

# Hybrid Polymer THz Receiver PIC with Waveguide Integrated Photoconductive Antenna: Concept and 1<sup>st</sup> Characterization Results

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**Abstract:** An all-photonic THz-receiver PIC comprising an on-chip frequency stabilization scheme and a novel InP-based photoconductive antenna is presented. Characterization of the key photonic building blocks shows the functionality of the PIC. © 2022 The Authors

## 1. Introduction

The photonic generation of mm-wave (mmW) and THz frequency signals is deemed to be key in 5G and beyond wireless communications due to the high bitrates that can be achieved with photonic components [1]. This concept was first demonstrated in optical fiber-based systems [2], and more recently, using Photonic Integrated Circuits (PICs) [3]. However, photonic mmW/THz receivers reported till now are based on vertical illumination [4], which hinders its co-integration with other photonic building blocks on a PIC level such as the optical sources and the optical phase correlation and frequency stabilization schemes. In this paper, we demonstrate for the first time an all-photonic THz receiver PIC with a novel waveguide-based InP photoconductive antenna (PCA). On this PIC, a tunable laser followed by two cascaded phase modulators generates an optical frequency comb (OFC), which is used as the master signal for phase-locking and frequency-stabilization of two other tunable lasers by means of injection locking. These two stabilized laser signals mix at the PCA enabling the photonic detection of an incoming wireless signal. This device is based on HHI's PolyBoard hybrid photonic integration platform which allows combining functionalities of this technology such as tunable lasers [5], thermo-optically adjustable couplers [6] and optical isolators [7], together with InP modulators and the novel waveguide-based PCA. This hybrid approach enables using the adequate material for each function in order to maximize the performance of the whole PIC. The characterization results of the key building blocks after the hybrid assembly proves the functionality of the PIC.

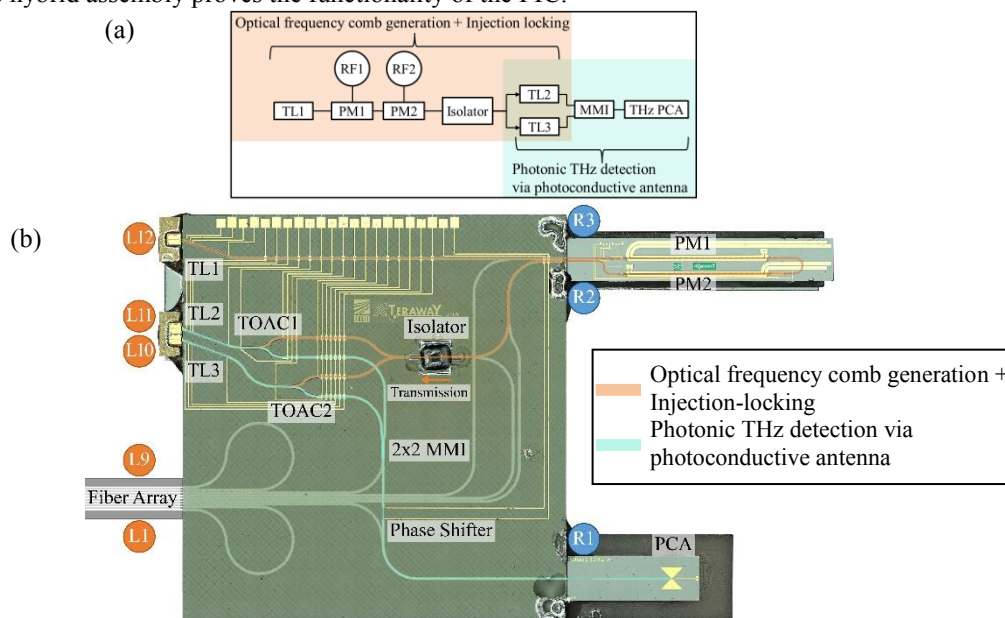


Fig. 1. (a) Functional schematic of the THz receiver PIC. (b) Picture of the hybrid PIC. TL: tunable laser; PM: phase modulator; TOAC: thermo-optically adjustable combiner; PCA: waveguide-based photoconductive antenna.

