A W-Band Photonic Transmitter-Mixer Based on High-Power Near-Ballistic Uni-Traveling-Carrier Photodiode (NBUTC-PD) for 1.25-Gb/s BPSK Data Transmission under Bias Modulation

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Abstract: We demonstrate W-band photonic transmitters-mixers, which are composed of near-ballistic-uni-traveling-carrier-photodiodes and quasi-Yagi antennas without integrating Si-lens. By utilizing it, data-transmission at W-band can be achieved under bias modulation of 1.25-Gb/s BPSK with 5GHz IF signals.

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

I. Introduction

The millimeter wave (MMW) band above 60GHz (V-band) or 100GHz (W-band) has begun to receive greater attention as the carrier frequency for the realization of system with high transmission data rates in excess of gigabits-per-second. Recently, the research group at NTT has reported excellent results for a 10Gb/s wireless link at 120GHz achieved by using a uni-traveling-carrier photodiode (UTC-PD) based photonic transmitter [1,2]. A costly optical modulator, to let the electrical 10Gb/s data signal be carried by the optical wave, is a necessary component in this kind of system [1]. The bias modulation of the UTC-PD is another way to modulate the output millimeter wave which eliminates the necessity of an optical modulator [3]. However, to use such a technique, it is necessary to swing the bias of the UTC-PD to a forward bias and its speed and power performance will thus be seriously degraded [3]. Furthermore, it is usually necessary with such a photonic transmitter to integrate an additional Si-lens to overcome the substrate-mode problem [2] of the antenna. In our previous work [4], we have demonstrated a photonic transmitter/mixer that operates in W-band, which is consisted of a high-speed and high-power near-ballistic uni-traveling-carrier photodiode (NBUTC-PD) [5] and a planar quasi-Yagi antenna [6] on an aluminum-nitride (AlN) substrate, which is insensitive to the aforementioned substrate modes and thus do not call for an additional Si-lens integration. By utilizing the strong bias dependent nonlinearity of speed under a reverse bias regime, our transmitter can also serve as a photonic mixer [7], generating high-power up-converted millimeter wave signal and eliminating the problem of forward bias modulation of UTC-PD based mixer [3]. In this current work, we further improved the radiated (detected) power performance of such transmitter by improving the structure and directivity (gain) of our quasi-Yagi antenna. Furthermore, we also demonstrated wireless data transmission at W-band (100GHz) by use of our novel device under direct bias modulation of 1.25Gb/s binary phase shift keying (BPSK) data signal with 5GHz intermediate-frequency (IF) signal.

II. Device Structure

Figure 1 shows the top view of the demonstrated device. The device consists of a diced NBUTC-PD chip with a 100μm^2 active area, which exhibits a 100GHz optical-to-electrical (OE) bandwidth under a 25Ω load resistance with a 0.15A/W responsivity [5] and a quasi-Yagi planar antenna chip. The whole module was formed on an AlN substrate, giving it good thermal conductivity for high-power operation. Details of the structure of the epi-layer and the fabrication process can be referred to in our previous work [5]. The antenna chip comprises a quasi-Yagi antenna [6], a fan-shaped broadband transition between the co-planar waveguide (CPW) and the slot-line, an impedance matching circuit; a flip-chip bonded active NBUTC-PD, an IF signal input port, a W-band RF choke, and bond pads for the DC bias. The detail functionality of each part in antenna chip can be referred to our previous work [4]. The planar quasi-Yagi antenna is of end-fire and directional radiation patterns, which have much more immune to the influence of substrate-mode, compared with other types of planar antenna [6]. Indeed, the additional Si-lens integration technique employed in [2] can thus be avoided. As compared to our previous work [4], we have increased the number of directors and modified the geometric size of our antenna to greatly increase its directivity and bandwidth. The simulated gain and directivity of the quasi-Yagi antenna at around center operating frequency (100GHz) is 9.4 and 9.8dB, respectively. During measurement, the optical LO signal is generated by the heterodyne-beating technique with the central optical wavelength fixed around 1550nm. The modulated optical signal, which runs through the erbium-doped-fiber-amplifier (EDFA) and a tunable optical attenuator (Att), is then

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focused on the microlens [5] on the backside of the diced NBUTC-PD by a lensed fiber. The LO signal with the up-converted RF signals are all radiated to free-space through the quasi-Yagi antenna and detected by the standard horn antenna at the W-band with a 24dB gain, connected to a W-band mixer (Agilent 11970W) and a spectrum analyzer (Agilent E444BA).

