Optically Pumped Mixing in Photonically Integrated Uni-Travelling Carrier Photodiode

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***Abstract*—We report the first demonstration of optically pumped mixing using a monolithically integrated photonic chip. On that chip, uni-traveling carrier photodiodes (UTC-PDs) were monolithically integrated with two lasers to generate the optical heterodyne that will drive the optically pumped mixing. The two DFB lasers wavelength spacing was tuneable from 70.5 GHz to 92.4 GHz. When an RF signal at 70 GHz was supplied to the UTC-PD with the optimum voltage bias, the UTC-PD successfully down-converted the RF signal to an intermediate frequency (IF) that was tuneable from 0.5 GHz to 16.4 GHz. These results demonstrate the potential of this photonic integrated circuit in spectroscopy, sensing and as millimeter wave wireless receivers.**

I. INTRODUCTION

THE characteristics of the millimeter waves (MMWs) have attracted the interest of many fields. For instance, the short wavelength of the MMWs increases distance resolution in radar systems. Also, the abundance of spectrum in the MMW range (30 GHz - 300 GHz) allows for high speed communications, while the high propagation loss makes it more secure. Moreover, MMWs have found interesting applications in imaging, sensing, and medicine [1].

Previously, optically pumped mixing (OPM) has been demonstrated at 100 GHz using a single non-integrated uni-traveling carrier photodiode (UTC-PD) [2, 3].

In this paper, we report OPM using a UTC-PD that is monolithically integrated with two lasers and semiconductor optical amplifiers (SOAs). The lasers generated optical tones with tuneable spacing between 70.5 GHz and 92.4 GHz. When an RF signal at 70 GHz was supplied to the UTC-PD with the optimized voltage bias for mixing, the UTC-PD down-converted the RF signal to an intermediate frequency (IF) that was tuneable from 0.5 GHz to 16.4 GHz.

II. DEVICE DESCRIPTION

As shown in Fig. 1, the monolithically integrated chip used in this work [4] incorporates two UTC-PDs, two distributed feedback (DFB) lasers to provide the optical heterodyne, several SOAs to amplify the optical signals, multimode interference (MMI) couplers and electro-absorption modulators (EAMs). Moreover, this chip has an optical monitoring output.

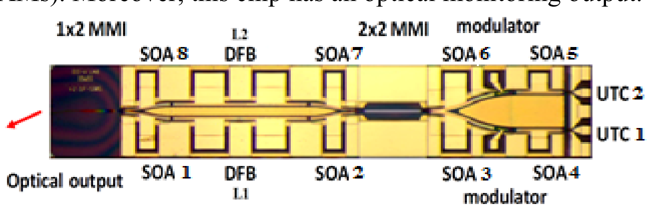

Fig. 1. Picture of the photonic integrated circuit.

III. HETERODYNING EXPERIMENT

In order to assess the performance of the PIC as an optical heterodyne MMW generator, we conducted a heterodyning experiment (Fig. 2), by which the lasers and SOAs were biased using a multi-contact DC probe, and the generated electrical heterodyne signal (ΔF) was extracted using a coplanar probe from UTC 1, which is shown in Fig. 1. Consequently, SOA5 and SOA6 were disconnected as they are in the optical path of UTC 2. Also, SOA1 and SOA8, which are used to amplify the optical signal for monitoring purposes, were disconnected to minimize reflections. The total current supplied to the other SOAs was fixed at 467 mA. A bias Tee was used to apply the voltage bias to the UTC-PD, which was fixed at -2 V.

By monitoring the optical output of the photonic integrated circuit (PIC) we observed that the DFB lasers' threshold currents were 40 mA for L1 and 54 mA for L2. The lasers bias currents were gradually increased (up to 113 mA for L1 and 100 mA for L2) causing their operating wavelengths spacing to change. The wavelength tuning was observed by monitoring both the optical spectra and the generated electrical heterodyne. Wide tuneability from 70.5 GHz to 92.4 GHz was achieved, as shown in Fig. 3. The electrical spectra of the generated electrical heterodyne signals were measured, as shown in Fig. 4, using an electrical spectrum analyzer (ESA) which has a 75 GHz to 110 GHz mixer at its input.

