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Design and Analysis of a Widely Tunable Sampled Grating DFB Laser Diode with High Output Power

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A widely tunable SG-DFB (Sampled Grating Distributed Feedback) laser diode is proposed and its feasibility is confirmed through simulation. The new SG-DFB laser diode is composed of a pair of sampled gratings, some parts of which are gain sections and the other parts of which are phase control sections. It is shown that a few tens of nanometers can be tuned through the adjustment of two currents into the phase control sections. Higher output power is expected compared with a SG-DBR laser diode with similar parameters. The dynamic single mode operation is also observed in the time-domain simulation.

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Widely tunable monolithic laser diodes with tuning range of a few tens of nanometers have been known to be advantageous for many applications. They can be used for the backup source in DWDM (dense wavelength division multiplexing) systems, which can replace fixed wavelength sources resulting in the reduced inventory fixed-wavelength sources. They are also essential for the realization of the next generation photonic networks [1-3]. The widely tunable laser diodes can be used to implement tunable wavelength converters by themselves[4] or as a tunable pump source for cross gain modulation or cross phase modulation.

A variety of approaches have been applied to the implementation of the widely tunable monolithic laser diodes [5]. The SG-DBR (sampled grating distributed Bragg reflector) laser diodes or SSG-DBR (superstructure grating distributed Bragg reflector) laser diodes are one of the commercially successful devices among the existing widely tunable lasers. Nevertheless they still have some aspects to be improved. High output power seems to be difficult to achieve in the SG-DBR LD which has SG-DBR's on both sides of a cavity. For the tuning of such LD's, at least three tuning currents are required, one of which is used to adjust the cavity mode location. Recently a fixed wavelength SG-DFB laser diode targeted for a CWDM light source is reported [6]. It is perceived that the fixed wavelength SG-DFB laser diode can be extended to widely tunable laser diodes through the proper incorporation of phase control sections between the gratings and through the tuning of the lasing wavelengths from a pair of the SG-DFB laser diodes.

In this paper, a new concept of a widely tunable laser diode composed of a pair of sampled grating DFB laser diodes in which phase control regions are sandwiched, is presented. The sampling periods of two sampled gratings are slightly different from each other. Each SG-DFB laser diode tends to be multi-moded with mode spacing determined by the sampling periods. Therefore, two SG-DFB laser diodes should have mode spacings slightly different from each other. By changing the tuning current in the phase control section, a set of modes can be shifted altogether while the mode spacing is almost unchanged. Therefore, with the proper adjustment of the tuning currents of two SG-DFB laser diodes, it is possible to tune the lasing wavelength at which a pair of modes are aligned. In the proposed tunable laser, only two tuning currents are required, which makes the tuning control simpler than in the conventional SG-DBR laser diodes. Furthermore, the output power can be directly coupled into a single mode fiber without the intervention of the SG-DBR, hence the enhanced output power from the laser can be extracted.

The schematic configuration of the proposed widely tunable device is shown in Fig. 1. Two SG-DFB laser diodes with slightly different sampling periods are placed back to back. The mode spacing of the SG-DFB laser diode is given by

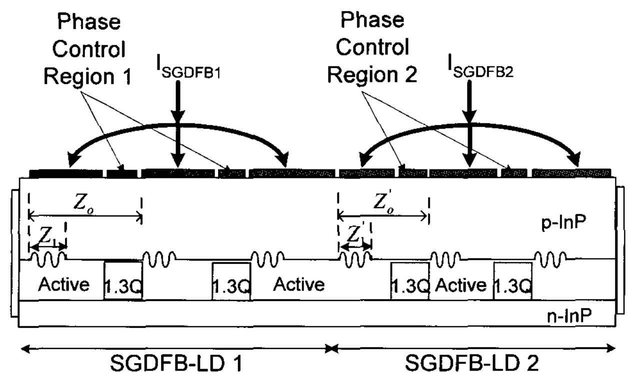

FIG. 1. Schematic Configuration of Widely Tunable Sampled Grating DFB Laser Diode.

