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Terahertz Signal Generation Based on a Dual-Mode 1.5 µm DFB Semiconductor Laser

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Abstract: A novel dual-mode DFB semiconductor diode laser has been demonstrated. Using photomixing techniques, a terahertz signal at ~560 GHz has been generated. The THz signal shows power fluctuations related to mode competition in the laser.

OCIS codes: (140.3490) Lasers, distributed-feedback; (300.6495) Spectroscopy, terahertz

1. Introduction

Terahertz (THz) frequency sources have attracted much attention in the research area and are already used in the fields of environmental monitoring, security, agriculture and medicine [1]. Many different techniques have been developed to generate THz signals [2]. One of the promising methods is called photomixing. Two wavelengths from lasers with a frequency difference in the THz frequency range can generate THz signals by photomixing in a high-speed detector connected to an antenna. Specifically, photomixing based on semiconductor lasers has the advantages of compactness and low cost [3]. If the wavelengths are in the optical communications wavelength range, the THz signals can be transmitted conveniently through an optical fiber. Here, a novel dual-mode distributed-feedback (DFB) semiconductor diode laser based on sampled Bragg gratings (SBGs) has been designed and fabricated. Both lasing wavelengths are generated simultaneously in one cavity in the C-band wavelength range (1530-1565 nm) and a terahertz signal of 560 GHz is generated by photomixing based on mode beating effects.

2. Device Design

The dual-mode DFB laser uses SBGs within the gain section which have phase-shifted sections in each sampling period. This technique was first described in reference [4], and a dual-wavelength fiber laser was also realized. It was then successfully applied to DFB semiconductor lasers [5]. The dual-mode laser here is based on an SBG with two phase-shifted sections in a single sampling period (Fig. 1(a)), which we will call a 2PS-SBG structure. For a normal SBG with a duty cycle of 0.5, half of the sampling period is blank. For the 2PS-SBG structure, the blank half period is filled with a π-phase shifted grating. In this circumstance, the ±1st-order reflections in the reflectivity spectrum will be enhanced and the 0th-order reflection will be eliminated. As the sampling period *P* is increased, the ±1st-order reflections become more closely spaced. With the introduction of an equivalent π-phase shift [6], single-mode lasing will occur simultaneously on both of the ±1st-order channels. In this design, the seed grating period was 244 nm and the sampling period was 134.67 µm.

Figure 1(b) shows a micrograph of the fabricated laser diode, which uses ridge waveguides with sidewall gratings [3]. The cavity length of the DFB section was 1200 µm and the semiconductor optical amplifier (SOA) had a length of 300 µm, separated by an isolation region of 20 µm. The SOA had a curved output waveguide with radius of 1724.1 µm making an angle of 10° at the output facet. To avoid back reflections from the other facet, a waveguide, of length 125 µm with a radius of 233.3 µm and an angle of 32° at the facet, absorbed the light. Since the curved waveguides minimized back reflections from both facets, the lasing wavelengths should only depend on the gratings in the DFB section.

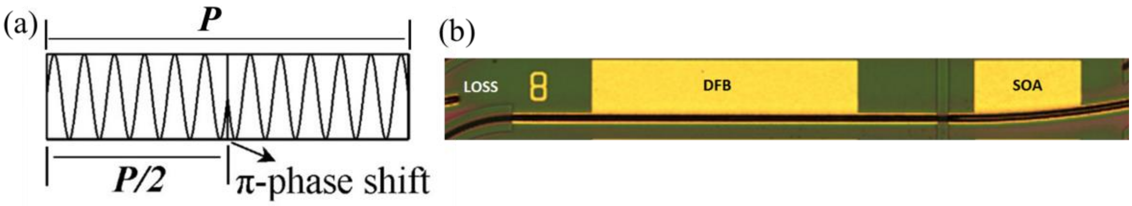

Fig. 1. (a) A 2PS-SBG grating structure, *P* is the sampling period, (b) the micrograph of the fabricated device.

3. Measurements

Figure 2(a) shows a 2D-wavelength map with SOA current set to 40 mA. It can be seen that the two lasing modes are quite stable over a large range of the DFB injection currents and the threshold current is ~50 mA. The optical spectrum was also measured at an SOA current of 40 mA and DFB current of 120 mA, as shown as Fig. 2(b). Under these injection currents, the wavelength difference of the two modes is 4.45 nm. The power difference of the two modes is about 0.5 dB and the side mode suppression ratio (SMSR) of the two modes is

>30 dB. The corresponding autocorrelation trace is shown in Fig. 2(c), with the average period of the emitted pulse train measured as 1.8 ps, which corresponds to a beating frequency of 560 GHz, consistent with the optical spectrum shown in Fig. 2(b).

