Low Phase Noise Millimeter-Wave Generation by Integrated Dual Wavelength Laser Diode

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Abstract: We report millimeter-wave generation by an integrated dual wavelength laser diode based on optical sideband injection locking. Low phase noise millimeter-wave carrier at 42 GHz has been generated from 5.25 GHz modulation signal.

OCIS codes: (140.5960) Semiconductor lasers; (130.3120) Integrated Optics Devices

1. Introduction

Millimeter-wave (mm-wave) wireless communication has attracted considerable attention during the past few years due to its unique advantages, such as wide bandwidth, reuse of frequency band, and good confidentiality [1]. Optical generation and transmission of mm-wave signal are desirable for future broadband wireless communication systems due to its low system cost, low transmission loss, and immunity to electromagnetic interference [2]. Among various methods for mm-wave carrier generation by optical means, optical sideband injection locking is able to produce mm-wave carriers with frequency tunability as well as high spectral purity [3]. In addition, it has the potential to be realized with monolithic integrated device [4], which is important for reducing system complexity and cost. Furthermore, mm-wave generation system based on discrete devices using sideband injection locking may suffer from deteriorated phase noise due to optical path difference between the beating lights [5]. This problem can be solved by monolithically integrating the master laser and the slave laser on a single chip, so that the optical path difference can be made negligible.

In this paper, we report low phase noise mm-wave carrier generation by an integrated dual wavelength laser diode. Frequency multiplication can be realized with the integrated device using optical sideband injection locking. Millimeter-wave carrier at 42-GHz with a phase noise of −94.6 dBc/Hz at 10 kHz offset is demonstrated.

2. Device Structure

Fig. 1(a) presents the schematic of the integrated dual wavelength laser diode, which consists of two distributed feedback (DFB) lasers and one Y-branch section monolithically integrated on the same AlGaInAs multiple quantum well (MQW) active layer. The DFB laser section and the Y-branch section are 420 and 400 μm in length, respectively. The angle between the two DFB lasers is 4°, and the smallest distance between the two lasers is 14 μm, which ensures that no mode coupling would occur. The end facets at the DFB laser section and the Y-branch section are both left as cleaved. Fig. 1 (b) shows the photograph of the fabricated device.

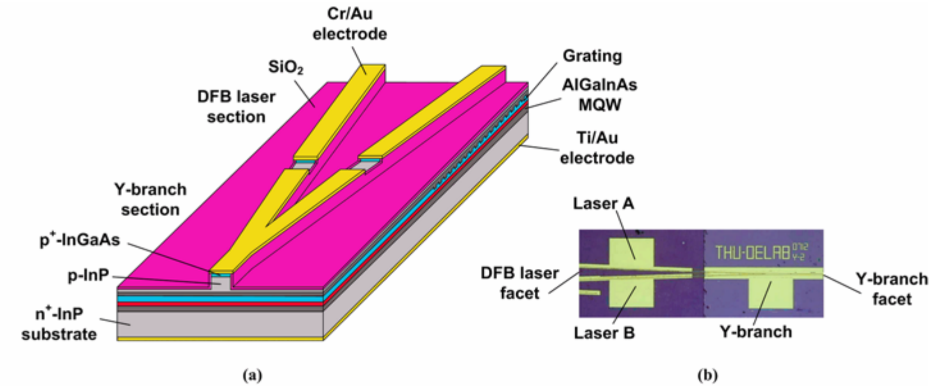

Fig. 1. (a) Schematic diagram and (b) photograph of the integrated dual wavelength laser diode for mm-wave generation.

The threshold current of the DFB lasers measured with the Y-branch section unbiased is around 17 mA. The lasing spectrum and RF spectrum measured at the Y-branch facet are plotted in Fig. 2. A Lorentzian-shaped peak around 27 GHz is recorded when both lasers are in free-running state. The full-width-at-half-maximum (FWHM) linewidth of the beat signal is on the order of 10 MHz, due to the lack of phase-correlation between the two lasers.

