100 Gbit/s THz Data Transmission and Beyond using Multicore Fiber Combined with UTC Photodiode Array

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Abstract: Photonics-driven transmitters are leading the race towards high data-rates at THz frequencies. Here, spatial-multiplexing based on multicore fiber and photodiodes array is considered to alleviate the limited output power. Sub-systems have been developed and validated.

1. Introduction

In a recent report, CISCO forecasts that global IP traffic by 2022 will be about 4.8 ZettaOctets [1]. In order to handle this tremendous increase of data exchange, different solutions are envisioned among which the use of the THz band in wireless networks. THz frequencies range from 100 GHz to 10 THz, paving the way to Tbit/s wireless links that will meet the requirements of applications such as holograms, vehicle-to-vehicle communications and virtual reality [2]. The "300 GHz band", corresponding to 250-320 GHz frequency band that is regulated by IEEE 802.15.3d standard has recently boosted the THz communications research. Most of THz receivers are electronic-based devices (Schottky barrier diodes, sub harmonic mixer) whereas, at the transmitter side, both an electronic approach (mixers, SiGe transistors, …) and a photonics-based one (photomixers, quantum cascade lasers…) are being investigated [3]. Generating THz signals via the photomixing technique presents many advantages such as a linearity of the signals over a wide bandwidth and the possibility to perform easily multi-carrier transmission by increasing the number of lasers. Usually, THz signal results from the beating of two lightwaves f_1 and f_2 in an UTC-PD (UniTravelling Carrier PhotoDiode) or a PIN photodiode resulting in a carrier frequency, $f_{THz} = |f_1 - f_2|$. The dynamics of UTC-PD is solely governed by the velocity of electrons and offer a larger bandwidth with higher saturation current compared to PIN photodiodes [4]. In any case, one of the key parameters for any wireless link is the transmitted power. Unfortunately, the photonics-based approach suffers from output power limitations that limits the reach of the wireless links. Hence, there is a need to develop new approaches in order to increase the power of the THz carrier.

In this paper, an innovative approach based on the use of an UTC-PD array excited by a multicore fiber is proposed to tackle the power issue and enable long distance THz transmissions. Such an approach makes it possible to increase the generated THz power by N, N being the number of UTC-PDs in the array and the number of optical channels that can be multiplexed over the same number of SSMF (Standard Single-Mode Fiber). In order to achieve this goal, some of the elementary components of the future multipath system have been developed and characterized. The electrical performances of a single UTC-PD operating in the 290-350 GHz range are presented and on-wafer data transmission up to 100 Gbits/s data rates are reported together with BER measurement at different bit rates. A multicore fiber adapted to the multipath THz approach is also presented and the cross-talk performances of this fiber equipped with fan-in fan-out devices are also reported.

2. Test of a single UTC-PD at 320 GHz

The InP/InGaAs UTC-PD under test is a 4x4 µm^2 device with a square shape mesa. After the alignment marks definition, the photodiode mesa etch concerns part of the epitaxy between the p and n contact layers. Two wet chemical selective etching solutions are used for InGaAs and InP. The mesa is protected by a SiO_2 hard mask during the wet etching. Same configuration process, SiO_2 and wet etching, is used for the mesa dedicated to isolate the devices up the substrate. The ohmic contacts, N and P, are done by using a e-beam bilayer resist and a lift-off process. The top electrode (P) consists of 300 nm Au and the bottom contact (N) consists of Pd/Ti/Pt/Au, both realized by e-beam evaporation. Coplanar waveguide (CPW) accesses are connected to the photodiode by air-bridges. A tri-layer resist scheme using selective resist development is used to define jointly the air-bridge and accesses in order to connect photodiode to coplanar lines. Ti/Au (100-600nm) metallization is deposited and finally a lift-off process is used to realize the air bridge and coplanar

