Radio Frequency Generation using Transfer-Printed Uni-traveling Carrier Photodiode for Microwave Photonics Applications

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***Abstract*—We report RF signal generation up to 50 GHz by beating two lasers on an in-house fabricated transfer-printed uni-traveling carrier photodiode. A 10 dB improvement in the RF signal at 40 GHz is observed with -2V bias compared to zero-bias condition of the photodiode.**

I. Introduction

Microwave photonics (MWP) [1] merges photonics and microwave engineering to harness the benefits of optical systems for processing and transmitting microwave and millimeter-wave signals. By leveraging the high bandwidth, low loss, and immunity to electromagnetic interference offered by optical fibers, MWP significantly improves the performance of microwave systems. Optical techniques in MWP facilitate wideband signal generation, low-phase-noise signal distribution, and precise time and frequency control, which are crucial for advanced communication [2] and radar systems [3].

MWP has garnered significant attention due to its potential to revolutionize high-frequency communication systems. A critical technique in this field is the generation of radio frequency (RF) signals through heterodyne processes, which involves mixing two optical signals with slightly different frequencies to produce a beat frequency in the RF domain [4]. This method leverages the high precision and low phase noise of optical sources, offering substantial improvements over traditional electronic RF generation techniques. The heterodyne approach is particularly advantageous for applications requiring wide bandwidth, high-frequency stability, and low phase noise, such as radar systems, wireless communication, and signal processing.

Uni-traveling carrier photodiodes (UTC-PDs) have emerged as a pivotal technology in MWP due to their superior performance in high-speed and high-frequency applications [5]. Unlike traditional photodiodes, UTC-PDs use only electrons as the active carriers, significantly enhancing bandwidth and reducing transit time. This results in high saturation current, wide bandwidth, and low distortion, making them ideal for generating and detecting microwave and millimeter-wave signals. In MWP, UTC-PDs are essential for high-speed optical communication links, millimeter-wave signal generation, and advanced radar systems, meeting the demands for higher data rates and broader bandwidths.

Transfer printing technology has become a significant enabler in advancing MWP systems, providing a versatile and efficient method for integrating heterogeneous materials and devices onto a single platform [6]. This technique involves the precise transfer of pre-fabricated micro and nano-scale components from their original substrates to desired locations on target substrates using an intermediate elastomeric stamp. In MWP, transfer printing allows for seamless integration of high-performance photonic and electronic components onto various substrates, including flexible and unconventional ones. This capability enhances the performance and functionality of MWP systems and reduces manufacturing complexity and costs, driving the development of compact, high-performance, and cost-effective microwave photonics solutions.

In this paper, we show RF signal generation through heterodyne beating of two lasers on a transfer printed UTC-PD which is grown and fabricated in-house.

II. UTC-PD structure

The expitaxial structure of the UTC-PD grown on a InP wafer is shown in Fig. 1. The structure was simulated in Silvaco and the parameters including doping concentration and layer thicknesses were optimized. The photodiode has an active area of 25 μm^2. A top oxide encapsulation is used as