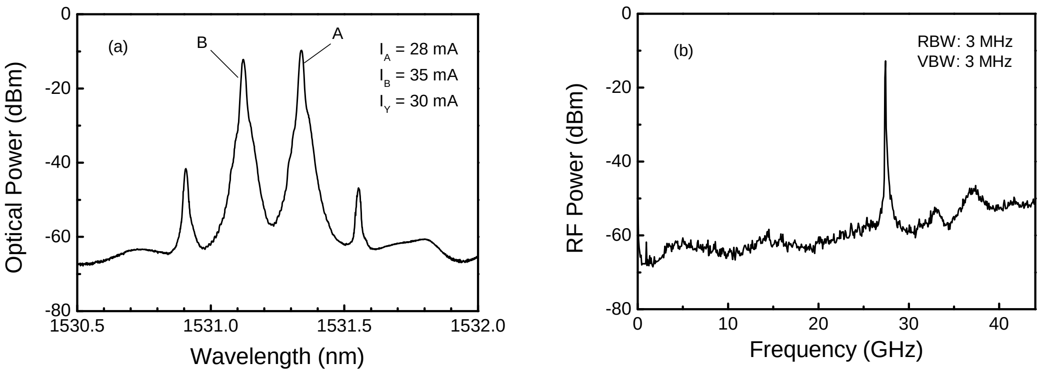

Fig. 2. (a) Optical spectrum and (b) RF spectrum of the integrated device under free-running state.

3. Low Phase Noise Mm-wave Generation

Fig. 3 depicts the experimental setup for low phase noise mm-wave carrier generation. Laser B is chosen as the master laser (ML) and directly modulated through a bias Tee, whereas Laser A works as the slave laser (SL). Light injection between the ML and the SL is realized by reflection at the end facet of the Y-branch section, and the injection level can be adjusted by varying the current of the Y-branch section.

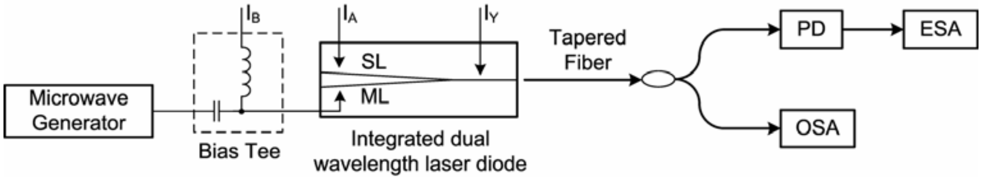

Fig. 3. Schematic diagram of the experimental setup. ML: master laser; SL: slave laser; PD: photodetector; ESA: electrical spectrum analyzer; OSA: optical spectrum analyzer.

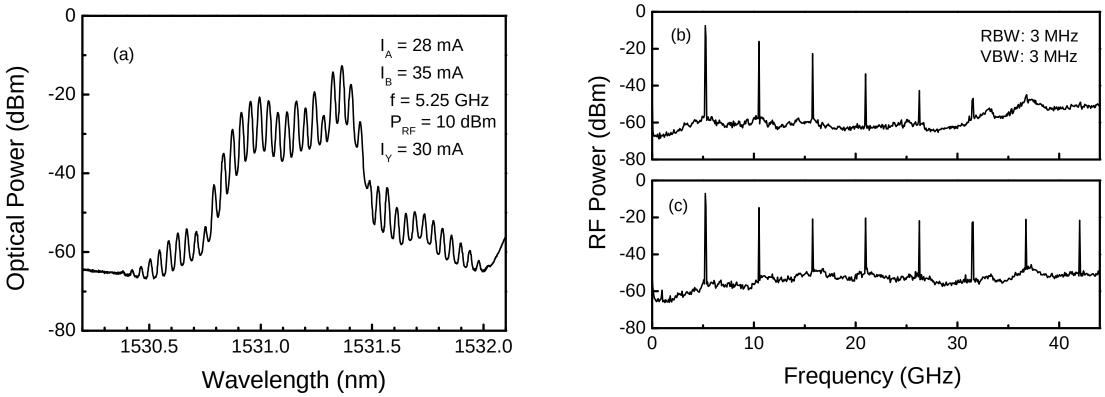

Fig. 4. (a) Optical spectrum and RF spectrum of the integrated dual wavelength laser diode: (b) laser B modulated at 5.25 GHz, laser A unbiased; (c) laser B under modulation, laser A locked to one of the sidebands.

