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12.5-Gb/s Wireless Data Transmission by Using Bias Modulation of NBUTC-PD Based W-Band Photonic Transmitter-Mixer

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Abstract: We demonstrated near-ballistic uni-traveling-carrier photodiode based broadband photonic transmitter-mixers with quasi-Yagi radiators fed horn antennas. 100GHz wireless transmission with date rate as high as 12.5-Gb/s via bias modulation under high photocurrent (20mA) has been achieved.

OCIS codes: (230.5170) Photodiodes, (230.4110) Modulators

I. Introduction

The next generation of wireless links for gigabit wireless access applications may be constructed based on Radio-over-fiber (RoF) communication systems [1]. High-speed and high-power photonic transmitters, which are composed of an antenna and a photodiode, serve as the key-components in the last-mile of the RoF system [2,3]. Uni-traveling carrier photodiode (UTC-PD) and UTC-PD based photonic transmitter attracts lots of attention due to its excellent speed and saturation current performance [4]. In addition, in the RoF system with a long transmission distance (>100km) between central and base stations, chromatic dispersion induced inter-symbol interference (ISI) becomes another serious problem [5]. Remote signal up-conversion techniques with nonlinear photodetection scheme provide a promising solution for the aforementioned problem [3]. By use of the nonlinear bias modulation of UTC-PD, 10-Gb/s signal generation [6] and 1.25-Gb/s wireless data transmission [7] has been demonstrated. Nevertheless, in order to enhance the bias dependent nonlinearity of UTC-PDs, it is necessary to swing the bias voltage into the forward bias region (-1V to +0.5V), which induces the minority carrier injection in the active layers of PD and further limits the modulation bandwidth up to around 7GHz [6]. 10-Gb/s data transmission by using such approach still remains a challenge. Near-ballistic uni-traveling carrier photodiode (NBUTC-PD), which is another kind of high-power PD, has demonstrated superior saturation-current bandwidth product and modulation bandwidth to those of UTC-PD due to higher electron drift-velocity in its collector layer [8-10]. In this paper, we demonstrated a novel broadband NBUTC-PD based photonic transmitter-mixer at W-band (100GHz). Such device is composed of a flip-chip bonded NBUTC-PD with quasi-yagi radiator for WR-10 waveguide based horn antenna feeding. By use of such device under high-current operation (20mA) and bias modulation technique, wireless data transmission at 100GHz with data rate as high as 12.5-Gb/s has been successfully demonstrated.

II. Device Structure

Figures 1(a) and (b) show the top-view of our novel photonic transmitter-mixer and the measurement system setup for wireless data transmission. As can be seen in Figure 1(a), the photonic transmitter-mixer is composed of a diced NBUTC-PD with a 100μm^2 active area, a planar quasi-yagi radiator, a fan-shaped broadband transition between the co-planar waveguide (CPW) and the coplanar slot-line (CPS), an intermediate-frequency (IF) signal input port, a W-band radio-frequency (RF) choke, and bond pads for flip-chip bonding process on a 100μm thick aluminum-nitride (AlN) substrate for good thermal conductivity. The 3-dB O-E bandwidth of used NBUTC-PD in our device is around 200GHz with around 30mA saturation current under a 25Ω load [9]. As shown in Figure 1(b), the quasi-Yagi radiator employed discussed herein is for WR-10 waveguide feeding and comprised of a half-wavelength dipole element and a ground reflector. This makes it significantly more compact than the traditional tapered slot antenna (TSA) used for rectangular waveguide feeding. The MMW signal is delivered to the horn antenna via the WR-10 waveguide. Figure 1 (a) also shows the simulated coupling efficiency of the MMW power launched into the WR-10 waveguide. In our simulation, the radiator is assumed to be fed with a 50Ω signal source. As can be seen, a small coupling loss (<-1.7dB) can be achieved. As shown in Figure 1, during measurement, the electrical IF signal (12.5-Gb/sec) is injected into the IF input port of device by use of an on-wafer probe to modulate its bias point. The optical MMW local oscillator (LO) signal (100GHz), which is provided by octupling the modulated optical frequency [11], is injected onto the device through a lensed fiber. The electrical signal is thus up-converted to the W-band, before being fed into the WR-10 waveguide based horn antenna. The receiver end is composed of another W-band horn antenna, a W-band low-noise-amplifier (LNA) (QuinStar: QLW-90a06030-P1), and a fast W-band power detector (Militech: DXP-10-RPFW0) for detecting the envelope of transmitted MMW power. The down-converted data signal is then further amplified, sampled, and demodulated by an IF amplifier, high-speed real-time scope, and off-line signal processing [3].