$$\Delta v = \frac{c}{2n_g Z_o} \quad (1)$$

where n_g is the group refractive index and Z_o is the period of the sampled grating. If the sampling period of the other SG-DFB laser diode is Z_o', the spacing of the two aligned modes in two SG-DFB laser diodes, which is called the repeat mode spacing, is

$$\Delta v_{rep} = \Delta v \frac{\Delta v}{\Delta v' - \Delta v} = \frac{c}{2n_g Z_o} \frac{Z_o'}{Z_o - Z_o'} \quad (2)$$

Then, the repeat mode spacing would be approximately equivalent to the tuning range of the SG-DFB laser diodes. First the refractive index of the phase control section in the left SG-DFB laser diode is fixed. As the refractive index of the phase control section in the right SG-DFB laser diode is changed, the position of the modes shifts. When a certain mode in the right SG-DFB laser diode is aligned with any mode in the left SG-DFB laser diode, the aligned mode would lase. Therefore, through the tuning of the phase section of right SG-DFB laser diode, each mode of the left SG-DFB can be selected successively. When n_g is 3.7 and Z_o is 202.5 μm, the mode spacing is about 200 GHz. Assume that the sampling period of the right SG-DFB laser diode is 192 μm, then the mode spacing is 210.94 GHz. When the sampling periods are 202.5 μm and 193 μm, respectively, the repeat mode spacing is 3600 GHz (i.e. 28.8 nm) according to Eq. (2). Therefore, for this specific case the tuning range is estimated to be 28.8 nm.

The widely tunable SG-DFB laser diode as shown in Fig. 1 is considered for the simulation. The sampling periods of the left and right SG-DFB laser diodes are 202.5 μm and 192 μm, respectively. Each SG-DFB laser diode has three sampling periods, therefore the total length of the device is 1183.5 μm. The burst length of both SG-DFB laser diodes is 6 μm, and the length of phase control regions in both SG-DFB laser diodes is 75 μm. The coupling coefficient of the grating is set to be 200 cm^{-1}. The other parameters are shown in Table 1. For the analysis of the proposed SG-DFB laser diodes, we used the split-step time-domain model which has been shown to be efficient for the simulation of DFB laser diodes and the sampled grating DBR laser diodes [7].

The tuning characteristics of the widely tunable SG-DFB laser diode are shown in Fig. 2. In this simulation, the current applied to the SG-DFB laser diode is 130 mA. The current injected into the phase control region in the left SG-DFB laser diode set to be constant. As

TABLE 1. Simulation Parameters for the Widely Tunable SG-DFB Laser Diode.

Spontaneous Recombination Coefficient(A)	$1\times10^{8} s^{-1}$
Bimolecular Recombination Coefficient(B)	$1\times10^{-10} cm^3 s^{-1}$
Auger Recombination Coefficient(C)	$1.3\times10^{-28} cm^6 s^{-1}$
Transparency Carrier Density	$1.5\times10^{18} cm^{-3}$
Linewidth Enhancement Factor	3
Waveguide Loss in the Active Region	$30 cm^{-1}$
Waveguide Loss in the Passive Region	$5 cm^{-1}$
Confinement Factor for Gain	0.17
Confinement Factor for Phase Control Region	0.7
Effective Refractive Index	3.2
Effective Group Index	3.7
Waveguide Stripe Width	1.5 μm
Thickness of Gain Layer	0.12 μm
Thickness of Passive Waveguide	0.23 μm
Differential Gain	$3\times10^{-16} cm^2$
Coupling Coefficient of Grating	$200 cm^{-1}$

the refractive index of the phase control region in the right SG-DFB laser diode is changed, the lasing wavelength is discretely selected in the interval of 1.6 nm. The entire tuning range is found to be about 24 nm and the tuning range could be extended through the optimized choice of sampling periods, burst length, etc. The output power of the laser diode is 23.5 mW, which is quite large compared with that of well known SG-DBR laser diodes, and doesn't fluctuate much as the refractive index changes. The lasing spectrum from the tunable laser diode is shown in Fig. 3, and 16 wavelength channels are clearly observed. When the refractive index of the phase control section in the left SG-DFB laser diode is kept constant, the laser diode is tuned discretely in the interval of 1.6 nm as the refractive index of the phase control section in the right SG-DFB laser diode is changed. For the continuous tuning, the refractive index of the left SG-DFB laser diode should be adjusted simultaneously.

