC in the vertical and horizontal directions, respectively. The width of the passive ridge waveguide was set to be 7 µm in all SSC regions. To reduce the facet reflection, the waveguide of the SSC was tilted 7 degrees with respect to the cleaved facet and the cleaved facet of the SSC is then anti-reflection (AR) coated (R<0.1%) with two layers of SiO2/TiO2.

3. Results and discussion

Figure 3 shows the spontaneous emission spectrum (ASE) of the gain region at an injection current of 80 mA. The 3-dB spectral width of the emission spectrum is about 40 nm. Spectral ripples reflected from the ring resonator occur at the ASE with a specific resonant mode spacing of 0.81nm.

The output powers emitted from the PBG and SOA are simultaneously measured. Figure 4(a) shows the L-I curve emitted from the PBG of the tunable ECL laser at a temperature of 25 °C when the current of the gain increases from 0 to 120 mA. The output power of the laser is measured at a wavelength of 1557 nm. The threshold current of the laser is less than 27 mA

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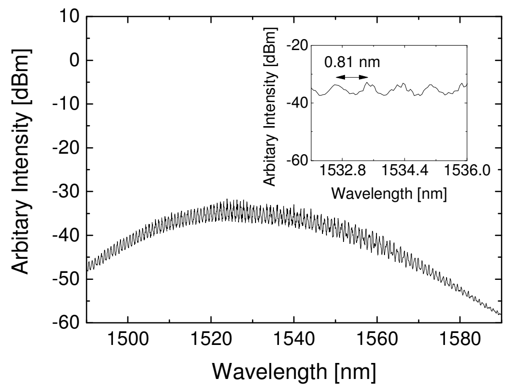
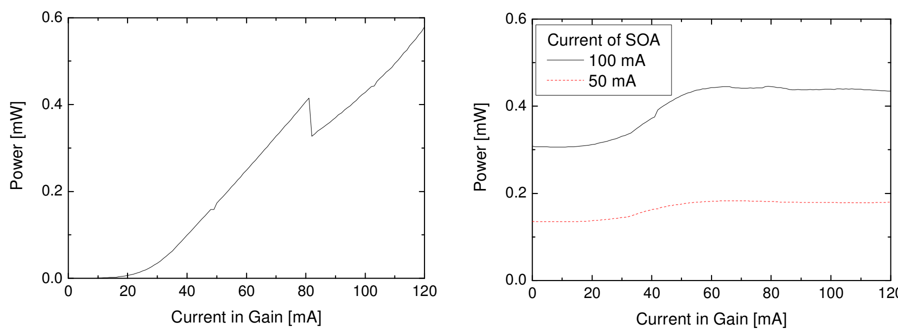


Fig. 3. The spontaneous emission spectrum of the gain region at an injection current of 80 mA.



(a) (b)

Fig. 4. L-I curves of the tunable ECL (a) output power emitted from the PBR and (b) Output power emitted from the SOA.

and its output power is 0.6 mW at a gain current of 120 mA. A kink occurs because an increase in the current causes a shift from lasing mode to the adjacent external cavity mode by about 0.05nm [22]. Figure 4(b) shows the output power emitted from the SOA of the tunable ECL when the current of the gain increases from 0 to 120 mA and the currents of the SOA are fixed at 50 mA and 100 mA. The maximum output powers of the tunable ECL are 0.45 mW and 0.18 mW at SOA currents of 100 mA and 50 mA, respectively. The output power of the tunable laser can be increased when the saturation output power of the SOA is increased by optimizing its length and core height.

Figure 5 shows the superimposed spectra emitted from the SOA of the tunable ECL. The gain and SOA currents are 120 mA and 15.2 mA, respectively. The side-mode suppression ratio of the laser is larger than 30 dB. The lasing wavelength of the tunable ECL is blue-shifted discretely from 1557.2 (CH 1) to 1542.7 nm (CH 19) in 0.8 nm steps when an electric power of 0 to 78 mW is applied to the PBR heater. The 3-dB and 20-dB bandwidths of the lasing mode are less than 0.01 nm and 0.05 nm, respectively.

