DFB Laser Array Based on Four Phase-Shifted Sampled Bragg Gratings

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***Abstract*—A four-channel distributed feedback laser array based on four phase-shifted sampled Bragg gratings with a channel spacing of 0.8 nm at around 1560 nm lasing wavelength is reported. Side-mode suppression ratios >50 dB with an output power of around 57 mW were achieved.**

***Keywords*— Distributed-feedback lasers array, semiconductor optical amplifier, Phase shift, sidewall Bragg gratings.**

I. INTRODUCTION

To satisfy the massive growth in internet traffic, dense wavelength division multiplexing (DWDM) systems with more wavelength channels are required. Multi-wavelength distributed feedback (DFB) laser arrays offer stable and reliable operation of each laser in a single longitudinal mode (SLM) and are therefore highly desirable light sources for DWDM systems [1]. One major challenge is precisely controlling the grating period Λ to give the exact Bragg wavelength: $\lambda_B=2\times n_{eff}\times\Lambda$, where n_{eff} is the effective index of the propagating mode. For example, assuming n_{eff}=3.2, steps of only 0.125 nm in Λ are needed to give a 0.8 nm spacing in λ_B, and fabrication to this tolerance is beyond the typical resolution of 0.5 nm of electron beam lithography (EBL). The other challenge is to ensure stable SLM operation of every laser [2]. The research in [3] has indicated that multiple phase-shifted sampled Bragg gratings (MPS-SBGs) offer very precise wavelength spacing and a high effective grating coupling coefficient κ. By dividing one sampling period into m equal sections (m>2) with each adjacent grating period subjected to a $2\pi/m$-phase shift, DFB diode lasers with a narrow lasing wavelength spacing (≤0.8 nm) can be realized with high precision control by changing only the sampling period [3]. In [1], a 2PS-SBG based multiple-wavelength DFB laser array is reported with 0.8 nm channel spacing, but the DFB laser cavities were 1.2 mm long because of the relatively low κ (0.64× that of a uniform grating). Here we make the first report of a 4PS-SBG based DFB laser array with 0.8 nm lasing wavelength spacing. The cavity length was reduced to 800 µm because of the higher effective κ (0.9× that of a uniform grating). When we include an integrated semiconductor optical amplifier (SOA), the maximum output power can reach around 60 mW.

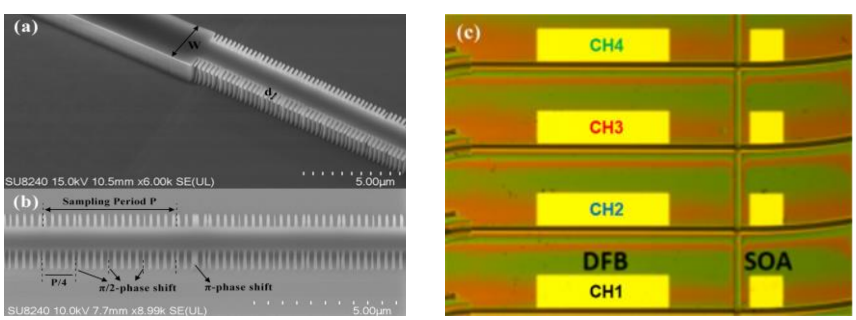

Fig. 1. (a) SEM picture of the 4PS-SBG sidewall gratings with a ridge waveguide width (W) of 2.5 µm and a recess depth (d) of 0.6 µm on each side of the ridge, (b) 4PS-SBG grating structure, P is the sampling period, (c) optical microscope picture of the fabricated four channel DFB laser array device.

