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Very High Frequency Self-pulsation and Stable Optical Injection Locking for Well-defined Multi-electrode DFB Lasers

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1. Introduction

Optical 3R (Re-amplification, Re-timing, Re-shaping) is a key function for optical time division multiplexing (OTDM) data transmission in near future. A self-pulsating (SP) laser with multiple DFB regions is very promising for realizing the optical 3R functions because of high frequency optical pulse generation and optical injection locking operation [1]. Recently, we have proposed introduction of phase shift into the DFB sections, to improve the device performance [2]. In this report, we present the SP characteristics of stable optical injection locking at 40 GHz as well as very high frequency SP behavior beyond 200 GHz. These promising experimental results were analyzed by numerical calculation of temporal behavior with solving traveling wave equations in time domain [3].

2. Device structure

We fabricated three-electrode DFB devices with a buried heterostructure, which serves for high device reliability. Gratings in the front and rear DFB sections with an InGaAsP bulk active layer were fabricated by electron beam lithography, while a transparent waveguide region for phase tuning was formed between the two DFB sections by butt-joint growth procedure. A schematic structure is shown in the inset of Fig. 1, whereas the device parameters are listed for investigated two devices (A and B) in Table I.

3. Optical Injection Locking at 40 GHz

For device A with no phase shift and 4 nm detuning between front and rear gratings, we observed stable SP behavior at 40 GHz repetition of 1547 nm light for proper current injection. For this oscillation state, we performed optical injection measurement. Here, sinusoidally modulated 1557.5 nm light with a frequency of 39.8 GHz was used as an injection pulse. Figure 1 shows the injection pulse power dependence of rf spectra. Without light injection, the 6 dB bandwidth of the SP was as relatively large as 350 MHz. With an increase of the input power, the SP spectra show partial locking behavior, not indicating a reduction of the bandwidth. Finally, full locking and a remarkable bandwidth reduction were demonstrated for an injection power of 12 mW.

In order to understand the present SP mechanism, we show the observed and calculated optical spectra in Figs. 2(a) and (b), respectively. Qualitative features of the simulation agreed well with the experimental results, especially the existence of the two dominant modes as well as their wavelength spacing. Furthermore, the calculated reflectivity spectra of the individual DFB sections clearly indicate that the longer wavelength part is attributed to the rear DFB stop-band edge, while the shorter one is ascribed to the front DFB region. Thus, we concluded that the observed SP is based on a beating type oscillation [1].

4. Self-pulsation beyond 200 GHz

The SP operation up to 84 GHz has been already reported with detuned grating devices [4]. However, further increase of the SP frequency will not be easy simply by increasing the detuning of the gratings, because unintentional laser oscillation at adjacent modes may occur between the edges of the stop-band of the DFB sections. Therefore, we designed and fabricated the device B with a $\lambda/4$ phase shift in the front DFB. Figure 3(a) shows measured optical spectrum, where two oscillation modes with a spacing of 2.2 nm and similar intensities are observed under a proper driving condition. In an auto-correlation profile of the output light, oscillation at as very high as 275 GHz was observed as indicated in Fig. 4, which just corresponds to the spacing of the two modes.

Figures 3(b) and (c) show calculated laser oscillation spectrum and reflectivity spectra of the two DFB sections,

Table I. Device parameters of multi-electrode DFB lasers.

Section	Parameter	Device A	Device B
Front (DFB)	Length (μm)	300	300
	Bragg wavelength (nm)	1550	1550
	Phase Shift	None	$\lambda/4$ at center
Center	Length (μm)	270	270
Rear (DFB)	Length (μm)	300	300
	Bragg wavelength (nm)	1554	1550
	Phase Shift	None	None

respectively. The oscillation spectra are again in good agreement with the calculation and experiment. Here, the longer wavelength oscillation mode should be ascribed to a dip of reflectivity in the front DFB stop-band, which is due to λ/4 phase shift. On the other hand, the shorter one should originate in the rear DFB. Thus, we concluded that the present self-pulsation beyond 200 GHz is due to an effect of the insertion of the λ/4 phase shift.

5. Conclusions

Self-pulsating multi-electrode DFB lasers were fabricated by introducing well-designed detuned grating and phase shift. Optical injection locking at 40 GHz and self-pulsation at a very high repetition of 275 GHz were experimentally demonstrated. Furthermore, calculated results explained the experiments clearly.