Further, photocurrent variation between 6.5 mA and 7.2 mA was observed. This is due to the large variation in the lasers bias currents, as shown in Fig. 3, which caused the power of the optical signal at the input of the photodiode to vary.

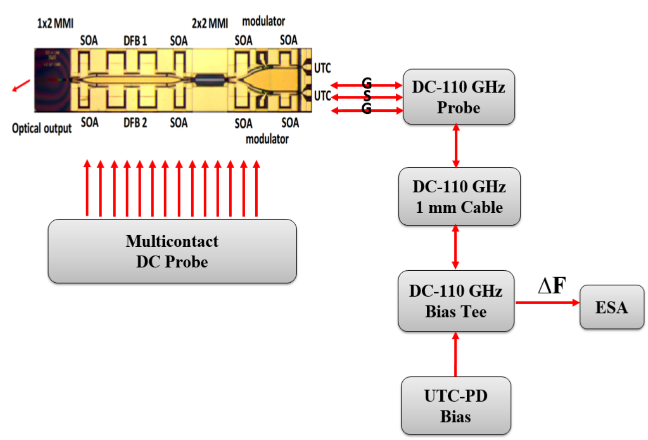

Fig. 2. Optical heterodyning experiment.

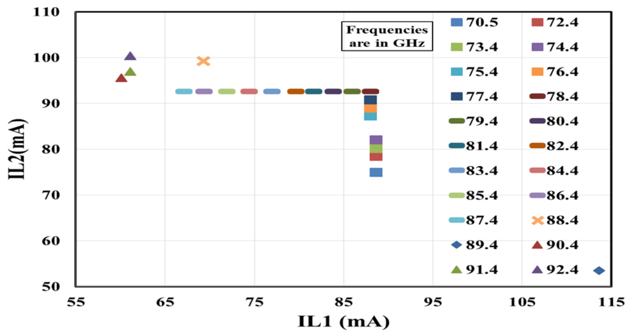

Fig. 3. Wide tuneability of the electrical heterodyne.

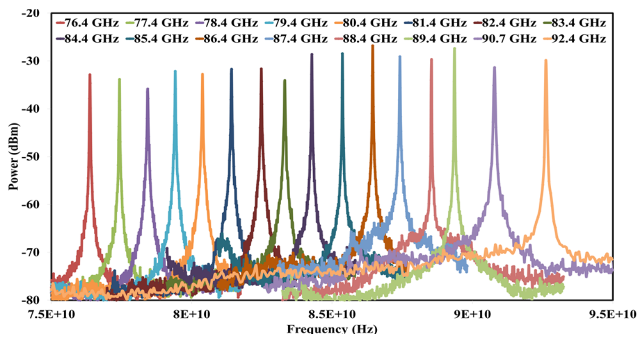

Fig. 4. Spectra of the electrical heterodyne (RBW = 300 kHz).

IV. Optically Pumped Mixing Experiment

The block diagram of our OPM experiment is shown in Fig. 5. In OPM, the UTC-PD is injected with two optical tones to generate the electrical heterodyne signal at ΔF. When an RF signal is supplied to the UTC-PD with a voltage bias, the UTC-PD generates a replica of the RF signal at IF. The power of the generated IF is maximized as the optimum voltage is supplied.