To generate mm-wave carrier from low frequency RF signal, the key point is to generate high order modulation sidebands, which can be realized by modulating the ML around its relaxation resonance frequency. In our experiment, the ML is modulated at 5.25 GHz, which is close to its relaxation resonance frequency of 5.95 GHz when biased at 35 mA. The frequency and the RF power of the modulation signal applied to the ML are 5.25 GHz and 10 dBm, respectively. By tuning the injection current of the SL and the Y-branch section, the SL can be locked to one of the high order modulation sidebands due to reflection at the Y-branch facet. Fig. 4(a) shows the optical spectrum measured at the Y-branch facet. A series of sidebands with similar intensity are generated due to the enhanced amplitude and frequency modulation response around the ML's relaxation resonance frequency. Fig. 4(b) and (c) are the heterodyne spectra, which illustrate the effect of locking the SL to one of the high order sidebands of the ML. Beat signal with a frequency up to 42 GHz is recorded, corresponding to 8-times the modulation frequency. It is believed that mm-wave carrier with even higher frequency can be generated, though it was not recorded with the current experimental setup, due to the bandwidth limit of the photodetector and the electrical spectrum analyzer.

Fig. 5 displays the phase noise of the 42-GHz mm-carrier. A phase noise of –94.6 dBc/Hz at 10 kHz offset and –98.5 dBc/Hz at 100 kHz offset is demonstrated. For comparison, the phase noise of the modulation signal at 5.25 GHz is also included in Fig. 5. Compared with the modulation signal, the phase noise of optically generated 42-GHz mm-wave carrier exhibits only 18 dB or so degradation, in good accord with the 8-time frequency multiplication.

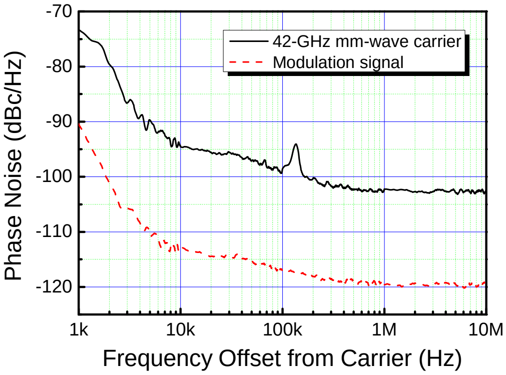

Fig. 5. Phase noise spectra of the generated 42-GHz microwave and the modulation signal.

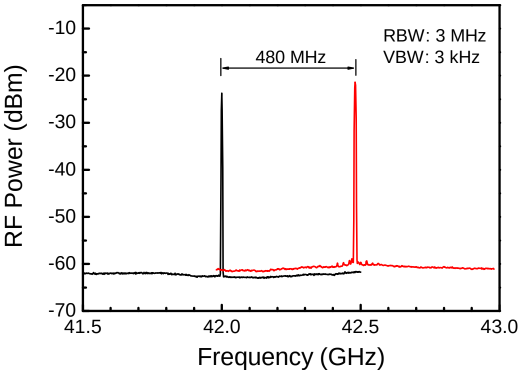

Fig. 5. Tunability of the generated mm-wave carrier by varying the ML's modulation frequency.

The frequency of the generated mm-wave carrier can be easily tuned by varying the modulation signal around the relaxation resonance frequency of the ML and adjusting the SL current accordingly. A tuning range over 480 MHz is demonstrated by adjusting only the modulation frequency of the ML, as shown in Fig. 5. On the other hand, a tuning range of over 4 GHz can be realized by adjusting the bias current of the SL as well as the modulation frequency. No significant variation in the RF power and spectral purity of the mm-wave carrier is observed within the tuning range.

4. Conclusion

An integrated dual wavelength laser diode has been fabricated to generate mm-wave signal based on sideband injection locking. Frequency multiplication up to 8 times of the modulation frequency has been demonstrated, and 42.0-GHz beat signal with a phase noise of –94.6 dBc/Hz at 10 kHz offset is generated. The device is believed to have great potential in future mm-wave mobile communication system.

5. Acknowledgements

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