

# The heterogeneous future of integrated Millimeter- and Terahertz-wave photonics

(Invited paper)

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## ABSTRACT

High frequency generation using photonic techniques combines the best of two worlds, photonics with RF electronics. Photonic integration technology has been shown effective in order to reduce size and cost of this approach. More recently, heterogeneous integration is bringing the advantage of choosing the integration substrate material to optimize the performance of each components for the function that performs, instead of having to compromise the epitaxial structure of different components with different function.

**Keywords:** microwave photonics, THz signal generation, photonic integration

## 1. INTRODUCTION

Photonic techniques are leading the access to the millimetre (MMW) and Terahertz (THz) frequency bands of the electromagnetic spectrum, ranging from 30 GHz to 300 GHz and from 300 GHz to 3 THz respectively. Compared with electronics techniques, photonics offers a range of advantages, benefiting from the low loss of optical fibers to transport these frequencies over long distances and the extremely wide modulation bandwidth of photonic components. These are key requirements for beyond 5G wireless communications, which need access to broad bandwidth regions to meet the ever-increasing demand for higher data rates, available only at carrier wave frequencies above 275 GHz [1]. It has been recognized that integration and packaging technologies are among the future issues for MM-wave and THz-wave systems [2].

Among the different photonic schemes to continuous wave (CW) signal generation of frequencies within the Terahertz range, the most advantageous in terms of frequency tuning range is optical heterodyning. This scheme uses a dual wavelength source, emitting at two wavelengths  $\lambda_1$  and  $\lambda_2$ , which are mixed on a photodiode or photoconductor to generate an electrical beat note with frequency given by the difference among the two wavelengths,  $f_{\text{beat}} = c/|\lambda_1 - \lambda_2|$ . There have been different solutions being proposed to achieve a dual wavelength source, the simplest being combining the output of two single wavelength tunable lasers as shown in *Figure 1*. To date, the widest frequency tuning range was provided by complex and costly external-cavity diode lasers. A simpler approach uses thermal wavelength tuning of distributed feedback (DFB) lasers, which through the combination of multiple DFBs, a tuning range of 2750 GHz was achieved without gaps [3].

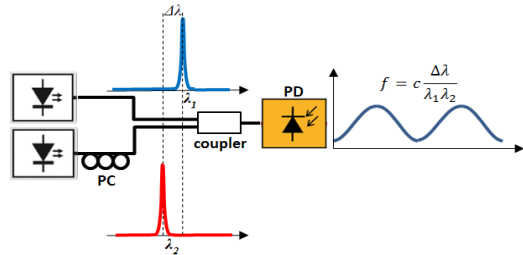


Figure 1. Photonic components required for the optical heterodyne signal generation scheme.

## 2. PHOTONIC-BASED INTEGRATED TERAHERTZ SIGNAL GENERATION

It is the common sense of photonic integration to use it whenever the number of components starts to increase, to keep size and cost at bay. Not being so numerous the number of components required for the optical

heterodyne signal generation technique, it turns that using photonic integration techniques produces significant improvements in the quality of the generated signal. The reason is that when fiber-based components are used (including optical fibers to interconnect them), the phase noise fluctuations in the generated signal are affected from changes in the optical path length difference between the lasers and the coupler due to temperature fluctuations or other external effects, such as vibrations [4]. In photonic signal generation applications, even moderate integration efforts have an impact on the quality of the signal. This is probably the main driver for the photonic integration efforts of photonic-based millimetre- and Terahertz wave signal generation, as placing all the critical components on the same chip will make them experience the same environmental fluctuations [5]. Additionally, photonic integration makes the optical heterodyne system more compact, which is advantageous to improve efficiency of delay sensitive feedback loops of noise reduction schemes.

We have already approach the integration of a photonic-based millimetre-wave transmitter module using Indium Phosphide (InP) monolithic integration. All the required components are grown on the same chip, including two DFB lasers, an optical wavelength combiner (a multimode-interference coupler), an electro-absorption modulator (EAM) for data, as well as various semiconductor optical amplifiers (SOA) to boost the optical signal through the chip, leading to a high-speed photodiode for wireless transmission [6]. We must highlight that this photonic chip enables to package a photonic-based signal generation system packaged in a module with electrical accesses only. Avoiding the need to assemble fiber optic accesses allows to decrease the packaging costs. In addition to the DC ports, the package includes an SMA connector for the input data signal towards the EAM and a WR-10 (75 GHz – 110 GHz) rectangular waveguide output to radiate the modulated millimetre-wave carrier wave signal. The advantage of placing all the components in the same substrate comes at the expense of making performance compromises to the components on the chip.