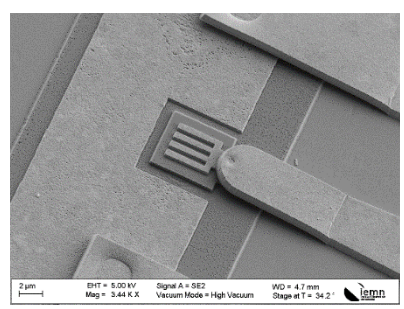
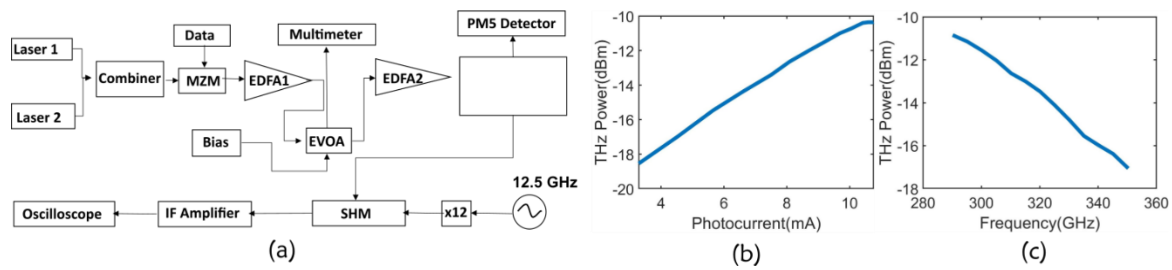


Fig 1. Top of view of the complete device with the top electrode square configuration.

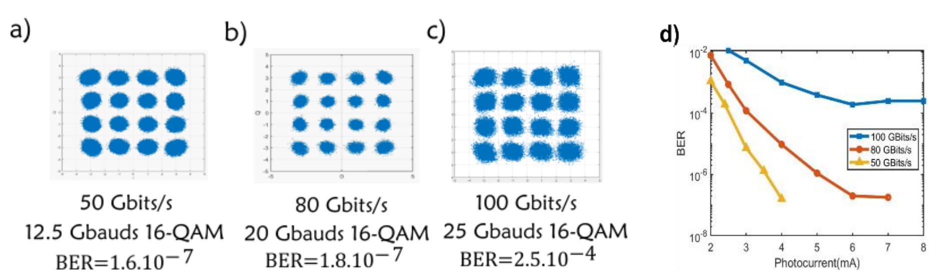
accesses. SEM view of the devices (Fig 1). The complete block diagram of the experimental setup used to characterize the UTC-PD is given in Fig. 2(a). Two Tunable Laser Sources (TLS) are combined and modulated using an I/Q modulator. Then, two Erbium-Doped Fiber Amplifiers (EDFA) with an EVOA (Electronic Variable Optical Attenuator) in between enable to control optical power prior to injection in an on-wafer UTC-PD coupled to a 300 GHz band CPW (CoPlanar Waveguide) probe. First, the setup enables to monitor the 300 GHz power level with respect to the photocurrent and the UTC-PD frequency response. In this case, the waveguide probe output is directly feeding a waveguide power-meter (PM5 Virginia Diodes). Then, for the communications measurements, the signal that is generated from the UTC-PD is processed at the receiver end by integrating an 8-10 dB conversion losses Sub-Harmonic Mixer (SHM) pumped by a multiplication chain and a 30 dB amplifier. The modulated THz signal is down-converted into an Intermediate Frequency (IF) of 20 GHz. The IF signal is driving a real-time oscilloscope and offline processing is applied to display I/Q mapping and compute both Bit Error Rate (BER) and Error Vector Magnitude (EVM). The measurements are performed in back-to-back configuration (the probe output is directly connected to the 300 GHz band receiver). For the electrical characterization, a reverse bias voltage of 1 V is applied as optimal value for the UTC-PD operation, this value being chosen for a linear operation of the UTC-PD over the power-range used, as shown by the figure 2.

Fig.2. (a) Block diagram of the experimental setup. (b) THz power versus photocurrent at 320 GHz and -1 V bias. (c) UTC-PD's frequency response between 290 and 350 GHz at 8 mA and -1 V bias.



As illustrated in Fig. 2(b) for a THz frequency of 320 GHz, the THz power is linearly dependent on the photocurrent, confirming that UTC-PD has a square-law operation, i.e. output THz power is proportional to i^2. The saturation occurs at I=10.4 mA (-1 V bias, 24.6 mW optical power) and results in a maximum THz power of -10.3 dBm. This saturation is attributed to space charge effect in the UTC-PD. Fig. 2(c) shows the frequency response of the UTC-PD measured by sweeping the carrier frequency from 290 GHz to 350 GHz with 5 GHz step with an 8 mA photocurrent and -1 V bias. As expected, the power decreases when the frequency is increased like a low-pass filter response. This observed frequency dependence may cause linear distortions in the I/Q signal which can be corrected by linear equalization. When the optical power is about 82.2 mW, the photocurrent is about 7.1 mA which leads to an UTC-PD sensitivity about 0.086 A/W, close to the already-reported UTC-PD sensitivity about 0.1 A/W [5]. Constellations and BER curves have been measured for up to 100 Gbits/s data rate. Fig. 3(a-c) presents the constellations at 50, 80 and 100 Gbits/s for 16 QAM modulation format. Fig. 3(d) shows the BER curve with respect to the photocurrent for each data rate. The results are promising as they are below FEC threshold ($\sim 4.10^{-3}$).