## 2. THz detection scheme and PIC architecture

The functional schematic of the photonic mmW/THz detection architecture considered in this work is shown in Fig. 1 (a). The first section comprises a tunable laser (TL), labelled as TL1, followed by two cascaded phase modulators (PM), labelled as PM1 and PM2, allowing for the generation of an optical frequency comb (OFC). The OFC is injected into two tunable lasers (TL2 and TL3), which are set to have a frequency difference equal to the mmW/THz frequency to be detected. An optical isolator placed before TL2 and TL3 avoids that light from the two lasers goes back towards the OFC generation section. The injected OFC allows correlating the optical signals of TL2 and TL3, hence enhance the frequency stability and reduce the phase noise in the photonic THz detection. Both phase correlated and frequency stabilized signals are combined and fed to a waveguide-based PCA for the THz photonic detection. The implementation of the THz detection scheme on a polymer-based hybrid PIC is shown in Fig. 1 (b). The polymer-based components featuring three hybrid InP/Polymer tunable Distributed Bragg Reflector (DBR) lasers [5] as TL1, TL2 and TL3, an optical isolator based on on-chip micro-optical elements [7], and two thermo-optically adjustable couplers (TOACs) [6]. Two InP PICs, one comprising the phase modulators PM1 and PM2 for the OFC generation and the second one implementing the waveguide-based PCA, are butt-coupled to the polymer PIC. The waveguide integrated PCA consists of a photoconductor with an iron-doped InGaAs absorber. A top-view schematic of the device is shown in Fig. 2 (a). The InGaAs absorber is grown on top of an InP based waveguide stack. This way the light is coupled into the edge of the chip and then guided to the PCA where it evanescently couples into the photoconductor as shown in Fig. 2 (b).

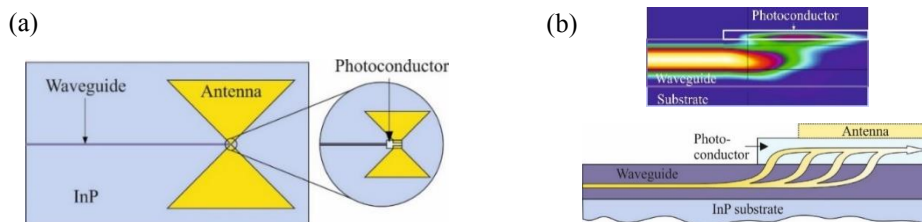


Fig. 2. (a) Schematic of the novel waveguide integrated photoconductive antenna PIC. (b) FIMMWARE simulation and illustration of the waveguide integration and evanescent coupling to the photoconductor.

Following the light path depicted in Fig. 1. (b), the first Tunable Laser (TL1) generates the optical carrier which is modulated by the two cascaded phase modulators (PM1, PM2) and forms the OFC signal at port R2. The comb goes through the on-chip integrated isolator and two TOACs which are used to control the injection ratio from the OFC signal towards TL2 and TL3. These two phase-locked and frequency-stabilized laser signals (TL2 and TL3) are combined by the 2x2 MMI and mixed at the waveguide based PCA. It is used as the photonic local oscillator for the THz receiver.

## 3. Characterization of the key PIC building blocks

To monitor the performance of the OFC generation section, the performance of the tunable laser TL1 and the optical isolator have been characterized. The measurement of the optical isolator has been done before the coupling of the InP gain chips for the DBR lasers and of the PM chip. The results are shown in Fig. 3 (a), where it can be seen that the IL for the TE polarized light in the forward direction have been measured to be 15.9 dB and 18.1 dB. The high IL values measured are due to non-optical coupling towards the fibers used for characterization, the losses of Y-branch, the undriven TOAC, the propagation losses, and the losses of the isolator. The dips in the curves at around 1550 nm correspond to the gratings for TL2 and TL3. The difference are due to the losses of the two branches after the isolator. In the backward direction, the isolator efficiently blocks the light propagation with an isolation of  $> 32$  dB for TE polarization across the C-band. The tuned spectra of the laser used for the generation of the OFC (TL1) has been characterized using ports L12 to L4, and the results are shown in Fig. 3 (b). Note that the power is normalized due to the non-driven InP-PM and additional tap-coupler in the characterization path which introduce additional losses. As it can be seen, the laser provides 18.8 nm tuning range in the target wavelength region, proving that butt-coupling of the PolyBoard and InP-PM chip has worked and that the OFC generation section is functional.

