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A Novel High Speed Directly Modulated Dual Wavelength 1.3 µm DFB Laser for THz Communications

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Abstract *We report a novel dual wavelength 1.3 µm DFB laser which has an over 26 GHz modulation bandwidth for THz communications. In dual wavelength working mode, NRZ data modulations at up to 50 Gb/s have been demonstrated successfully.*

Introduction

Terahertz (THz) wave, which is in frequency range from 0.1 to 10 THz, has many attractive applications including THz imaging for quantitative analysis of industrial products, security inspections, medical diagnosis, and spectroscopy [1]. When THz wave is used for wireless communications, the bandwidth of the systems can be expended greatly because its frequency is much higher than the now widely used wireless band and no specific applications have yet been allocated for the THz frequency spectra [2]. THz sources are key for THz communications and other applications. There are both electronic- and photonics-based ways for the generation of THz waves. In the latter way, two optical wavelengths mix in a photomixer, such as a UTC-PD, generating a THz signal whose frequency equals the separation between the two wavelengths. The photonics-based THz generation technique has advantages including wide frequency tuning range and low propagation loss of signals in optical systems [3].

Though two discretely packaged lasers can be used in the photonics-based THz sources, it is desirable that the two wavelengths can be provided by a monolithically integrated dual wavelength laser chip, because several advantages for the system can be expected including higher reliability, smaller size, and lower consumption of power. Up to now, there have been different types of integrated dual wavelength laser sources reported, such as side by side DFB lasers [4], two section DFB semiconductor lasers [5, 6], and multi-channel DFB laser arrays [7, 8]. However, the fabrication procedure is complex for these dual wavelength lasers, which leads to a high cost.

In this paper, we report a novel directly modulated dual wavelength 1.3 µm DFB laser for THz communication applications. The laser consists a distributed feedback (DFB) section and a passive distributed Bragg reflector (DBR) section, both having the the same grating parameters and the same InGaAlAs/InP multi-quantum wells (MQWs), which simplifies the device fabrication notably. The laser has an over 26 GHz direct modulation bandwidth, which facilitates high speed data modulation onto THz wave by eliminating external modulator. NRZ data modulations at up to 50 Gb/s have been demonstrated successfully. A larger than 35 mW optical power can be obtained from the device, which helps to get a high THz output power. This simple but powerful device will lead to a cost effective high speed THz communication system.

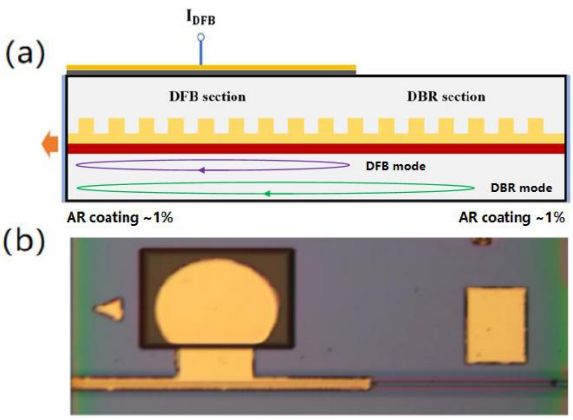

Fig. 1: Schematic structure and optical image of the laser.

Device structure and fabrication

Fig. 1 (a) shows the schematic cross-section structure of the dual wavelength laser, which consists a 200 μm long DFB section and a 150 μm long DBR section. Both the two sections have the same MQWs, which has 9 compressively strained InGaAlAs wells and 10 tensilely strained InGaAlAs barriers and has a 1300 nm peak photoluminescence (PL) wavelength. Gratings having a uniform pitch are fabricated in a layer of InGaAsP material above the MQWs in both the two sections. Because of the structure, the fabrication procedure of our dual wavelength laser is nearly the same as normal DFB lasers and is simplified notably compared with other reported devises [4-8], which leads to a low cost. Two 1/8 λ phase shift structures are placed in the middle of the DFB section. A ridge waveguide structure is adopted. The widths are 2 μm and 3 μm for the DFB section and DBR section, respectively. Electrode is formed in only the DFB section and a polymer layer is formed under the contact pad to decrease the parasitic capacitance. To reduce current diffusion from the DFB section to the DBR section, the InGaAs contact over the ridge of the DBR section is removed. A photograph of the fabricated device is shown in Fig. 1(b). Both facets are coated to have 1% reflection. As shown in Fig.1(a), one of dual mode emissions is supported by the DFB section grating, the other mode is selected by the DBR grating from modes of the cavity formed by the DFB section facet and the DBR grating.