III.Measurement Result:

There are two key points for realizing high data rate wireless transmission with bias modulation technique, one is the board optical-to-electrical (O-E) response of photonic transmitter and the other is the high modulation speed of integrated PD. Figure 2 shows the measured and simulated optical-to-electrical (O-E) frequency responses of our emitter module with two different geometric structures A and B. The geometric size of structure A, as shown in Figure 1(a), is optimized for broadband operation by using the 3-port equivalent-circuit-model of NBUTC-PD [8], which includes the O-E frequency response of device in the third port. On the other hand, the size of structure B is optimized based on electrical 2-port model. During measurement, the quasi-Yagi radiator of both devices is inserted into WR-10 waveguide for feeding the photo-generated MMW power and the other end of waveguide is connected to a power sensor to record the frequency response. The frequency of injected optical local-oscillator (LO) signal is swept from 75 to 110GHz and generated by the two-laser heterodyne beating system. As can be seen, for structure A, by using the response at 80GHz as reference point, the 3-dB bandwidth covers almost the full W-band (80-110GHz), which is consistent with our simulation result based on three-port model. However, for the measured trace of structure B, it exhibits a much poorer 3-dB bandwidth than that of structure A. Such measurement result clearly indicates that the 3-port equivalent circuit model [8] plays important role in the design of our photonic transmitter-mixer. Figure 3 shows the transfer curve of normalized MMW power (at 100GHz operating frequency and under two different optical pumping powers) in linear scale and photocurrent vs. reverse DC bias of our device. As can be seen, the measured MMW power varies seriously when the reverse bias ranges from -1V to -2.2V (35dB/Volt for the trace of 100mW optical pumping power). In addition, the measured DC photocurrent in the linear regime of transfer curve (-2.2V to -1.5V bias under 100mW pumping power) for optimum bias modulation performance is almost unchanged. We can thus conclude that the variation in detected MMW power is due to the significant bias dependent speed performance of NBUTC-PD [8], instead of the variation in photocurrent. For the case of UTC-PD, the bias dependent nonlinearity is mostly originated from the change in photocurrent when the bias voltage is swung into forward bias, which should seriously limit its modulation speed [6]. High available MMW power from our module is another key issue for practical application. Figure 4 shows the coupling power from our transmitter module under a 50Ω load and a -3V bias into WR-10 waveguide versus output photocurrent. The operating frequency is fixed at 100GHz with a 100% optical modulation depth. The maximum saturation current can be as high as around 30mA with around 4dBm maximum coupling power. Figure 5 (a) and (b) shows -log(BER) versus transmission distance with and without feed-forward-equalization (FFE) signal processing for 12.5-Gb/s and 8-Gb/s (PRBS: 2^{31}-1) on-off keying (OOK) data transmission, respectively. As can be seen, under 20mA operation current with FFE signal processing, 12.5Gbit/sec error-free operation can be achieved (BER less than 1×10^{-12}) with around 70cm transmission distance. The related 12.5Gbit/sec eye-pattern at 60cm with 20mA photocurrent is given as the insets of (a). As can be seen, clear eye-openings for 12.5-Gb/s can be observed with such long word-lengths (2^{31}-1), which indicate a flat modulation frequency response of our device from near DC to around 10GHz. By use of the forward-error-correction (FEC) technique, with coding threshold at BER=3.84×10^{-3} [11], the estimated maximum transmission of 12.5-Gb/s OOK signal distance is around 3.5 meter under 20mA output photocurrent operation.

IV.Summary:

In conclusion, we have demonstrated a NBUTC-PD based W-band photonic transmitter-mixer with extremely high modulation speed. By use of the three-port equivalent circuit model in the design process of such device, a broad O-E bandwidth (80-110GHz) can be achieved. Under high output photocurrent and bias modulation, 12.5Gbit/sec OOK wireless data transmission at 100GHz with FEC limited 3.5m transmission distance has been successfully demonstrated.

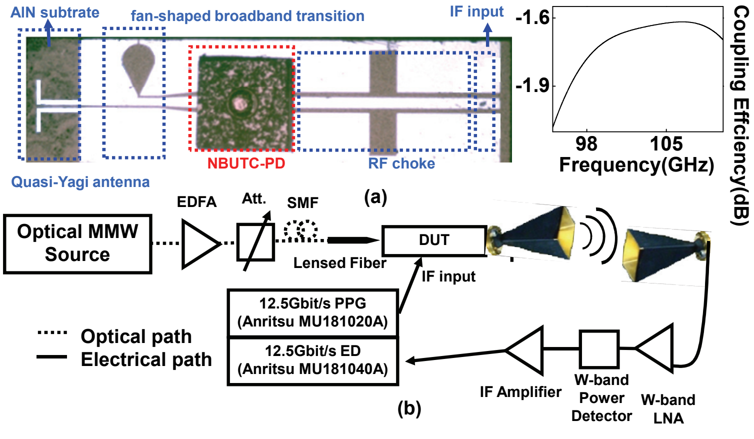

Figure 1. (a) Top-view of the demonstrated device and the simulated frequency response of the coupling loss; (b) measurement system setup for OOK wireless data transmission.