Fig. 3. (a), (b) and (c) Constellations obtained at 320 GHz for a photocurrent of 4, 7 and 8 mA respectively. (d) BER curves obtained at 50, 80 and 100 Gbits/s.



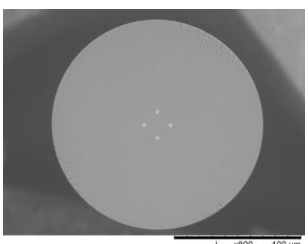
As expected, for a given photocurrent, the higher the data rate, the higher the BER. Moreover, as is also expected, the BER decreases when the photocurrent is increased. However, for photocurrent larger than 6 mA, the BER no longer improves due to the saturation of SHM. The fact that the BER curves recorded at different data rates do not have the same slope is due to the bandwidth limitations of SHM.

3. Towards THz power increase: the transmitter array approach

While the single UTC-PD enables to get clear 100 Gbit/s I/Q modulations, a multi-carrier signal can be used to reach beyond 100 Gbit/s data rate links or increase the wireless link range by combining the power of several devices. A possible way to get around this issue is to transpose, in the THz band, the power combining of different spatial paths; a well-known approach in other wireless systems [6]. This could be done, for example, by shinning an array of several UTC-PD. In order to efficiently address the different array UTC-PD, it is proposed here to use a multicore fiber (MCF). Two fibers with cores organized in a square mesh have been manufactured for this purpose. The pitch is about 15 µm and 20 µm, respectively for fiber A and fiber B. Fig. 4(a) shows a cross-section image of fiber A measured by a Scanning Electron Microscopy (SEM). The fibers were obtained from a single preform made by MCVD (Modified Chemical Vapor Deposition) and drawn into canes that have been used for stack and draw, as is commonly done to manufacture Photonics Crystal Fibers (PCF) [7]. For both fibers, each core of the fiber is single-mode at 1550 nm with a mode field diameter close to 4 µm at this wavelength. MCF were equipped with fan-in/fan-out fiber devices, spliced to the MCF, so as to selectively address each core using an SSMF. Such a device also permits to address the THz with optical signals coming from conventional fiber network. Power coupling between the different cores has been investigated by recording cross-talk (XT) matrices. Characterization was performed using a filtered ASE (Amplified Spontaneous Emission) source (wavelength 1550±1 nm) successively directed, via an optical switch, to the different SSMF input ports of the fan-in device and a powermeter that successively addresses the output port of the fan-out. The fibers were conditioned with a bending radius of 6.5 cm The results are reported in Fig. 4(b) and show that the 20 µm pitch fiber presents lower XT than the 15 µm pitch one. It can be noticed that the lowest coupling rates correspond to those between diagonal cores. The average insertion losses are about -2.1 dB and -1.1 dB for fibers A and B respectively.

Fig. 4 (a) SEM image of fiber A. (b) Table of inter-core coupling (extra diagonal elements) and insertion loss (diagonal elements) of fibers A and B equipped with fan-in/fan-out (values in dB)

(a)



(b)

Input / Output	Fibre A				Fibre B			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
1	-2,5	-10,3	-6,1	-17,6	-0,9	-60,3	-47,0	-72,3
2	-14,7	-1,8	-16,9	-8,8	-62,3	-1,1	-69,6	-29,5
3	-12,9	-17,8	-1,9	-7,7	-47,5	-67,4	-0.8	-35,5
4	-22,5	-11,1	-9,6	-2,1	-74,9	-31,9	-43,7	-1,4

The next step is the fabrication and characterization of the UTC-PD array for which these MCF have been designed. This original approach enables to increase the THz emission power four times compared to the state-of-the-art and is expected to demonstrate free space THz transmissions with increased reach.

4. Conclusion

We have reported the performances of a single UTC-PD operating at 320 GHz for up to 100 Gbits/s data rates with acceptable BERs. The maximum output power is about -10.3 dBm. Combining a set of 4 UTC-PD, up to 400 Gbit/s photonics-based transmitters could be realized for the 300 GHz band. It is planned to implement a UTC-PD array as an innovative approach in order to increase the THz transmitted power and overall, all data-rate of the THz link. Moreover, such an approach could be a beam steering enabler combining arrays and suitable antenna structures.

5. References

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