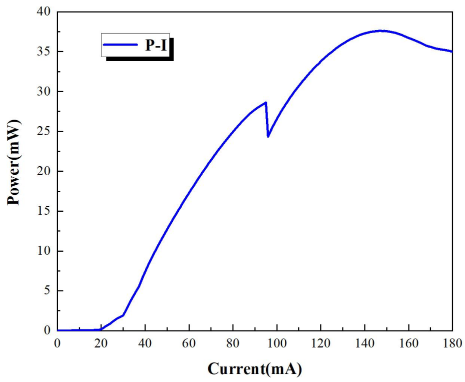

Fig. 2: Light-current characteristic of the laser.

Static optical characterizations

The device is soldered onto a AlN heat sink for static and high speed testings at room temperature. Fig. 2 shows the light output power as a function of injection current (PI). The optical spectra at three different currents are shown in Fig. 3. The threshold current of the laser is 20 mA. Above the threshold, light transmitted into the DBR section is reflected back to the DFB section and absorbed by the MQWs at the same time. As the current is increased, the light absorption in the DBR section saturates quickly and then the section acts as only a reflector, which leads to the slope change in the PI curve at about 34 mA as shown in Fig. 2. Below 90 mA current, the laser emits at only the DBR mode which is the long wavelength mode at around 1317 nm shown in Fig. 3. At 90 mA, a notable kink appears in the PI curve indicating the start of dual mode emission. When the current is larger than 90 mA, the DFB mode begins to emit at around 1310 nm as shown in Fig. 3. The intensity of the DFB mode increases gradually with the current, resulting a less than 3 dB difference from the DBR mode when the current is larger than 165 mA as shown in Fig. 3 (c). Fig. 4 shows the autocorrelation trace corresponding to Fig. 3(c). The average period is 0.918 ps, which corresponds to a 1.089 THz repetition frequency and agrees with the 6.5 nm wavelength separation between the two modes. As shown in Fig. 2, the optical power is larger than 35 mW when working at around 160 mA, which helps to get a high THz output power.

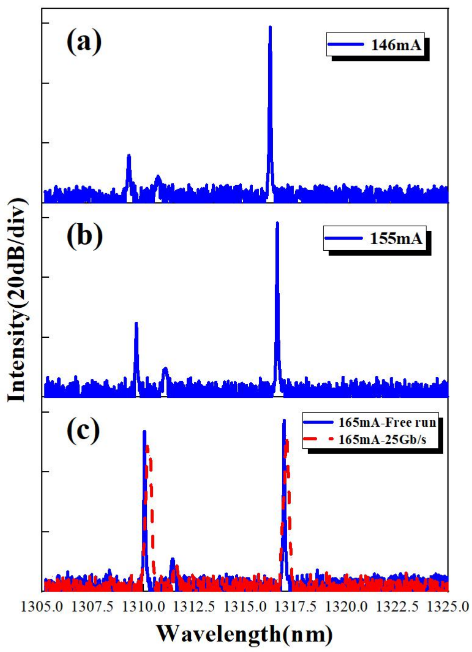

Fig. 3: Optical spectra at three different currents.

