High-speed Terahertz PIN Photodiode with WR-3 Rectangular Waveguide Output

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***Abstract*—In this paper we present a photonics-based terahertz source working in the J-band (220 – 325 GH). A high-speed InGaAs/InGaAsP PIN photodiode is integrated in a rectangular waveguide WR-3 package for photonic to terahertz conversion. An output power of 36.3 μW is achieved. To the best of our knowledge, this is the first WR-3-integrated emitter based on a PIN photodiode.**

I. INTRODUCTION

PHOTONIC techniques are of particular interest for terahertz (THz) wave generation in future wireless communication networks because of their enormous bandwidth and their broad tunability [1]. Until today, the uni-travelling carrier photodiode (UTC-PD), which is available in a quasi-optical (lens-mounted) and in a rectangular waveguide package, has been preferred as photomixer for sub-mmWave and THz generation [2 – 4]. However, we recently demonstrated that the PIN photodiode (PIN-PD) provides comparable performance in terms of emitted power and bandwidth [5].

In this work, we present, to the best of our knowledge, the first THz emitter, which uses a high power PIN-PD in a WR-3 waveguide package for operation in the J-band (220–325 GHz). The module provides a peak radiated power of -14.4 dBm.

II. WR-3 PIN PHOTODIODE MODULE

Fig. 1 shows the picture of our optical fibre coupled WR-3 emitter module. The diode chip has an active area of 5 × 7 μm^2 with a 50 Ω coplanar waveguide (CPW) output. The coupler circuit, shown in the bottom insets, is a grounded CPW to WR-3 transition that converts the QTEM mode into the dominant mode of the waveguide (TE10). The conversion is achieved by a $\lambda_g/4$-long monopole that radiates vertically into the waveguide, with λ_g being the guided wavelength in the substrate. A 4 mm long waveguide section leads to the output of the module, which has a standard UG-387/U waveguide flange. The coupler circuit is fabricated on a 130 μm-thick low-loss substrate Rogers/Duroid 5880 with an input impedance of 61 Ω. The coupler circuit also includes an RF choke filter for DC biasing the diode. Two 25 μm-wide wire bonds connect the PIN-PD with the coupler circuit (see bottom insets of Fig. 1). The overall dimensions of the module are 50 ×43 × 15 mm^3 and the responsivity is 0.3 A/W.

The emitter module is characterised in an optical heterodyne setup. The radiated THz power is measured with a calibrated pyroelectric detector (SLT THz20HS). Fig. 2 shows the power spectrum for a photocurrent (I_{ph}) of 8 mA (red) and 12 mA (blue), with a bias voltage of -1.2 V and an optical input power of 26 mW and 40 mW, respectively. A peak emitted power of -14.4 dBm (36.3 μW) is obtained at around 200 GHz, which is comparable to the power emitted by a lens-coupled quasi-optic

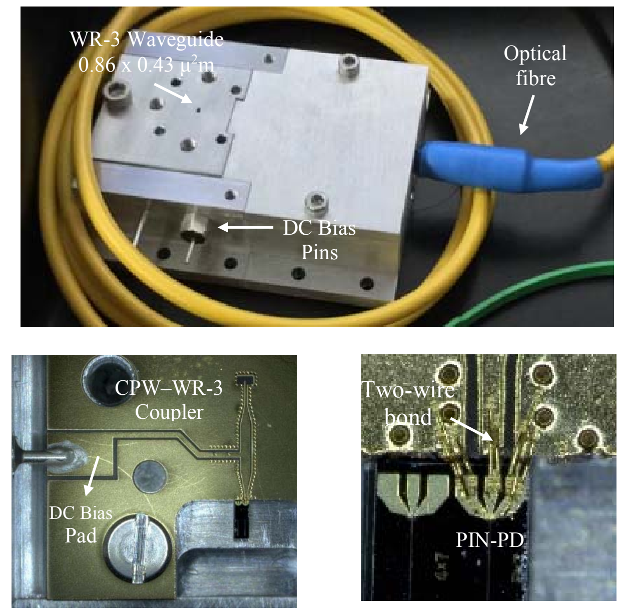

Fig. 1. Top: Photograph of the packaged WR-3 PIN-PD emitter module in a PM fibre-pigtailed custom housing. Bottom: The internal structure of the device showing PIN-PD chip coupled to the CPW-to-WR-3 coupler using two-wire bond interconnection.