III.Measurement Result:

The radiation pattern at the E-plane of the photonic transmitter was first measured without feeding in the IF signal. The measurement and simulation results are shown in Figure 2 (a). The simulation was performed using the full-wave electromagnetic simulator, Ansoft High-Frequency Structure Simulator (HFSS). As can be seen, the measured and simulated patterns are in excellent agreement and the beamwidth of measured far-field pattern is narrower than that reported value ($\pm 25^0$ vs. $\pm 30^0$) in our previous work [4] due to the improvement in our antenna design. By narrowing the beamwidth, a higher detected power can be expected. Figure 2 (b) shows the simulated S_{11} of the quasi-Yagi antenna without considering the integrated active device and the measured frequency response of the detected power of our transmitter as the LO frequency sweeps from 75GHz to 110GHz. During this experiment, we left the IF input port connected with a W-band 50Ω termination by use of a probe to increase the speed of NBUTC-PD and improve the output power [4]. The frequency response of measured power is marked by the open circles. We can clearly see that a significant resonance of radiated power exists at around 100GHz, which is consistent with the S_{11} of the quasi-Yagi antenna. Figure 3 shows the detected up-converted RF power vs. the injected electrical IF power under a fixed optical LO power (21dBm), which corresponds to around 18mA output photocurrent, and optimum bias point (-1.5V) for mixer operation. The 1-dB compression points of the up-converted RF power (-32dBm) and injected IF power (7.5dBm) have both been specified on this Figure. Except for the up-converted RF power, the maximum radiated LO power under high reverse bias (over -2.5V) is also an important factor for evaluating the performance of a photonic transmitter. Figure 4 shows the detected MMW power of the device with a $64\mu m^2$ active area under optical signal injection with a 100% modulation depth as a function of photocurrent under bias voltages of -3V and -5V. In order to generate the maximum radiated power, the operating frequency is fixed at 100GHz, which is the resonant peak in the radiated power spectrum, as shown in Figure 2(b). As indicated on the plot, the maximum detected power is -14dBm when the photocurrent is around 30mA. Such detected power is higher than that reported in our previous work [4] (-17dBm vs. -14dBm) due to the narrowing of far-field pattern and the decrease of coupling loss between radiated power and horn antenna. Figure 5 shows our system setup for the BPSK data transmission. As compared to the traditional On-Off Keying (OOK) data transmission [1] by use of photonic transmitter, the BPSK technique has a higher signal to noise (S/N) ratio and potential to further increase the total capacity of transmitted data [8]. In order to realize the free-space data transmission, we have also developed a high-performance W-band optical photonic source [9]. Such source can deliver a stable and clean optical signal with a modulated frequency up to 100GHz and is much less noisy than that of two-laser heterodyne-beating system, which was used in the characterization of our device. During our experiment, we mix the 1.25Gbit/sec BPSK signal, which has a pseudo random bit sequence (PRBS) of 2^{31}-1 and around 1V peak-to-peak (V_{pp}) voltage, with an analog intermediate frequency (IF) signal at 5GHz by use of an electronic mixer. The mixed signal is then fed into the IF input port of our photonic emitter/mixer, which was illuminated by the optical LO signal from our photonic source with a 100GHz modulated frequency, to modulate the bias point of device. The 1.25Gbit/sec PRBS signal is thus up-converted to 105GHz (LO: 100GHz. IF: 5GHz) and then radiated to the receiving end. Compared with the reported technique of direct up-conversion of baseband data to W-band [1], by mixing the additional IF signal with data, the total capacity of transmitted data has potential to be further increased by using the technique of phase shift keying [8]. In the receiver end, it was composed of a 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) to detect the envelope of transmitted signal. The detected IF signal and PRBS signal from power detector is boosted by an IF amplifier with a center frequency at 5GHz and then fed into a high-speed real-time scope to perform the off-line signal processing [8]. Figure 6 shows the output photocurrent of transmitter or received MMW power versus the error vector magnitude (EVM) of transmitted data. The inset shows the re-constructed BPSK eye-pattern with clear eye-opening at 1.25Gbit/sec under 15mA photocurrent. As can be seen, when the received MMW power is up to -42dBm and the output photocurrent is up to 10mA, the measured EVM can be less than around 30%. According to the measured frequency response of our system (channel), a higher transmitted data rate (>1.25Gb/s) should be expected by increasing the speed of our W-band power detector for envelop detection.

IV.Summary:

In conclusion, we have demonstrated a NBUTC-PD based W-band photonic transmitter/mixer. The relatively high-directional pattern of an integrated quasi-Yagi antenna and strong reverse bias dependent nonlinearity of the active NBUTC-PD are utilized to eliminate the need for an additional Si-lens and costly high-speed optical modulator, respectively. By use of such novel device, 1.25Gbit/sec BPSK wireless data transmission at 100GHz has been successfully demonstrated.

