Integrated W-band Photonic-Wireless Transmitter Enabled by Silicon Microring Modulator and On-chip Dual-mode DFB Laser

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Abstract: We propose an integrated W-band transmitter enabled by dual-mode DFB laser and silicon microring modulator for next generation wireless communication. Error free transmission of 10 Gb/s communication at 85 GHz have been experimentally demonstrated by utilizing off-chip free-running and on-chip DFB laser.

1. Introduction

The application of autonomous driving, metaverse, ultra-high-definition video and artificial intelligence are driving the ever-increasing demand for low-latency and high-speed wireless communications, which will require the advanced millimeter-wave (mm-wave) hardware design to provide much higher data throughput for wireless consumer applications. Particularly, millimeter and terahertz (Thz) wave generation and modulation by the optical technology are viable and scalable with the help of photonic integration that presents significant advantages of low loss,small footprint and operation flexibility [1]. For on-chip laser, an integrated III-V THz transmitter based on frequency comb injected distributed feedback (DFB) lasers was recently demonstrated for high-speed indoor communication applications [2, 3]. Moreover, silicon photonic has been promoted a versatile platform for embracing various applications including large-scale mm-wave wireless communication. For instance, THz communications using industrial Si photonic technology have been demonstrated at 300 GHz frequency carrier [4]. Silicon Mach Zehnder (MZ) modulator based photonic circuit has also been specially designed for facilitating wireless transmission at 300 GHz carrier [5]. This is the start of silicon photonic systems that are employed to build a complicated and robust wireless transmitter [6]. However, one of the key challenge is how to build fully integrated photonic aided wireless transmitter that comprise III-V lasers and silicon photonic circuits with supporting functions of high-speed modulation, phase-tuning, wavelength multiplexing and *etc*.

In this paper, we propose an integrated W-band transmitter enabled by dual-mode DFB laser with 85GHz frequency gapping and high-speed silicon microring modulator for next generation wireless communication. Compared with MZ modulators, microring modulators, with narrow-band frequency and small footprint, will show unique advantages of wavelength selectivity and multiplexing capability, which is especially of importance for radio frequency manipulation. The 10 Gb/s wireless communication experiment with intensity modulation and direct detection (IM-DD) is conducted to demonstrate error free transmission with 40-tap linear equalizer at 85 GHz frequency carrier. Moreover, communication performance by using on-chip dual-mode DFB laser and two free-running lasers are compared to show that the dual-mode DFB laser can achieve similar transmission performance as the free-running lasers at the same input optical power. We also implement the 40μm microring filters to suppress sidebands and noise of the DFB laser, which further improve the signal-to-noise-ratio (SNR) of communication systems. This proposed integrated architecture, by leveraging existing III-V and silicon manufacturing and packaging technology, will form a heterogeneous wireless transmitter that can be incorporated in an advanced handset to power next generation wireless communication.

2. Experiments for Integrated W-band Transmitter

Fig.1 shows the experimental setup for a W-band IM-DD communication system to demonstrate the integrated transmitter. The dual-mode DFB laser, shown in Fig. 1(a), follows a high-power design with 4 pairs of compressively strained AlGaInAs quantum wells and a cavity length of 1000 μm. A buried InGaAsP-based Bragg grating layer is used for longitudinal mode control. A double-trench ridge waveguide structure with a ridge width of 2.3 μm is used for lateral mode control. Two lasing modes can be obtained for lasers with a proper grating phase