PIN-PD emitter module [5]. Fig. 2 shows a continuous decrease of the radiated power for frequencies greater than 210 GHz, which is mainly attributed to the strong loss originating from the 400 μm-long bond wires. However, relatively stable output with less than 3dB variation is obtained from 175 GHz to 215 and 260 GHz to 290 GHz. The noticeable power drop around

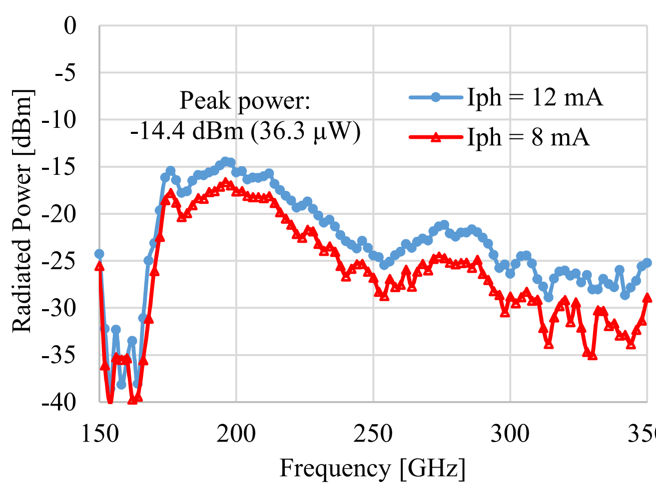

Fig 2. Radiated THz power as a function of frequency for the PIN-PD emitter integrated into a WR3 package. The red (blue) line corresponds to a photocurrent of 8 mA (12 mA) for an optical input power of 26 mA (40 W). The bias voltage was -1.2 V in both cases.

250 GHz stems from the cut-off frequency of the choke filter. We expect a considerable increase in the radiated THz power by replacing the bond wires with more advanced integration techniques such as ribbon bond or flip-chip bonding.

III. Conclusion

We demonstrated a terahertz photonic signal source with WR-3 rectangular waveguide output using a PIN-PD, working in the J-band frequency range. The packaged device provides an unsaturated peak radiated power of -14.4 dBm around 200 GHz. As most of the RF losses in the module emerge from wire bond interconnection, an improvement in output power as well as frequency response is expected by achieving advanced integration.

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References

[1]. T. Nagatsuma, G. Ducournau, and C. Renaud, “Advances in terahertz communications accelerated by photonics,” Nature Photonics, vol. 10, pp. 371–379, 2016.

[2]. H. Ito, et al., “Widely Frequency Tunable Terahertz-Wave Emitter Integrating UniTraveling-Carrier Photodiode and Extended Bowtie Antenna,” Applied Physics Express, Vol. 6, p. 064101, 2013.

[3]. H. Ito, et al., "Photonic millimetre- and sub-millimetrewave generation using J-band rectangular waveguide-output uni-travelling-carrier photodiode module," in Electronics Letters, vol. 42, no. 24, pp. 1424-1425, 23 November 2006.

[4]. T. Kurokawa, T. Ishibashi, M. Shimizu, K. Kato and T. Nagatsuma, "Over 300 GHz bandwidth UTC-PD module with 600 GHz band rectangular-waveguide output," in Electronics Letters, vol. 54, no. 11, pp. 705-706, 31 5 2018.

[5]. S. Nellen et al., “Experimental Comparison of UTC- and PIN-Photodiodes for Continuous-Wave Terahertz Generation,” J. Infrared, Millimeter, Terahertz Waves, 2019.