High Output Power at 110 GHz with a Waveguide Uni-Travelling Carrier photodiode

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***Abstract*- We present a waveguide uni-travelling carrier photodetector with a bandwidth greater than 110 GHz and record breaking power of 10 dBm extracted at 110 GHz.**

I. INTRODUCTION

Applications such as mm-wave over fibre communication, high data rate optical networking, security imaging (THz) and radio-astronomy are in need of photodetectors able to detect signals modulated at frequencies above 40 GHz with good linearity and high output power, in order to achieve high dynamic range and high signal to noise ratio.

So far, two main types of high speed detectors have emerged. The first uses a technique to match the optical velocity and the electrical velocity in a waveguide structure [1]. Such a travelling wave structure could offer a 3dB bandwidth well above 100 GHz [2]. The advantage of such a structure is that the power is distributed along the waveguide thus allowing for better power handling [4]. The second type of photodetector is using an electron-only transfer structure, as the electron transfer is faster than that for holes. In Uni-Travelling Carrier structures (UTC) the electrons act as the only active carriers and determine the photoresponse. These UTC structures (UTC) allowed a 3dB bandwidth of 310 GHz with 0.07 A/W responsivity [3]. Another advantage of the UTC structure is that the space charge effect is significantly reduced, since the carriers in the intrinsic region are moving electrons only. The UTC structure has also been used in a waveguide design offering up to 0.7 A/W responsivity with a 40 GHz 3dB bandwidth [4]. However none of these detectors offers high responsivity and high bandwidth at the same time. However it is clear that an optimised waveguide UTC structure should enable high bandwidth/high frequency and high saturated output power in excess of that obtainable for conventional *pin*-diodes.

This paper presents a novel waveguide UTC achieving a 3 dB bandwidth higher than 110 GHz, up to 36 mA photocurrent and a record breaking 10 dBm extracted power at 110 GHz. The fact that the device output power was not saturated with the maximum optical input of 100 mW shows that even higher power could be extracted from this device.

II. EXPERIMENT DESCRIPTION

The device was designed to have a 3 dB bandwidth above 110 GHz, thus the size (length and width) of the waveguide detector region, and the thickness of the intrinsic region were such that the capacitance of the device was sufficiently low to reach that target. Furthermore the intrinsic region was made sufficiently thin that the electron transit time was not the limiting factor for the frequency response if a high enough electrical field was applied. Fig. 1 shows a scanning electron microscope (SEM) image of the device. The active waveguide was 4 µm wide and 20 µm long. The device was tested using two coplanar probes (Ground-Signal-Ground) with 150 µm spacing. One was used to test the device from DC to 65 GHz and the other from 70GHz to 110 GHz. The device optical excitation was generated by an optical heterodyne system [5] which offered a tuneable single frequency (<1Hz linewidth) signal with 100% modulation depth from 10 GHz to 110 GHz in steps of 10 GHz. For frequencies below 10 GHz the optical signal was a directly modulated laser.

The optical signal was amplified up to 100 mW in order to assess how much power could be extracted from the device. Power was coupled to the device using a lensed fibre. Note that the device temperature was controlled during the experiment and stabilised at 20º C, and for optimal results the device was biased at -2V.

In order to measure the electrical signal extracted from the device, a calibrated spectrum analyser with internal mixers was used from 0.01 GHz to 50 GHz and from 70 GHz to 110 GHz a set of calibrated external harmonic mixers were used with the spectrum analyser.

