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High-Power and Low Phase Noise Full-band Tunable LD for Coherent Applications

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Abstract; High output power and low noise performances of CSG-DR-LD have been investigated. Kink-free fiber output power > 60mW over C-band with high SMSR have been demonstrated. Measured phase noise is lower than 170 kHz, exhibiting excellent noise properties as a monolithic and single stripe tunable LD. These characteristics reveal that CSG-DR-LD is a promising light source for the future digital coherent applications.

OCIS code: (140.5960) Semiconductor lasers; (140.3600) Lasers tunable

1. Introduction

Full-band tunable lasers are indispensable for DWDM optical communication systems. Recently, digital coherent technologies based on new modulation formats such as PM-DQPSK are promised for the future high bit-rate communication systems. For the light sources for such communication systems, a high output power with high side-mode suppression ratio (SMSR) and a narrow spectral linewidth are indispensable. In terms of the linewidth, recent developments of digital signal processors (DSP) enable to compensate for the phase noise under the frequency around 1 MHz. Therefore, the reduction of phase noises beyond capability of DSP is substantially significant.

The monolithically integrated single stripe type of full-band tunable LDs has the advantages of easy fabrication, assembling, small package size, and monolithic integration of other functional devices. Most of those single stripe LDs have an electrical phase control region by electron carrier injection [1,2]. As the electron carriers cause optical loss and fluctuations, it is difficult to obtain a high output power and narrow linewidth [3]. In contrast, tuning mechanism of full-band CSG-DR-LD (Chirped Sampled Grating Distributed Reflector Laser Diode) is based on thermal effect. No carrier injection into tuning section enables high output power, and longer time constant of heater (30 kHz) compared with carrier lifetime (GHz) contributes to low phase noise especially in the frequency range >100 kHz [4].

This paper provides high power and low noise properties of CSG-DR-LD. High power performance over 60 mW with SMSR >50 dB and low phase noises below 170 kHz have been achieved.

2. Laser designs

Fig.1 shows a schematic structure of CSG-DR-LD, which consists of three sections: SOA, SG-DFB and CSG-DBR. The front and rear facets are AR-coated. We adopted the configuration of the DR laser, which has a passive DBR integrated on the rear-side of an active DFB. This configuration can efficiently emit the lasing light from the front facet. The SG-DFB provides gain for lasing, where SGs are arranged in the same spacing, resulting in periodic peaks in gain spectrum. In the CSG-DBR, the spacings between adjacent SGs are slightly different from each other, resulting in periodic peaks in reflection spectrum which envelope shows a moderate swell due to interference of reflected light from each SG. This shape of the envelope works as a band-pass filter. The filter wavelength is significantly influenced by the phase of the reflected light from each SG. Therefore, it is efficiently tuned in wide range by small refractive index change. This technique enables the CSG-DR-LD works as a full-band tunable LD without any carrier injections. The wavelengths of periodic peaks and the filter wavelength in their envelope are thermally tuned by three heaters integrated on the CSG-DBR section. Each periodic peak shifts in response to average temperature of the heaters, and the filter wavelength is determined by temperature distribution along the CSG-DBR.

The filter function of the CSG-DBR coarsely restricts the lasing wavelength around the filter wavelength, and one of the gain peaks of the SG-DFB around the filter wavelength is selected as lasing mode by the Vernier effect in combination of the CSG-DBR. Then, the selected mode is adjusted to the target wavelength by changing average temperature of the chip. The SOA controls output power from the front facet, and also works as a shutter during dark tuning.

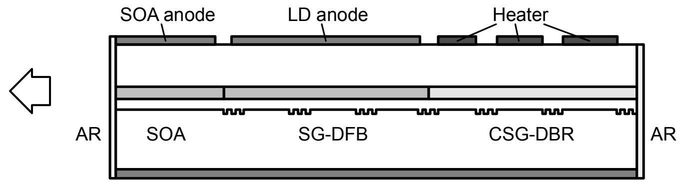

Fig.1 Schematic structure of CSG-DR-LD

3. High power and low noise performances

The fiber output power as a function of SOA current at worst channel condition, i.e. highest temperature condition, is shown in fig.2. Kink-free characteristic up to 60 mW is achieved, showing stable single mode operation. This is, to our knowledge, the highest value in the monolithically integrated single stripe structure. Fig.3 shows superimposed spectrum on the 50-GHz-spaced ITU-T grids of 89 channels at 17 dBm fiber output power. SMSR is typically over 50 dB and over 45 dB at all channels, indicating superior mode stability of CSG-DR-LDs.