### 3. HETEROGENEOUS INTEGRATION PLATFORMS

To avoid the compromises among the different components, heterogeneous integration techniques must be employed. These enable using the principle of the ‘best substrate for the function’, which becomes advantageous when combining photonics with RF electronics. Recently, a similar chip to the monolithic integrated photonic-based millimetre-wave transmitter demonstrated on InP in [6] was demonstrated using a heterogeneously integrated silicon/InP integration technology [7]. This heterogeneous integration platform shows waveguide photodiodes with 65 GHz 3-dB bandwidth and 42 nm wavelength tuning range lasers with lower than 150 kHz optical linewidth (one order of magnitude smaller than the DFB lasers). Recently, high speed uni-traveling carrier photodiode (UTC-PD) structures have been demonstrated on silicon using InP-based photonic membrane heterogeneous integration on silicon, with 3-dB bandwidth beyond 67 GHz with responsivity of 0.7 A/W [8].

A novel heterogeneous integration platform that we have demonstrated for photonic-based signal generation is the PolyBoard InP/Polymer heterogeneous photonic integration platform, developed by HHI’s Hybrid PICs Group [9]. This platform offers hybrid InP/Polymer DBR tunable lasers comprising a 400  $\mu\text{m}$  long InP gain element, and polymer thermo-optically tunable 200  $\mu\text{m}$  long phase and 1000  $\mu\text{m}$  long Bragg reflector sections as shown in *Figure 2(a)*. Frequency tuning (wavelength shifting) can be achieved through current injection in the gain, or heating the phase and DBR sections. The widest tuning range, in excess of 34.6 nm ( $\sim 4.3$  THz), is achieved with the DBR grating tuning as shown in *Figure 2(b)*. *Figure 3(a)* shows the tuning achieved through the gain and phase section, with different tuning sensitivity. It is worth to mention that the tuning steps are in the MHz range for the gain and in the GHz range for the phase. The beat note when the phase current section is varied from 16 mA down to 10 mA with a current step of 1 mA. Under this variation, the beat note frequency changed from 322 GHz to 337 GHz. It can be observed on *Figure 3(b)* that the wavelength step is not linear with the electrical current, as the tuning depends on thermal effects which are proportional to the electric power.

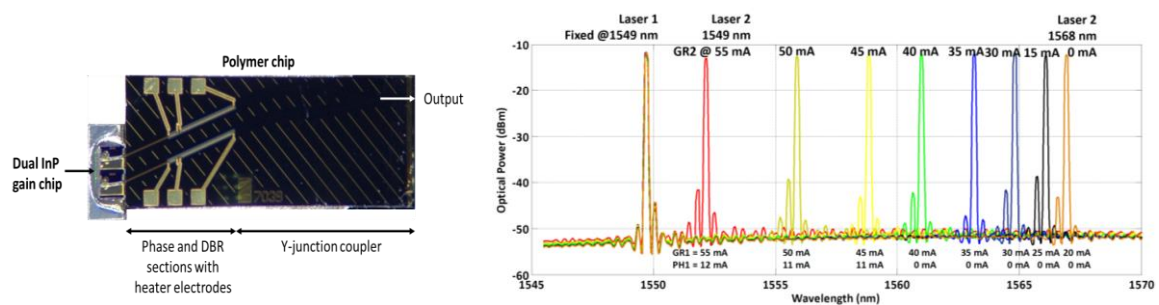


Figure 2. (a) Microscope photograph of the InP/Polymer chip, and (b) Wavelength tuning one InP polymer DBR laser varying the current injected into the DBR grating heater.

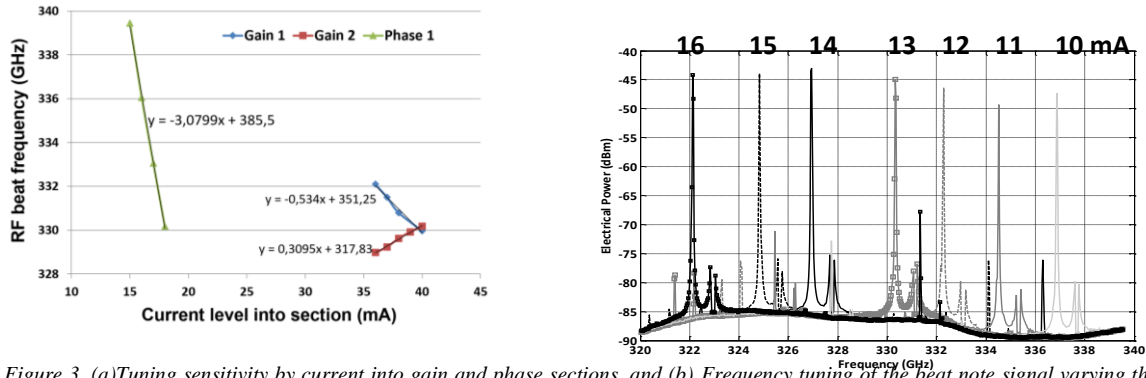


Figure 3. (a) Tuning sensitivity by current into gain and phase sections, and (b) Frequency tuning of the beat note signal varying the phase section heater current at 1 mA current steps, from 16 mA (322 GHz) down to 10 mA (337 GHz).

#### 4. CONCLUSIONS

We present the potential of heterogeneous photonic integration technology for photonic-based signal generation, specially an InP/Polymer heterogeneous platform.

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