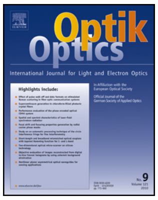
Optik 125 (2014) 2031–2035

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo



Noise reduction of tunable laser based on mutual injection-locked reflective semiconductor optical amplifiers

H.-D. Ku[a,*], C.-S. Park[b]

[a] Department of Information and Communication Engineering, Sungkyul University, 53 Sungkyuldaehakro, Manan-Gu, Anyang-city, Gyeonggi-Do, Republic of Korea
[b] School of Information and Communications, Gwangju Institute of Science and Technology, 261 Cheomdan-gwagiro, Buk-Gu, Gwangju, Republic of Korea

ARTICLE INFO

Article history:
Received 7 June 2013
Accepted 11 June 2013

Keywords:
Optical fiber laser
Gain-saturated RSOA
Mutual injection locking
RIN reduction
CNR improvement

ABSTRACT

A tunable laser source based on mutual injection-locked reflective semiconductor optical amplifiers (MIL-RSOAs) using a tunable bandpass filter was investigated to reduce relative-intensity noise (RIN) and improve the carrier-to-noise ratio (CNR) without additional optoelectronic compensation. Compared with laser based on self-injection-locked RSOAs (SIL-RSOAs), the laser based on MIL-RSOAs reduced RIN by as much as 16 dB and improved CNR by as much as 20 dB. The proposed method improved sensitivity for 1.25 Gb/s transmission by >15 dB compared with using traditional laser based on SIL-RSOAs.

1. Introduction

Tunable laser sources (TLSs) are attractive solutions for optical communication systems, diagnostic systems, and optical sensor networks. The application of TLSs to wavelength division multiplexing (WDM) systems as core devices to implement cost-effective solutions has increased. Although single-wavelength laser sources for fiber-to-the-home, conventional distributed-feedback laser diodes (DFB-LDs) have system costs and poor performance because of temperature instability [1]. To expand their potential applications, TLSs can be integrated with high performance with narrow linewidth, high side-mode suppression ratio (SMSR), low relative-intensity noise (RIN), and high carrier-to-noise ratio (CNR).

A semiconductor laser using the electrical feedback technique [2] and a switchable laser based on gain-saturated reflective semiconductor optical amplifiers (GS-RSOAs) [3] reduce laser linewidth. The SMSR suppression technique for fiber laser has been demonstrated by feedback-injecting a Fabry–Pérot laser diode (F–P LD) into an erbium-doped fiber amplifier ring cavity [4]. Spectrum slicing technology for WDM applications has been proposed as a cost-effective solution. Therefore, investigations should be conducted to reduce the intensity noise restricting the bit error rate (BER) of a given bandwidth because intensity noises limit the performance of WDM systems. Studies have investigated noise reduction with optoelectronic feedforward compensation to reduce intensity noise [5], a wavelength-locked F–P LD to suppress intensity noise [6], RSOA theory to enhance RIN characteristics [7], and GS-RSOAs to reduce phase noise [8]. In particular, several approaches based on directly modulated laser have been proposed to improve CNR and BER and suppress optical beat interference (OBI) noise [9,10].

In this paper, we propose a tunable laser based on MIL-RSOAs and a tunable bandpass filter (TBF) to improve signal quality and reduce noise characteristics compared with a self-injection-locked (SIL) laser. In Section 2, we explain the operational principles and experimental setup of the proposed tunable laser. Section 3 presents the experimental results of the proposed laser, such as of RIN, CNR, and BER performance. The experimental results showed that the SMSR, CNR, and BER improved, RIN was reduced, and OBI noise was suppressed.

2. Experimental setup

Fig. 1 shows the experimental schematic of the proposed tunable laser based on GS MIL-RSOAs. The laser consists of two RSOAs, a TBF, a polarization controller (PC), and an optical coupler (OC). Each seeded light from both RSOAs provides an MIL laser source. The proposed laser using MIL-RSOAs has narrower linewidth than the SIL laser because MIL laser has a half-round-trip cavity and higher total power than the SIL laser [11]. To compare the laser performance of two injection-locked processes, we make an SIL laser with a fiber mirror (FM); this laser cannot produce self-seeded

---

[*] Corresponding author. Tel.: +82 31 467 8113; fax: +82 31 467 8039.
E-mail address: hdku@sungkyul.ac.kr (H.-D. Ku).