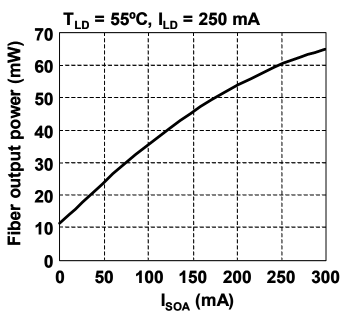

Fig.2 Fiber output power characteristics. LD current is fixed, while SOA current is swept.

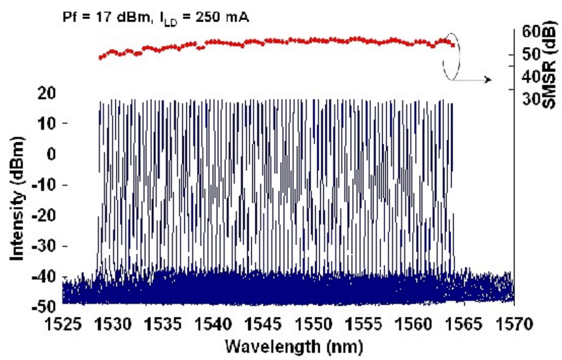

Fig.3 Superimposed spectra on the 50-GHz-spaced ITU-T grid at fiber output power of 17 dBm

For coherent applications, the phase noise is a significant property that corresponds to the effective linewidth. The phase noise of CSG-DR-LD is measured by using Fabry-Perot (FP) etalon and Electrical Spectrum Analyzer (ESA). The FP etalon acts as an optical frequency discriminator converting the laser instantaneous frequency into amplitude signal [5]. An amplitude signal can be square law detected and analyzed with the help of ESA. Fig. 4 shows the schematic outline of experimental arrangement. A FP etalon with free-spectral range (FSR) of 15 GHz is used and an isolator is placed in front of the LD to prevent the reflection from FP etalon. The optical output from the FP etalon is analyzed with a Lightwave Signal Analyzer (LSA, Agilent 71400C). The frequency dependence of the phase noise is given by:

$$S_\nu(f)=\left(\frac{FSR}{\pi P}\right)^2\frac{|J(f)|^2}{RBS}=\left(\frac{dP_{out}}{d\nu}\right)^{-2}\frac{|J(f)|^2}{RBS}, \tag{1}$$

where $J(f)$ is the ESA spectrum of frequency f and $dP_{out}/d\nu$ indicates signal FP etalon transparency with respect to the optical frequency. In this method, measured noise spectra on the ESA comprise of amplitude components and frequency components. For better accuracy, $J(f)$ should be replaced with $J_\nu(f)$ defined as follow:

$$J_\nu(f)=J(f)-J_a(f), \tag{2}$$

where, $J_\nu(f)$ is the phase noise eliminated amplitude noise and $J_a(f)$ is amplitude noise measured without FP etalon. $J_a(f)$ corresponds to relative intensity noise (RIN), which is lower than –155 dB/Hz.

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Fig. 5 shows phase noise spectrum of CSG-DR-LD at fiber output power of +16 dBm at 1528.773 nm (196.10 THz). The spectrum exhibits white noise of around 20 kHz^2/Hz for rover 40 MHz and averaged noise from 100 kHz to 10 GHz below around 170 kHz. This value is substantially low as a single stripe structured full-band tunable laser comparing with carrier injection tuning devices [3]. These results indicate phase noises in the frequency range beyond the DSP capability are very low, and the CSG-DR-LD is promising for the light source for the digital coherent communications.

Fig. 4 Outline schematic of phase noise measurement

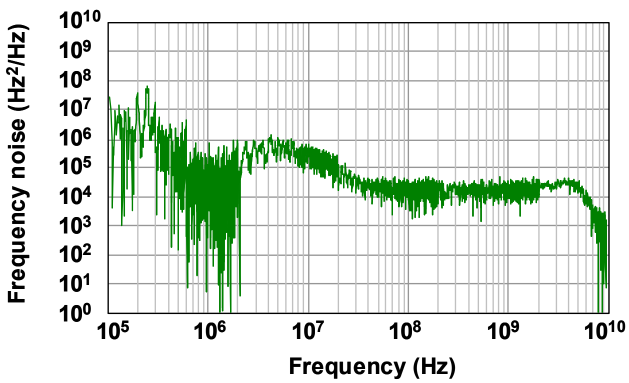

Fig. 5 Phase noise spectrum at fiber output power of 16 dBm

3. Conclusion

High output power and low noise performances of CSG-DR-LD have been demonstrated. Kink-free fiber output power > 60 mW over C-band with high SMSR have been obtained. The averaged phase noise which corresponds to the effective linewidth is lower than 170 kHz in frequency range from 100 kHz to 10 GHz, exhibiting excellent noise properties as a monolithic and single stripe tunable LD. These characteristics originate from the thermal tuning mechanism without any carrier injection, and reveal that CSG-DR-LD is a promising light source for the future digital coherent applications.

4. References

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