For the characterization of the THz detection section, the power from TL2 and TL3 that reaches the waveguide-based PCA was measured after the 2x2 MMI. The P-I curves for TL2 and TL3 measured at port L7 are shown in Fig. 3 (c). Maximum power of 1.2 mW and 0.45 mW for TL2 and TL3 are measured. The difference has been deemed to be caused by different performance of the Bragg gratings that comprise TL2 and TL3. From a loss-breakdown analysis, it was calculated that the lasers deliver around 10 mW output power. Improving the thermal management of the gain sections will allow increasing that value.

Finally, the photocurrent generated at the PCA by the optical signals arriving from the tunable lasers for photonic THz detection was characterized. Applying a current in the active section of 50 mA in TL2, the result in Fig. 3 (d) shows around 10  $\mu\text{A}$  photocurrent difference is achieved. Activating the laser TL3 a similar behavior is observed, proving that the THz detection section is functional. Since it's the first iteration of the waveguide-based PCA, improvement of the PCA as well as the alignment process will be investigated to increase the current levels generated at the photomixer.

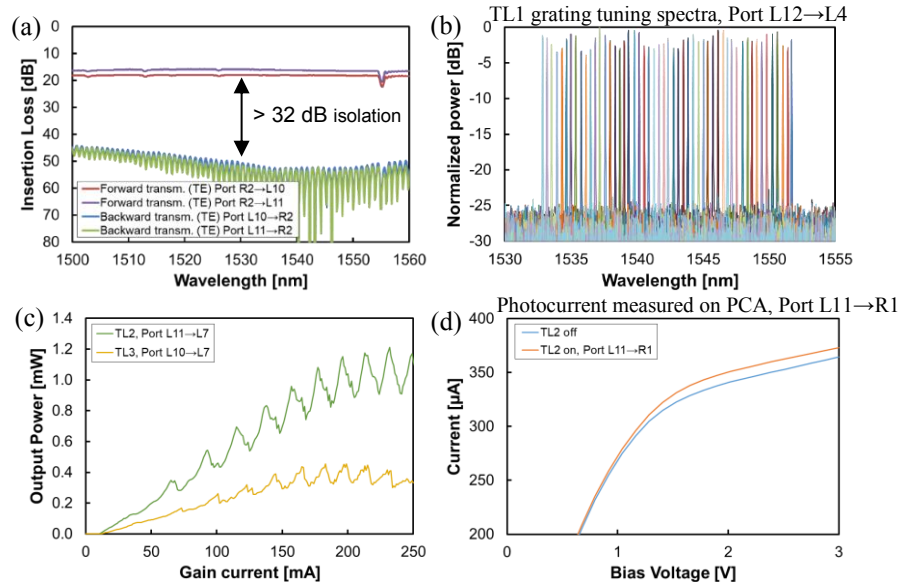


Fig. 3. (a) Passive characterization of the on-chip isolator before coupling of gain chips (for TE polarized signal). (b) Grating tuning spectra of tunable laser for the OFC generation section. (c) P-I curves of the tunable lasers for the THz detection section. (d) Measured photocurrent on In-PCA by switching on TL2

#### 4. Conclusion

We demonstrate for the first time, a THz receiver PIC with a novel waveguide integrated photoconductive antenna and an on-chip frequency stabilization scheme. The PIC implements an optical frequency comb generation section for phase-locking and frequency-stabilization, and an injection-locked THz detection section. Characterization of the key building blocks of both sections prove the functionality of the hybrid PIC and show its potential for the detection of wireless signals. The on chip loss and can be further improved by means of improving the individual components and hybrid assembly processes. In a next step, the on-chip injection locking and the detection of wireless signals experiments will be tested.

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