II. Device Structure and Fabrication

The epilayer and fabrication process are the same as reported in [1]. The DFB lasers were based on sidewall gratings which can be simultaneously fabricated with the ridge waveguide, simplifying the fabrication process. Figure 1(a) shows a scanning electron microscope (SEM) picture of a 2.5-μm-wide ridge waveguide with sidewall gratings with a recess depth (*d*) of 0.6 μm on each side of the ridge. Here, a 4PS-SBG structure is used for the DFB laser as shown in Fig. 1(b), in which there are four phase-shifted sections in a single sampling period. Each adjacent section has a π/2-phase-shift and there is a π-phase shift in the middle of the cavity to ensure SML operation. A four-wavelength DFB laser array was fabricated and an optical microscope picture is shown in Fig. 1(c). For all four channels (CH1 to CH4), the seed grating period was set to 257 nm, which locates the 0^{th} channel at 1630 nm (taking the effective refractive index to be 3.19 at 1.55 μm and the dispersion coefficient to be −0.00021 /nm). The periods of the sampling gratings for CH1 to CH4 varied from 4.887 μm to 5.042 μm in steps of 51.5 nm to give channel spacings of 0.8 nm around a lasing wavelength of 1560 nm. For each DFB laser, the cavity length was 800 μm, and the length of SOA was 450 μm, separated by an isolation region of 20 μm. The SOA was used to increase the output power of the DFB laser, and has a curved waveguide with a radius of 1810 μm, making an angle of 10° at the output facet to reduce facet reflections. On the other side of the DFB laser diode, a 125-μm-long waveguide with a radius of 233.3 μm and an angle of 32° was used to absorb the light from the DFB laser and reduce back reflections. In the final stage of fabrication, the sample was cleaved into individual laser bars and the devices with uncoated facets were measured from the SOA side under CW conditions at 20˚C.

III. Device Performance

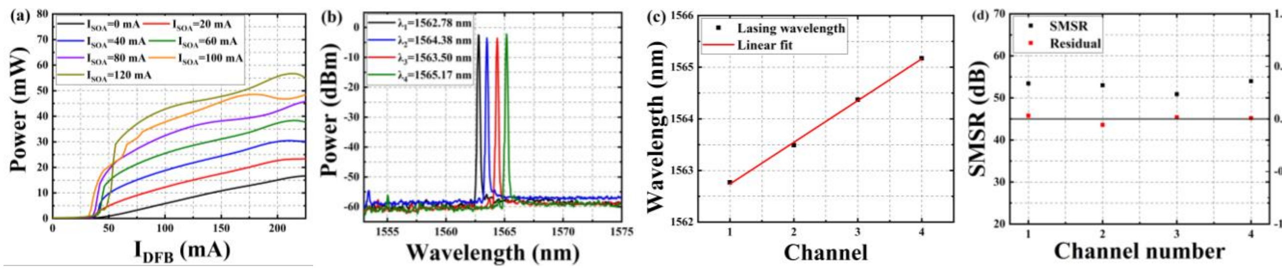

Fig. 2. (a) *P*-I_{DFB} curves under different SOA currents from the SOA side, (b) measured optical spectra, and (c) lasing wavelengths and the linear fitting of the four channels with I_{DFB} =280 mA, I_{SOA} = 100 mA, (d) measured SMSRs and the residual of the lasing wavelength in Fig. 2(c) after linear fitting.

Figure 2(a) shows typical (for CH2) output power vs DFB current (I_{DFB}) characteristics under different SOA currents (I_{SOA}). The threshold current of the DFB is 38 mA. With increasing I_{SOA}, the output power from the SOA side is also increased. When I_{DFB}=210 mA and I_{SOA} = 120 mA, the output power reaches its maximum value of 56.69 mW. For I_{DFB} from 38 mA to 330 mA and I_{SOA} from 0 to 120 mA, the DFB laser array maintained stable SLM operation. Figure 2(b) shows optical spectra for each channel with drive currents of I_{SOA} =100 mA and I_{DFB} = 280 mA. The lasing wavelengths are 1562.78 nm, 1563.50 nm, 1564.38 nm, and 1565.17 nm from CH1 to CH4, meeting the DWDM standard spacing of 0.8 nm. These results demonstrate the excellent wavelength precision that can be achieved by the 4PS-SBG structure. Figure 2(c) shows the four channel lasing wavelengths and the corresponding linear fitting curve. The slope of the line is 0.796 nm, with an error of 0.004 nm compared with the designed wavelength spacing of 0.8 nm. Figure 2(d) shows the measured single-mode suppression ratios (SMSRs) and residual errors of the four channel lasing wavelengths after linear fitting of the lasing wavelengths in Fig. 2(c). The SMSRs of all four channels are more than 50 dB and the residuals vary from −0.056 to 0.032 nm.

IV. Conclusion

In summary, a sidewall 4PS-SBG structure has been successfully applied to fabricate a four-wavelength DFB laser array with a channel spacing of 0.8 nm. This approach has the advantages of giving precise control over the individual lasing wavelengths accompanied by a high coupling coefficient. By eliminating the crystal re-growth required with traditional fabrication methods the manufacturing yield of SLM lasers is high. A maximum output power of around 57 mW was demonstrated, and high power, stable operation at precise wavelengths could be maintained over a wide range of drive currents for both the DFB and SOA.

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