So far the static properties of the SG-DFB laser diode is studied using the split-step time-domain model, and the wide tunability and the single mode operation is well confirmed from the simulation. In addition to the static single mode property, it is important to maintain the single mode operation under the high-speed modulation. To look at this property, the sinusoidal current waveform is applied to both the electrodes of the gain regions of a pair of SG-DFB laser diodes. The peak-to-peak current amplitude is set to 26 mA, the bias current is set to 130 mA. The modulation fre-

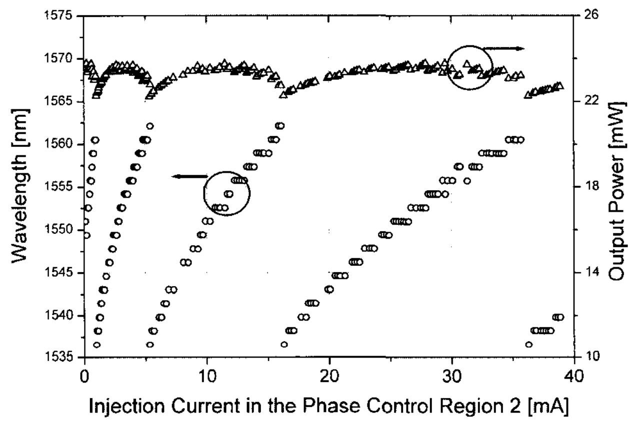

FIG. 2. Tuning Characteristics of the Widely Tunable SG-DFB Laser Diode.

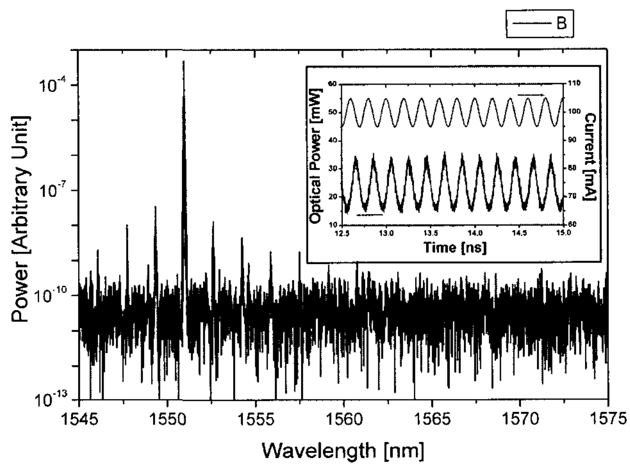

FIG. 4. Lasing spectrum of the widely tunable SG-DFB laser diode under 5 Gbps (NRZ) modulation. The inset shows the modulation current waveform and the corresponding optical output waveform.

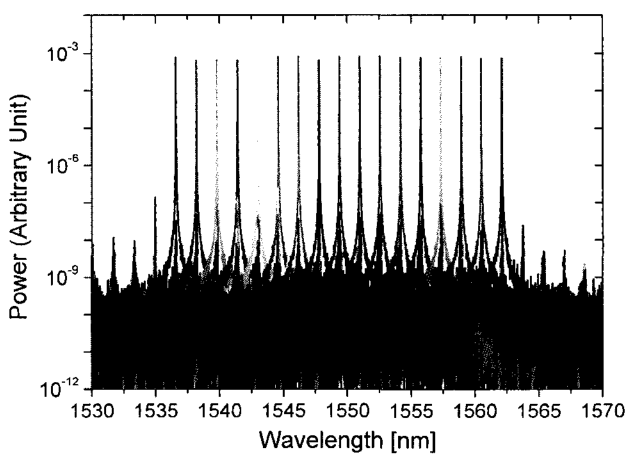

FIG. 3. Lasing spectrums of the widely tunable SG-DFB laser diode.