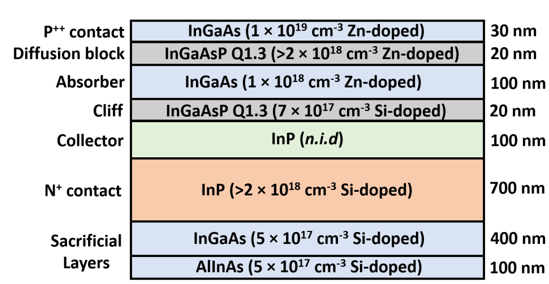

Fig. 1. Epitaxial structure of the UTC-PD

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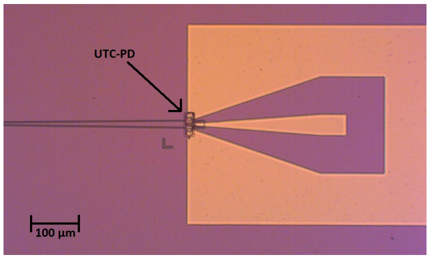
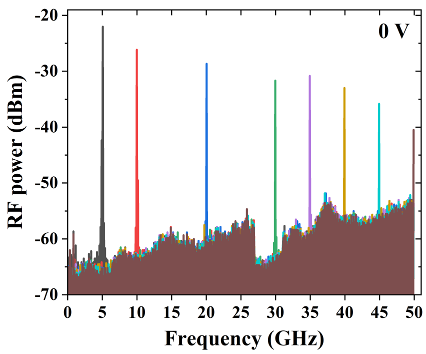
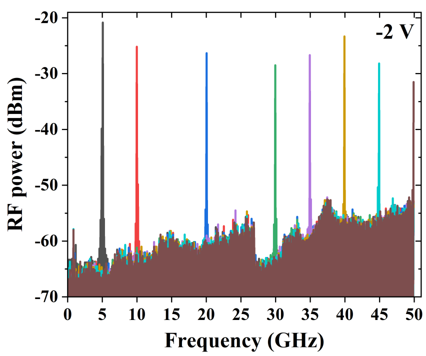


Fig. 2. Microscope image of the transfer printed UTC-PD.



(a)



(b)

Fig. 3. Measured RF signal from the UTC-PD under (a) zero-bias and (b) -2V bias.

tether structure to hold the UTC-PD while the InGaAs and AlInAs sacrificial layers are etched away to enable pick up of the device for transfer print.

A fiber-to-fiber grating coupler was defined on a 220 nm silicon-on-insulator (SOI) wafer using electron beam lithography. The UTC-PD was printed on one of the grating couplers. Silicon dioxide was used as the top cladding. Vias were created to open the UTC-PD contacts. Gold was deposited to form the coplanar waveguide (CPW) ground-signal-ground (GSG) electrodes. The GSG pads were designed in Ansys HFSS to have 50 Ω impedance to match with the GSG probe. Fig. 2 shows the microscope image of the transfer printed UTC-PD with the GSG pads.

III. Results and Discussions

A heterodyne measurement is done for the RF signal generation using two lasers that are not phase locked. A 1552.5 nm fixed laser and a tunable laser source were used with +12 dBm optical power. The two lasers were coupled though a fiber followed by a erbium-doped fiber amplifier and a polarizer. The optical loss for the fiber grating coupler along with the polarizer is estimated to be greater than 10 dB. The grating coupler is designed for $\sim$30% light coupling to a single mode fiber at 10°. A GSG probe with 125 μm pitch is used to collect the generated RF signal. A bias-tee is used to reverse bias the UTC-PD. The RF signal is measured using Agilent 8565EC spectrum analyzer with 50 GHz measurement range. A fixed 21 dB RF amplifier is used to amplify the generated RF signal before measurement.

The measured RF signals at different beat frequencies are shown in Fig. 3(a) and 3(b) under zero-bias condition and 2 V reverse bias of the UTC-PD, respectively. The measured RF power includes losses from GSG probe, coaxial cables, and the bias-tee. The bandwidth is limited by the measurement setup. The generated RF power spans 18.5 dBm over 50 GHz frequency range under zero-bias condition of the UTC-PD. With -2V bias, a 10 dB improvement in the RF power at 40 GHz and 9 dB improvement at 50 GHz is observed. Consequently, the RF power spans 10.7 dBm over 50 GHz frequency range at -2 V bias. Further improvement in the signal intensity and quality is possible by phase locking the lasers, maximizing the waveguide-to-PD optical coupling, and designing the CPW electrode to have inductive peaking at higher frequencies.

IV. Conclusion

We present the experimental results of RF signal generation up to 50 GHz, limited by the range of the measurement system, through heterodyne beating of two laser sources on a transfer-printed uni-traveling carrier photodiode. A variation of 18.5 dBm of the generated RF power in the 50 GHz frequency span is seen with zero-bias of the UTC-PD which improves to 10.7 dBm with 2V reverse bias. The study shows the feasibility of microwave signal generation for millimeter-wave microwave photonics applications using transfer-printing to realize compact heterogeneous solutions.

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