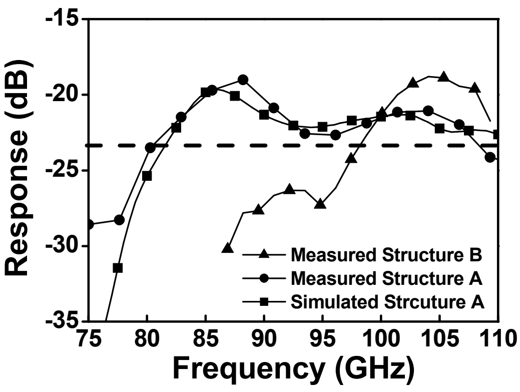

Figure 2. The measured optical-to-electrical (O-E) frequency responses of our photonic transmitter-mixer with different structures A and B.

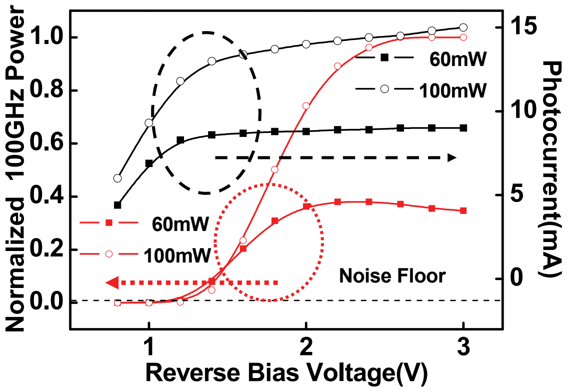

Figure 3. The transfer curve of normalized MMW power with corresponded photocurrent vs. reverse DC bias

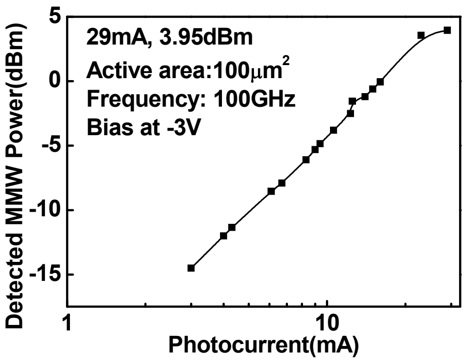

Figure 4. The maximum coupling power into WR-10 waveguide versus photocurrent for an operating frequency fixed at 100GHz under bias voltages of -3V.

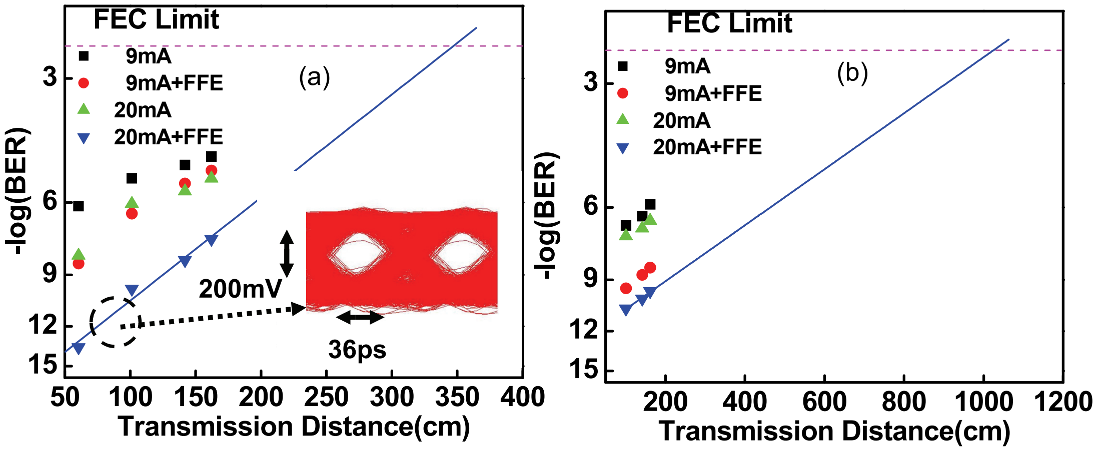

Figure 5. –log(Bit Error Rate) vs. transmission distance with and without FFE under different photocurrents (9mA and 20mA) during 12.5-Gb/s (a) and 8-Gb/s (b) OOK data transmission. Measured 12.5Gbit/sec eye-pattern under 20mA photocurrent at 60cm is also specified in (a)

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