0030-4026/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ijleo.2013.06.103

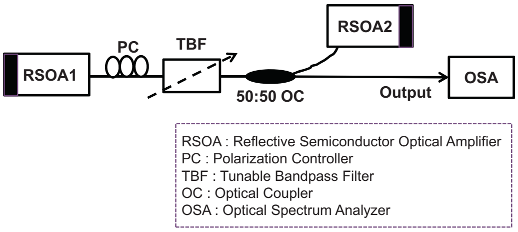


Fig. 1. Experimental setup of tunable laser based on MIL-RSOAs.

light but can passively reflect self-seeded light from RSOA1. In other words, an SIL laser can simply be made by replacing the FM with RSOA2 (Fig. 1). The linear cavity comprises two RSOAs operating as a noise compressor in the nonlinear gain compression region [12]. Polarization should be controlled with a PC to obtain maximum laser output. However, polarization-independent components and RSOAs improve field applications. TBF determines and tunes the lasing wavelength of the MIL laser. To obtain maximum laser output, the coupling ratio of the OC is fixed at 50:50. An optical spectrum analyzer with a resolution of 0.01 nm is used to measure the spectral properties of the laser, such as linewidth and SMSR.

3. Experimental results

The proposed laser can be generated over 31.08 nm from 1528.146 to 1559.226 nm (Fig. 2). We observe the laser dynamics of the proposed laser under a tuning range. Fig. 2 shows the laser dynamics at the first, middle, and last lasing wavelength over all tuning ranges with different bias currents of both RSOAs. The applied bias current varies from 0 to 90 mA. Experimental results show that the laser based on MIL-RSOAs generates a single-wavelength laser without mode-hopping over all bias current and tuning ranges.

The optical spectrum of the proposed laser is measured with the OSA at a resolution of 0.01 nm. In the experiments, the 3-dB bandwidth, SMSR, peak power, and peak wavelength of the TBF are 0.404 nm, 23.29 dB, −46.75 dBm, and 1549.962 nm, respectively. Fig. 3 shows the optical spectra of both lasers. The black and red lines in Fig. 3 show the laser with SIL-RSOAs and MIL-RSOAs, respectively. The 3 dB bandwidth, SMSR, peak power, and peak wavelength of the SIL laser are 0.036 nm, 60.63 dB, −16.34 dBm, and 1550.030 nm, respectively. The 3 dB bandwidth, SMSR, peak power, and peak wavelength of the MIL laser are 0.013 nm, 67.02 dB, −10.54 dBm, and 1550.070 nm, respectively. The shift to a longer wavelength of the MIL laser can be attributed to the temperature increase inside the layer of RSOA [13]. In sum, the 3 dB bandwidth of the proposed laser is reduced by 64%, and the SMSR is improved by 77% compared with the SIL laser.

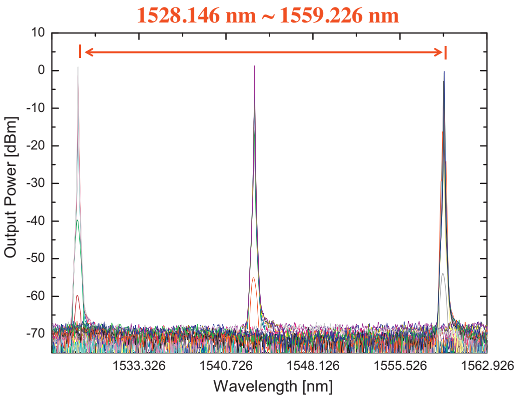


Fig. 2. Laser dynamics of proposed laser under tuning range.