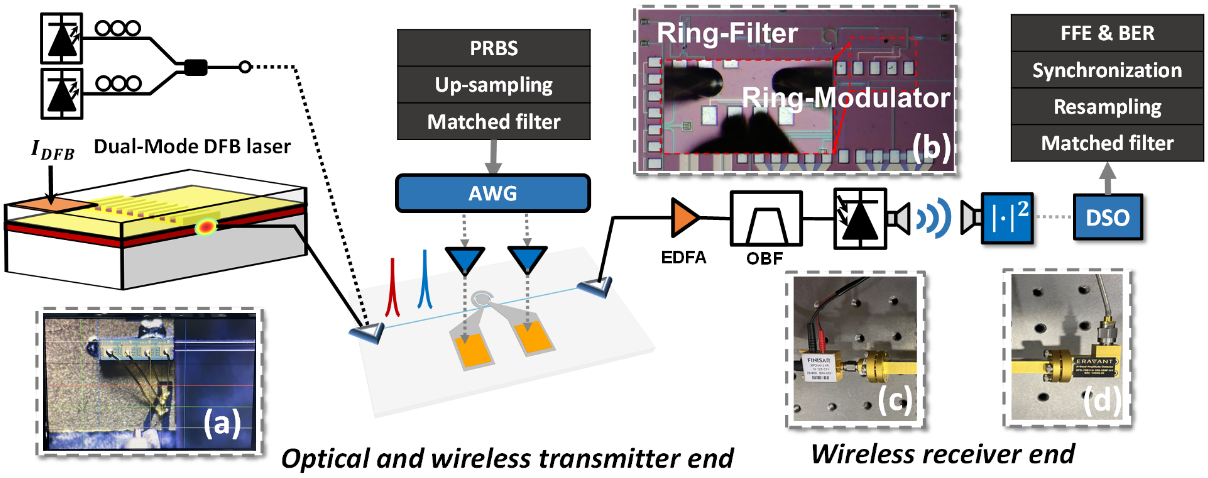

Fig. 1. Experimental setup for a W-band IM-DD wireless communication system. (a) On-chip dual-mode DFB laser. (b) Silicon photonic integrated circuit (PIC) containing microring modulator and filter. (c) High-speed photodetector with W-band transmitting antenna. (d) Envelope detector with W-band receiving antenna.

relative to the facet, and the mode separation is determined by the coupling coefficient of the grating. The photonic integrated circuit (PIC) contains microring modulator and passive components including thermal-tune based 40 μm radius filter and multimode interferometer (MMI). The working frequency of the microring modulator is tuned through thermal phase shifter to accommodate the DFB wavelength. The on-chip filter can be used to select two optical sources with specified wavelengths.

In this experiment, we choose the wavelength of DFB at the input current of 270 mA. The corresponding frequencies of the double longitudinal modes are 191.424 THz and 191.509 THz with the output optical power of -5.048 dBm and -3.039 dBm respectively. The filtered optical signal of DFB is then coupled to the microring modulator. The PRBS electrical signaling generated by arbitrary waveform generator (AWG) is loaded on the modulator through the electric pads. The output optical signals generated by the PIC is amplified by EDFA and transmitted to the high-speed PD. The PD is connected to the W-band transmitting antenna for spatial radiation. A pair of horn antennas, with 25 dBi gain and 10 cm distance, is used for W-band wireless transmission. The modulated electromagnetic signal is down converted to baseband through an envelope detector with a same received antenna. The detected signal is collected and processed by offline digital signal processing(DSP) such as matched filtering, resampling and equalization.

3. Experimental Results and Discussion

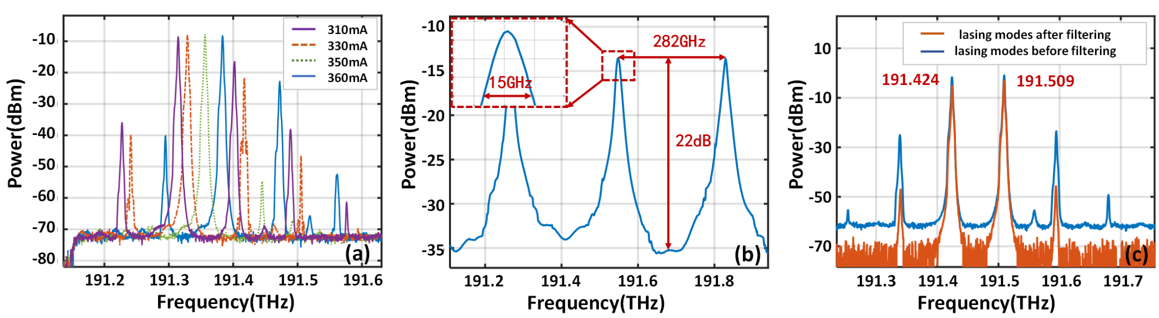

Fig. 2. (a) dual-mode and single-mode of DSB at different input currents. (b) transmission spectral line of on-chip ring filter. (c) modulated optical source and reference source before and after filtering.