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References

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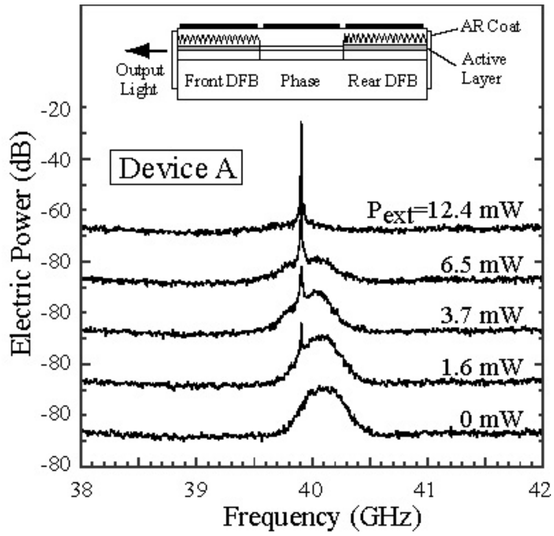

Fig. 1 Injection pulse power dependence of pulsating rf spectra of device A at 40 GHz. A schematic device structure is shown in the inset.

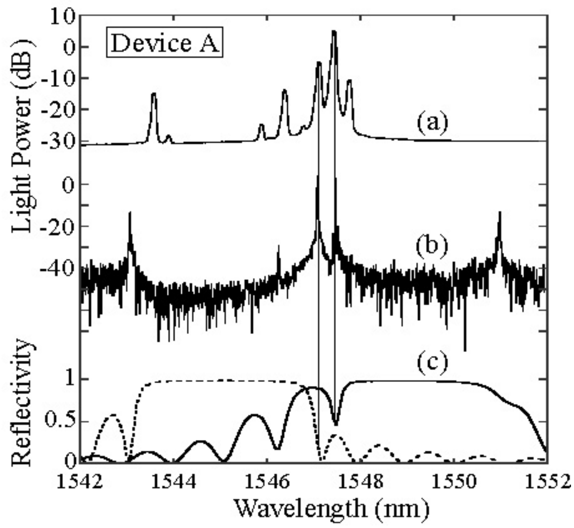

Fig. 2 Optical spectra of the 40 GHz pulsation for device A.
(a) measured and (b) calculated laser oscillation, (c) calculated reflectivity of front DFB (dashed curve) and rear DFB (solid curve). Two SP modes are indicated by vertical lines.

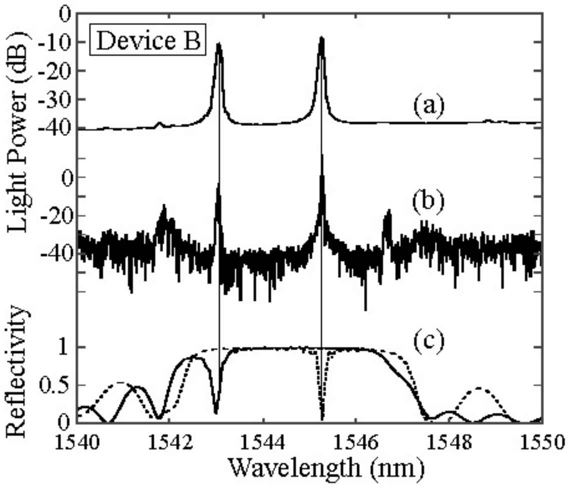

Fig. 3 Optical spectra of device B.
(a) measured and (b) calculated laser oscillation, (c) calculated reflectivity of front DFB (dashed curve) and rear DFB (solid curve). Two SP modes are indicated by vertical lines.

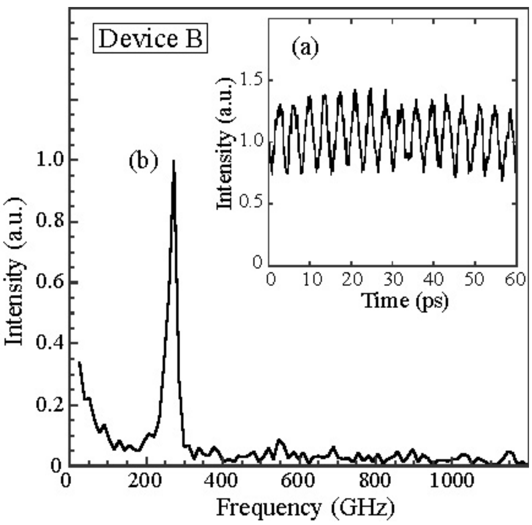

Fig. 4 Self-pulsation at 275 GHz for device B.
(a) a measured auto-correlation profile of the output light,
(b) a Fourier-transform spectrum of its profile.