There are two reasons for the wavelength difference between the two modes though both the DFB and DBR sections have the same grating pitch. First, the width of the ridge of the DBR section is 1 μm larger than the ridge width of the DFB section, leading to a larger refrective index and thus a larger Bragg wavelength. Then, carrier injection into the DFB section leads to a decrease of the refrective index, decreasing the Bragg wavelength correspondingly [9]. As shown from Fig. 3, the wavelengths of both the two modes increase with injection current because of self heating effect of the current. However, because heat is generated in only the DFB section, the move of the DFB wavelength is faster than the DBR wavelength, resulting in a small amount of tuning of wavelength separation tuning. To get a larger tuning range, which corresponds to a larger THz frequency tuning range, thin film heaters can be integrated into the device.

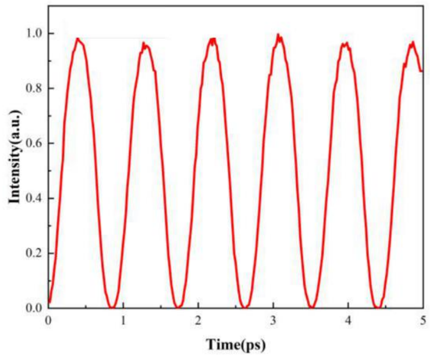

Fig. 4: Autocorrelation trace corresponding to Fig.3 (c).

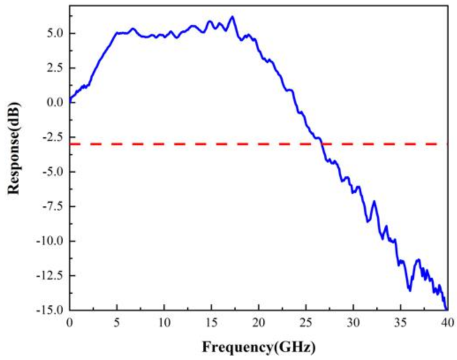

Fig. 5: Small signal direct modulation response of the laser.

High speed performance

A 50-GHz network analyzer is used to study the small signal direct modulation properties of the device. The modulation signal is fed to the device through a GSG probe with a bandwidth of 50 GHz. Fig. 5 shows the measured small signal direct modulation response when the current is set as 165 mA at which the laser works at a dual mode emission state. The measured 3 dB direct modulation bandwidth is 26.5 GHz. Variation of the laser current between 160 mA and 170 mA has only a small effect on the modulation bandwidth.

Data modulation experiments when the laser is biased at 165 mA are then conducted. The device is modulated at different data rate by nonreturn to zero (NRZ) pseudo random bit sequence (RPBS) data patterns having a 2^{15}-1 length, which are generated by a commercial pulse pattern generator (PPG, SHF-12125B). Fig. 6 shows the obtained eye diagrams. As can be seen, for the 25，40 and 50 Gb/s modulations， clearly opened eye diagrams can be obtained for both BTB conditions and after 10 Km of single mode fiber transmissions. The optical spectrum of the laser under 25 Gb/s modulation is shown in Fig. 3(c). Clear dynamic line broadening resulted from direct modulation can be observed for both the two modes.

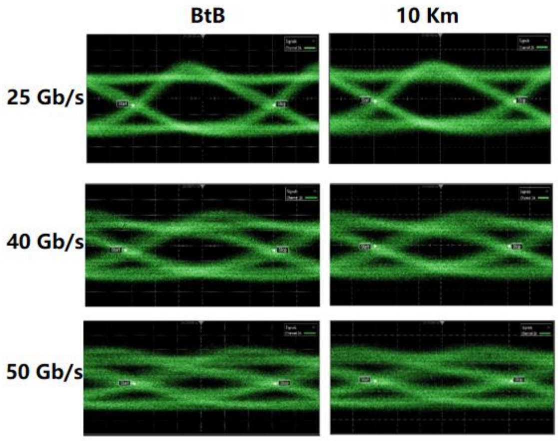

Fig. 6: Eye diagrams under NRZ data direct modulation.

Conclusions

In this paper, we report a novel dual wavelength DFB laser which has a simple fabrication procedure and high direct modulation bandwidth. Dual mode emissions at 1.3 μm band with 6.5 nm wavelength separation have been obtained. NRZ data modulations at up to 50 Gb/s have been conducted successfully. This device is a cost effective light source of photonics-based THz source system for THz communications.

Acknowledgements

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