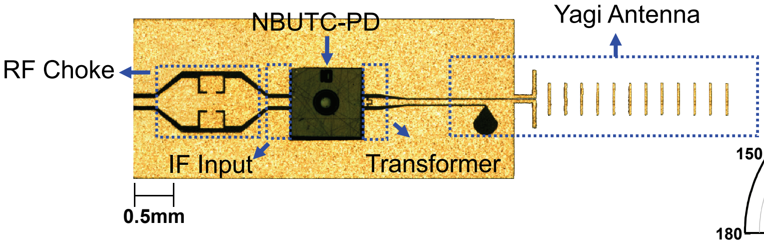

Figure 1. The top-view of demonstrated device

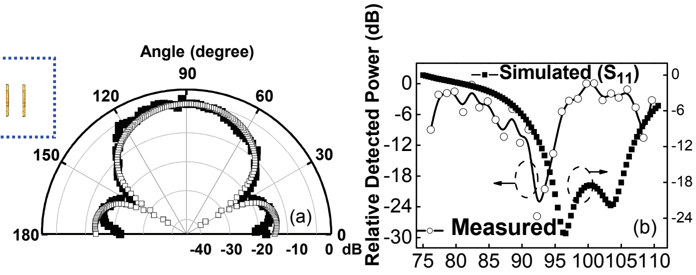

Figure 2. (a) The measured (close squares) and simulated (open squares) radiation patterns for the demonstrated device at the E-plane. (b) The simulated S_{11} parameter (close squares) and the detected power (open circles) spectrum.

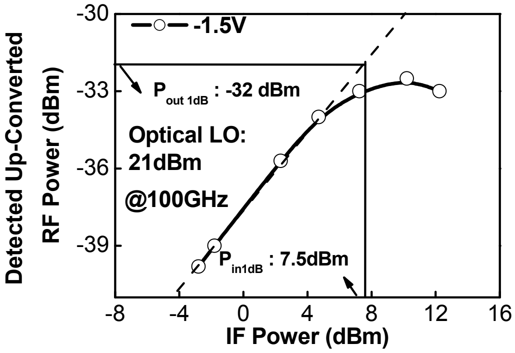

Figure 3. The up-converted RF power versus IF power under -1.5V and 21dBm optical LO power injection.

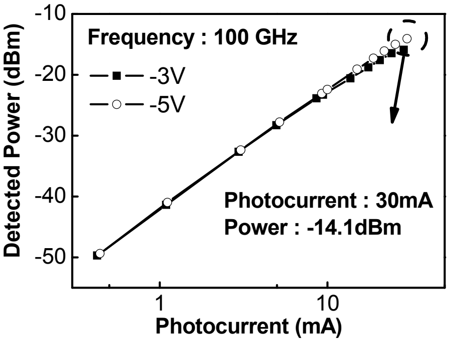

Figure 4. The maximum detected power versus photocurrent for an operating frequency fixed at 100GHz under bias voltages of -3V and -5V

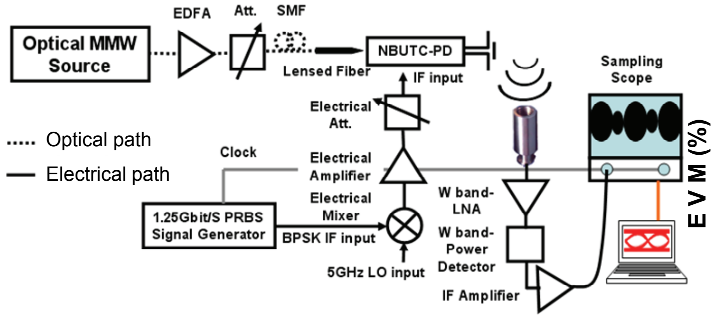

Figure 5. The system setup for BPSK data transmission.

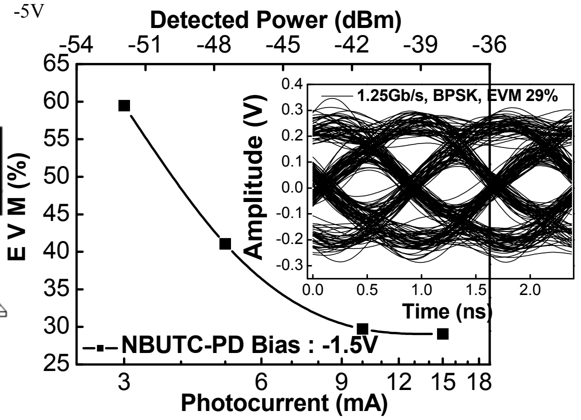

Figure 5. The measured EVM vs. received MMW power and output photocurrent. The inset shows the re-constructed BPSK eye-pattern at 1.25Gbit/sec.

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