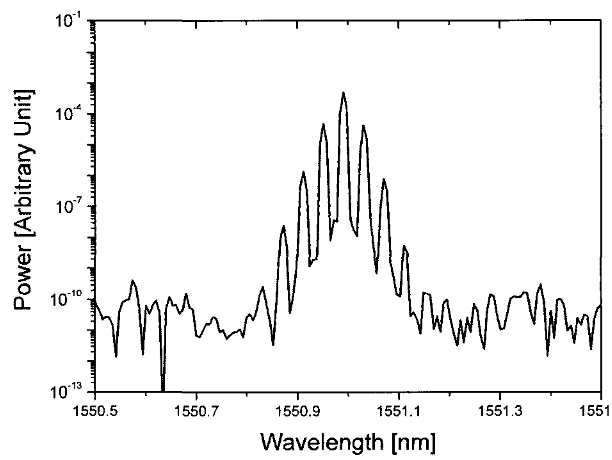

FIG. 5. Enlarged view of the lasing spectrum (FIG. 4) of the widely tunable SG-DFB laser diode under 5 GHz sinusoidal modulation.

quency is 5 GHz. The refractive index increase in the phase control regions of both the SG-DFB laser diodes is set to zero. The modulated laser output spectrum and the waveform is shown in Fig. 4 and in the inset of Fig. 4, respectively. The enlarged view of the optical spectrum is shown in Fig. 5. It is shown that the widely tunable SG-DFB laser diode can be operated in single mode dynamically.

The new concept of the widely tunable monolithic SG-DFB (sampled grating distributed feedback grating) laser diode is proposed and its feasibility is studied using the split-step time-domain model. The two SG-DFB laser diodes with slightly different sampling periods can be widely tuned by adjusting the refractive index of the phase control sections properly incorporated between the grating bursts. A specific design is presented and the tuning range is found to be 24 nm for this case. The output optical power is found to be as high as 23.5 mW, which is quite large compared with SG-DBR laser diodes with similar parameters. It is also numerically shown that this laser diode can preserve the single mode characteristic when it is dynamically operated under 5 GHz sinusoidal modulation.

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REFERENCES

[1] M. Veeraraghavan, R. Karri, T. Moors, M. Karol, R. Grobler, "Architectures and protocols that enable new applications on optical networks," *IEEE Communications Magazine*, vol. 39, pp. 118-127, 2001.

[2] M. Zirngibl, "Multifrequency lasers and applications in WDM networks," *IEEE Communications Magazine*, vol. 36, pp. 39-41, 1998.

[3] I. White, R. Penty, M. Webster, Y. J. Chai, and A. Wonfor, "Wavelength Switching Components for Future Photonic Networks," *IEEE Communications Magazine*, vol. 40, pp. 74-81, 2002.

[4] O.A. Lavrova, L. Rau, D.J., Blumenthal, "10-Gb/s agile wavelength conversion with nanosecond tuning times using a multisection widely tunable laser," *IEEE J. of Lightwave Technol.*, vol. 20, pp. 712-717, 2002.

[5] L. A. Coldren, "Monolithic tunable diode lasers," *IEEE J. on Selected Topics in Quantum Electron.*, vol. 6, pp. 988-999, 2000.

[6] Sang-Wan Ryu and Jeha Kim, "An Asymmetric Sampled Grating Laser and Its Application to Multi-Wavelength Laser Array," *ETRI Journal*, vol. 24, pp. 341-348, 2002.

[7] B.-S. Kim; Y. Chung; J.-S. Lee, "An efficient split-step time-domain dynamic modeling of DFB/DBR laser diodes," *IEEE J. of Quantum Electron.*, vol. 36, pp. 787-794, 2000.