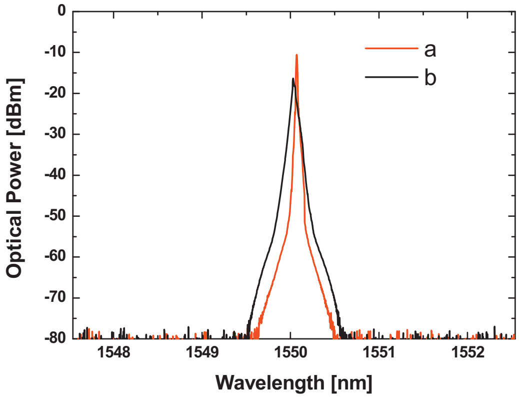
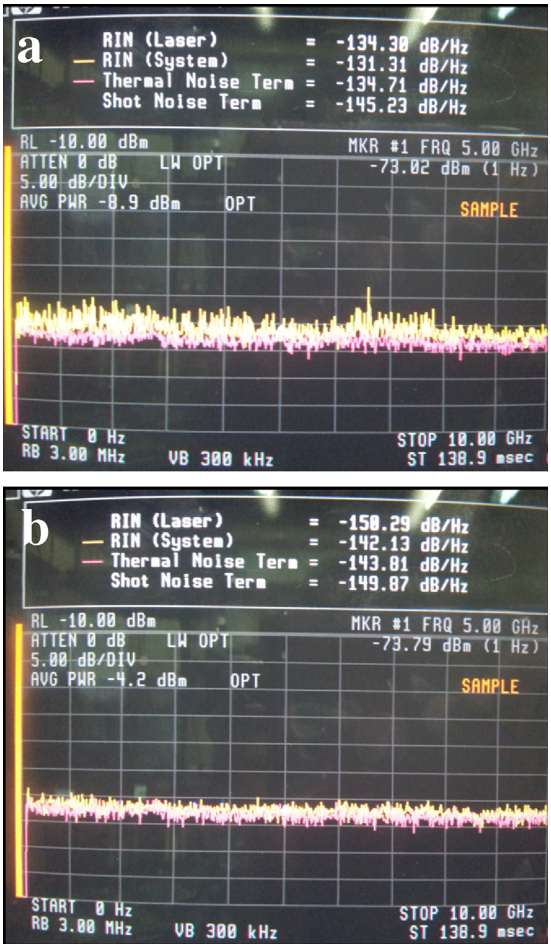


Fig. 3. Optical spectra of laser based on (a) MIL-RSOAs and (b) SIL-RSOAs. (For interpretation of the references to color in this sentence, the reader is referred to the web version of the article.)

Fig. 4 shows the RIN spectra within the 10 GHz bandwidth of the SIL and MIL lasers. Figs. 4(a) and (b) show the RIN of the laser with SIL-RSOAs and MIL-RSOAs, respectively. The RIN of the SIL and MIL lasers is −134.30 and −150.29 dB/Hz, respectively, at a 5 GHz bandwidth. In other words, the proposed laser has a lower RIN than the SIL laser, and the RIN suppression is 16 dB. The proposed laser has lower RIN than the conventional DFB laser (−143 dB/Hz).



```
RIN (Laser)          = -134.30 dB/Hz
RIN (System)         = -131.31 dB/Hz
Thermal Noise Term   = -134.71 dB/Hz
Shot Noise Term      = -145.23 dB/Hz
RL -10.00 dBm                MKR #1 FRQ 5.00 GHz
ATTEN 0 dB    LW OPT          -73.02 dBm (1 Hz)
5.00 dB/DIV
AVG PWR -8.9 dBm    OPT                  SAMPLE
START 0 Hz                      STOP 10.00 GHz
RB 3.00 MHz    VB 300 kHz       ST 138.9 msec
```

```
RIN (Laser)          = -150.29 dB/Hz
RIN (System)         = -142.13 dB/Hz
Thermal Noise Term   = -143.81 dB/Hz
Shot Noise Term      = -149.87 dB/Hz
RL -10.00 dBm                MKR #1 FRQ 5.00 GHz
ATTEN 0 dB    LW OPT          -73.79 dBm (1 Hz)
5.00 dB/DIV
AVG PWR -4.2 dBm    OPT                  SAMPLE
START 0 Hz                      STOP 10.00 GHz
RB 3.00 MHz    VB 300 kHz       ST 138.9 msec
```

Fig. 4. RIN of laser based on (a) SIL-RSOA and (b) MIL-RSOAs.