Fig.2(a) shows the output spectral lines of the DFB laser at different input currents. Dual-mode lasing can be obtained at certain bias current range. Therefore, it is necessary to determine the optimal working current of the DFB laser output, which will limit the output wavelength range of the DFB laser. However, this working point selection can be realized by tuning resonance frequency of micro-ring modulators.

Fig.2(b) shows the transmission spectral line of the ring filter, which has 15G half width and 20dB side-mode suppression ratio. The frequency difference of the W-band is limited to one FSR. We use waveshaper to simulate the transmission spectrum of the on-chip filters. Fig.2(c) shows the output lasing modes of DFB before and after filtering. It can be seen that other side-modes and noises are suppressed. The power of the modulated light source at 191.509THz is higher than that of the reference source. Because of the input power limit of the PD, the modulated light source should have a higher power occupancy ratio, so that the system has a higher SNR.

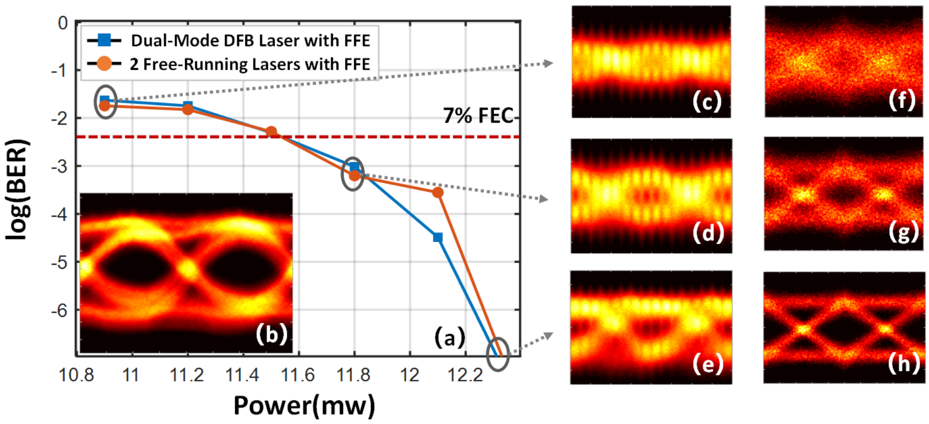

Fig. 3. (a) BER versus input optical power. (b) eye diagram before wireless transmission. (c-e) eye diagrams without processing. (f-h) eye diagrams with FFE equalizing.

Fig.3 shows the bit error rate and eye diagram results versus input optical power of PD. The two lines are the results of BER using on-chip dual-mode DFB laser and two off-chip free-running lasers respectively. Fig3(b) shows modulated eye diagram of 10G signal without wireless transmission. Fig.3(c-e) describes the eye diagrams without processing versus the input optical power of 10.9 mw, 11.8 mw and 12.3 mw respectively. Fig.3(f-h) shows the eye diagrams after equalization by the linear FFE equalizer with 40 tap coefficients and an error-free transmission is realized when the input optical power exceeds 12.3 mw.

4. Conclusion

We experimentally demonstrated the W-band wireless communication based on dual-mode DFB laser and silicon photonic microring modulator. The error-free of 10 Gbps transmission is realized by matching the optimal working wavelength of DFB with microring modulator. The same communication performance of W-band transmitter can be achieved by using on-chip DFB laser or two free-running lasers, while with much smaller size and lower power consumption of integrated transmitter. With wavelength multiplexing capability, this proposed integrated architecture will become a heterogeneous wireless transmitter that can be widely employed in next generation wireless communication.

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