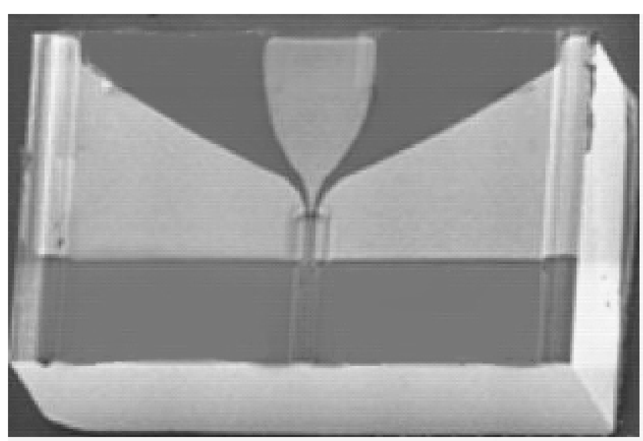

Fig. 1: SEM picture of the waveguide UTC device

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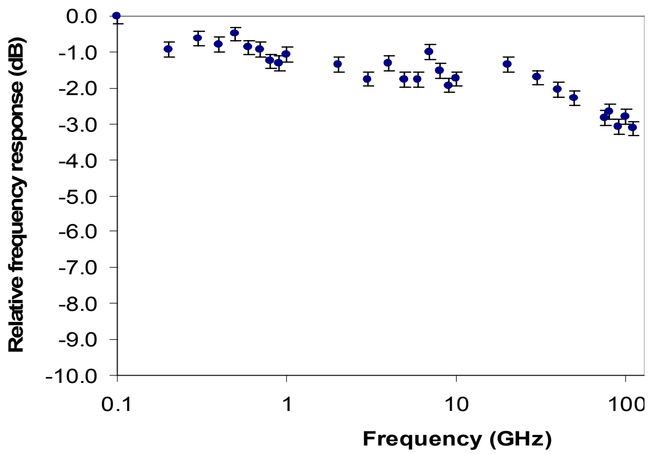

Fig. 2: Relative frequency response of the waveguide UTC photodiode

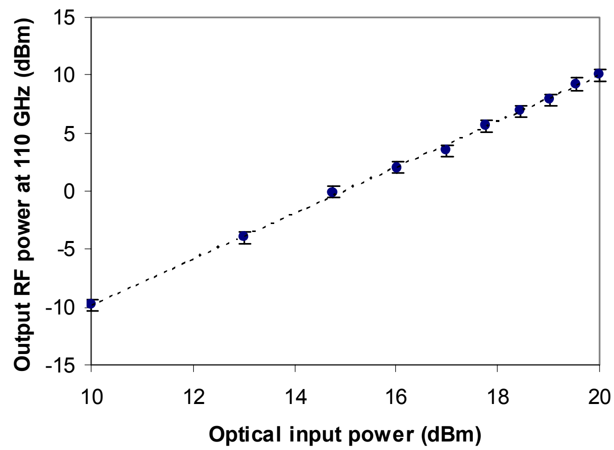

Fig. 3: Extracted power as a function of optical input power

III. Results and Discussion

First the device responsivity was measured using an ammeter in series with the bias source, with a continuous wave optical input from 0 to 100 mW. The result for the best device was 0.36 A/W, and a maximum current of 36 mA for the 100 mW optical input and no saturation was observed. Considering that simulation showed that coupling to the waveguide from the lensed fibre to the semiconductor waveguide was of the order of 45%, this gives an internal responsivity (current generated to light coupled) of 0.8 A/W.

Next the device was excited with 30 mW of optical power to measure the frequency response up to 110 GHz. Note that for the measurement a correction for the power losses in connections and cables was made. Fig. 2, shows the relative frequency response of the device form 0 to 110 GHz. Note that to correlate the low frequency measurements with the measurements above 10 GHz, we simply normalised both measurements to the value found at 10 GHz. One can see on Fig. 2, that the relative frequency response remained better than -3 dB up to 110 GHz, thus the 3 dB bandwidth of the device could be expected to be at a higher frequency.

Finally the power extracted at 110 GHz was measured for an optical input power up to 100 mW. The actual measurement of the peak power of the resulting heterodyne signal was corrected for the losses in the cable, connections and probe. Fig. 3 shows the dependence of the extracted power on the optical input power. The device did not show any sign of saturation with up to 100 mW optical input power, and a record breaking 10 dBm was extracted at that frequency. The same measurement was made at 50 GHz again with no visible saturation and a maximum extracted power of 11 dBm.

IV. Conclusion

We have demonstrated an UTC waveguide photodetector with a 3dB bandwidth higher than 110 GHz. Up to 36 mA of photocurrent was observed in the detector with no saturation. At 110 GHz the achieved extracted power was a record breaking 10 dBm, and as with the continuous wave excitation no saturation was observed. These results demonstrate the capability of this detector to be used to produce high power at high frequencies.

Future work will include the introduction of a mode converter in order to increase the coupling ratio from fibre to detector, thus increasing the responsivity of the detector, and integration of the detector with antennas in order to use it as an emitter for frequencies above 60 GHz.

Acknowledgement

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