Transmission experiments at 10 Gbps were performed using a nonreturn-to-zero (NRZ) pseudorandom bit stream (PRBS) with pattern length of 2^{31}-1. Bias currents of 100 mA are applied at both the gain and SOA. The EAM is biased at −2 V with a 5 V peak-to peak swing through an RF amplifier. An erbium doped fiber amplifier (EDFA) is used to measure the Eye diagram by increasing the output power of the laser. The filtered eye diagrams, as shown in

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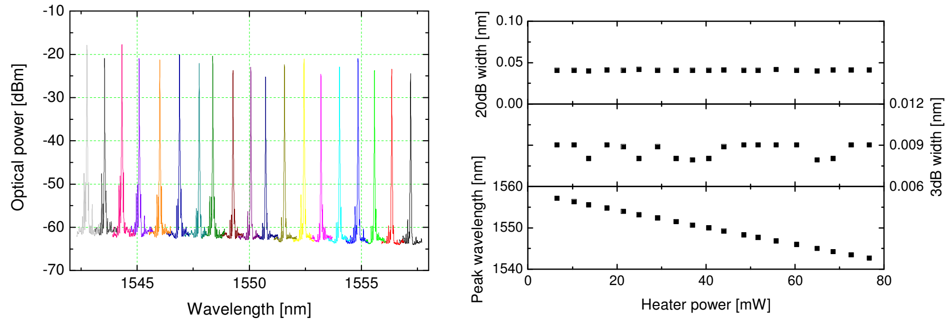
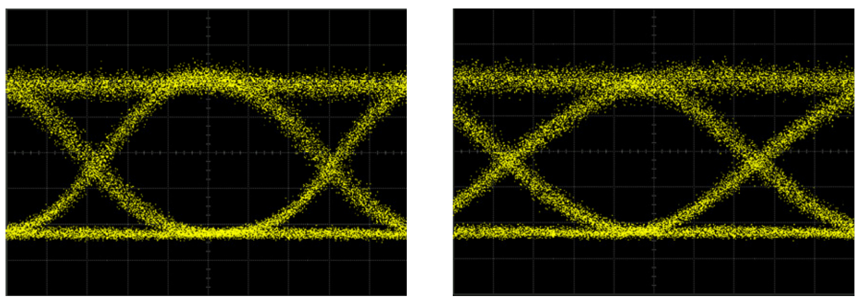
Fig. 6, are taken at a wavelength of 1558 nm for back-to-back (BTB) and 20-km single-mode fiber (SMF) transmission. A clear eye pattern is obtained and the extinction ratios (ERs) are larger than of 7.5 dB and 7.2 dB for the BTB and after 20-km transmissions, respectively.



(a) (b)

Fig. 5. Spectral characteristics of the tunable ECL (a) superimposed spectra and (b) peak wavelength, 3-dB and 20-dB bandwidths of each channel for various electrical powers applied to a PBR.



(a) (b)

Fig. 6. 10-Gbps eye diagrams of ECL (a) BTB and (b) after 20-km SMF transmissions.

3. Conclusion

A tunable ECL using a PBR and a highly-integrated gain chip was proposed and demonstrated. The output wavelength of the tunable laser is discretely tuned in steps of about 0.8 nm through the thermal-optic effect of the PBR and the predetermined mode spacing of the ring resonator. Although the wavelength tuning range of the tunable laser was 14.5 nm, which can be used for a 19-channel WDM-PON system with 100GHz spacing, the tuning range of the tunable laser can be easily extended by increasing the tuning range of the PBR. A clear eye opening of the tunable laser was shown at a modulation speed of 10 Gbps for both BTB and post 20-km-SMF transmissions.

Acknowledgments

This work is supported by the IT R&D Program of KCC (10913-05002) Rep. of Korea.

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