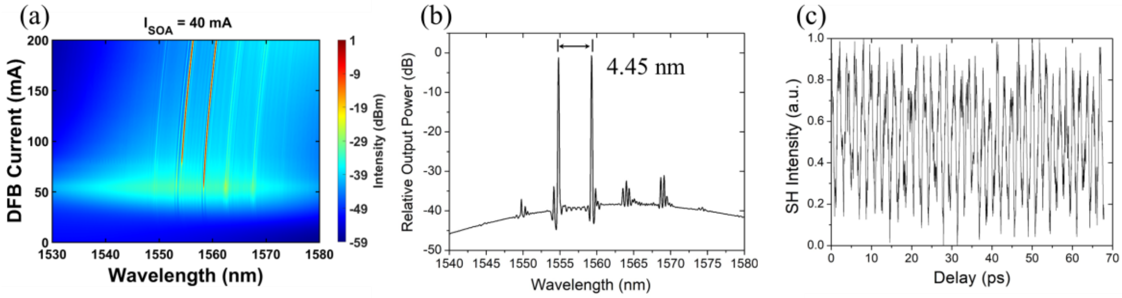

Fig. 2. (a) 2D-wavelength map at an SOA current of 40 mA, (b) the optical spectrum at an SOA current of 40 mA and DFB current of 120 mA, (c) corresponding autocorrelation traces showing mode beating frequency of 560 GHz.

A setup for THz signal generation and detection has also been built, shown in Fig. 3(a). The DFB diode laser was mounted on a thermoelectric cooler (TEC) for temperature control. The output light was coupled into a lensed optical fiber and transmitted to an erbium-doped fiber amplifier (EDFA) through an isolator. Then the light was sent to a photoconductive antenna (PCA) to generate THz signals. The free-space THz signals were then detected by a Golay cell THz detector. A lock-in amplifier together with a pulse generator was used to extract the signals from the noisy environment. Both the current driver and the lock-in amplifier were controlled by a computer through the general purpose interface bus (GPIB) interface. Figure 3(b) shows a 3D-power map of the THz signal as a function of SOA and DFB injection currents. The ridges and troughs in the plot show THz power oscillates strongly with DFB drive current, which we tentatively ascribe to mode competition and mode switching effects in the laser. The ridges in the 3D-map bend slightly with SOA current, which is related to laser heating. The apparent negative THz power appears to due to interactions between the laser and the ASE power from the EDFA, combined with the lock-in amplifier mechanism.

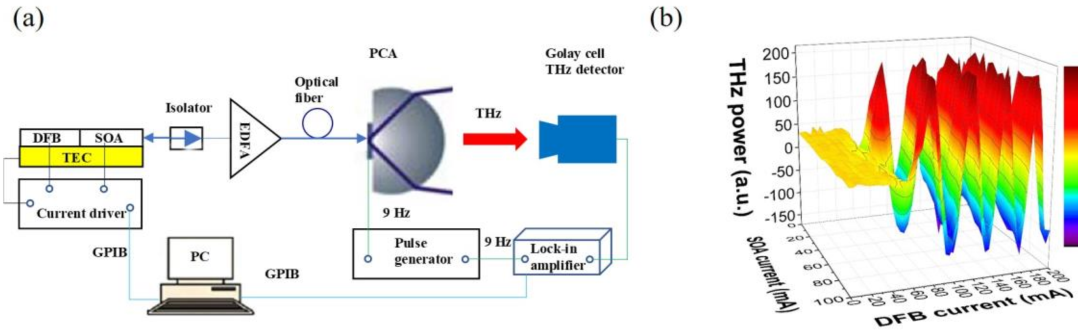

Fig. 3. (a) Setup for THz signal generation and detection, (b) the relative power map of the THz detected signal.

4. Conclusions

A novel dual-mode DFB semiconductor diode laser based on a 2PS-SBG structure was designed and fabricated. Based on mode beating effects and photomixing techniques, a THz signal with frequency of 560 GHz was successfully generated and detected. The THz power oscillates with DFB injection current, possibly indicating regions of mode competition, but stable dual-wavelength lasing can be achieved over wide ranges of drive current. Dual-mode DFB lasers are promising devices for compact, low-cost THz frequency sources.

5. References

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