The received RF signal was generated by a signal synthesizer at 70 GHz, coupled, using a bias Tee, with a UTC-PD voltage bias that is optimum for mixing, and sent to the UTC-PD via a coplanar probe. The optimum biasing voltage was found by sweeping the applied voltage bias while monitoring the power of the IF signal. The optimum voltage bias varied between -1 V and -1.4 V across the IF range, while the photocurrent varied between 3.2 mA and 4.5 mA. These variations are attributed to the change in the optical signal power at the UTC-PD input as the lasers bias currents were tuned. A power splitter was used to allow for the simultaneous supply of the RF to the UTC-PD and the extraction of IF from the UTC-PD. After considering the typical losses of the components in the RF path, the RF signal received at the UTC-PD was estimated at -7 dBm.

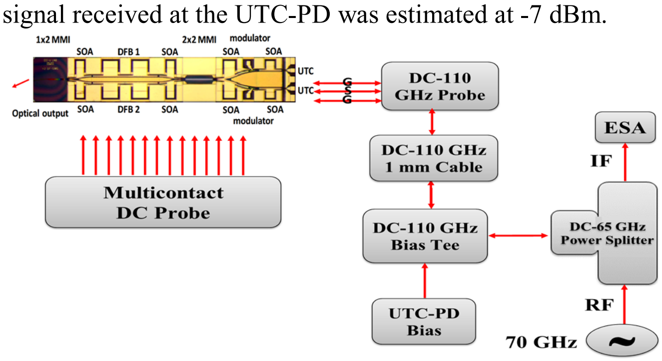

Fig. 5. Block diagram of the optically pumped mixing experiment.

V. OPM Experiment Results

Fig. 6 shows the electrical spectra after down-conversion in the range from 0.5 GHz to 16.4 GHz, while Fig. 7 shows the conversion loss (CL) performance across the IF range. Here, CL is defined as the ratio between the estimated power of the incoming RF signal to the UTC-PD, and the generated IF signal power, at a UTC-PD bias voltage that is optimum for mixing. Fig. 7 shows a flat CL across the IF range except at 0.5 GHz due to impedance mismatching at this frequency [2]. The CL values presented here are higher than the values reported in [2,3] because the UTC-PDs on this PIC are optimized for MMW emission rather than mixing. Results around 10 GHz are not shown due to lasers relaxation oscillation at this frequency, which interfered with the down-converted IF.

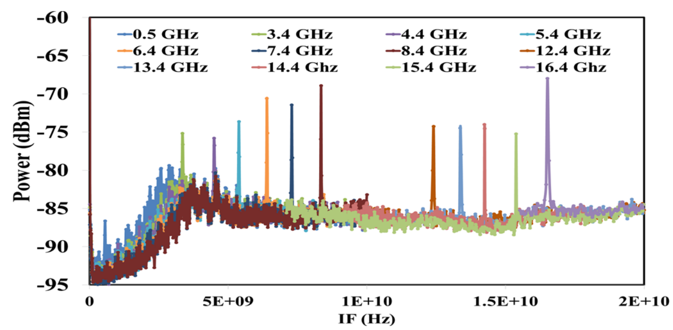

Fig. 6. Wide tuneability of IF (RBW = 1 MHz).

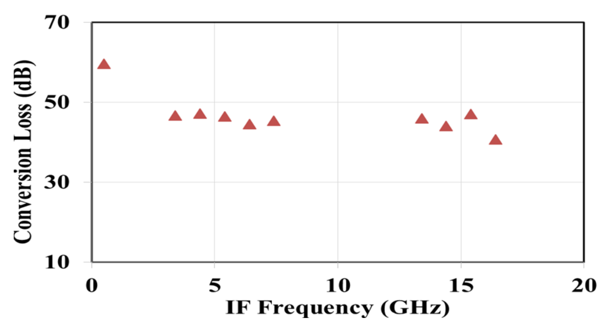

Fig. 7. Conversion loss across IF range.

VI. Conclusion

We demonstrated optically pumped mixing on a PIC, with a relatively flat conversion loss across a wide frequency range from 3.5 GHz to 16.4 GHz. Considering that a similar PIC was used as MMW emitter [4] and the potential bandwidth for down-conversion, such a PIC would offer a compact MMW transceiver for a range of applications.

References

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