High Speed Photodetectors

Cyril. C. Renaud, J. Seddon, C. Graham, X. Lin, A. J. Seeds
University College London, Department of Electronic and Electrical Engineering, WC1 7JE London, UK
c.renaud@ucl.ac.uk

Abstract: High speed photodetectors are important for a number of applications. This work is about accurate design of uni-travelling carrier photodetectors. In particular, integrated devices with antenna for operating frequencies above 100 GHz.

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1. **Introduction**

Photonic generation of CW microwave signals is underpinned by the development of high-speed photodetector technology. The key figures of merit for high speed photodiodes are wide-bandwidth, high output power, and optical responsivity[1], [2]. Uni-Travelling Carrier photodiodes (UTC-PD) are high speed, high output power photodiodes developed to overcome the bandwidth limitations of conventional pin photodiodes. In a UTC-PD the bandwidth is limited by the electron carrier transit time, as opposed to electron and hole transit time in pin photodiodes where the hole carrier transit time is the main limiting factor. Initially vertically illuminated devices were developed however, for these devices there is a tradeoff between bandwidth and optical responsivity. This trade off can be mitigated through the use of edge coupled photodiodes[3], where the optical power from a passive optical waveguide is evanescently coupled to an active region. In this geometry the optical propagation and carrier transport are perpendicular, allowing for a much thinner active region while maintaining high optical responsivity.

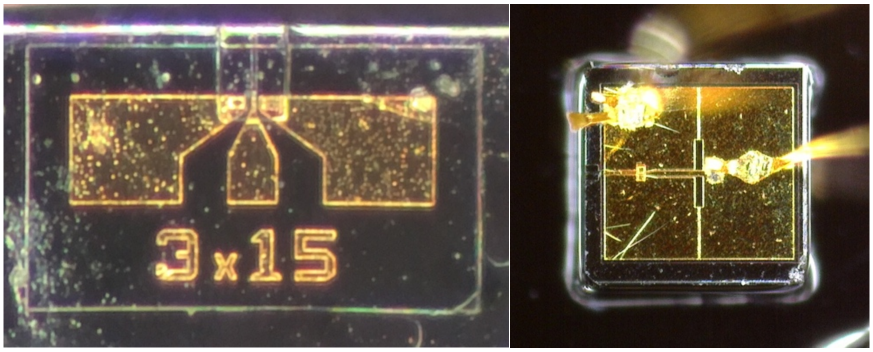

Fig.1. Co-planar waveguide integrated UTC PD with 3x15 μm^2 active area (left) and slot dipole antenna integrated device with 3x15 μm^2 active area (right)

2. Results

First in order to assess the efficiency of our design tools based of full wave modelling combined with a simple model for the device complex impedance [4], we look at a simple coplanar connection device. The key parameter for the operation of these devices we will assess, is their saturated power. Typically, the saturation is caused by a combination of thermal and space charge effects. In UTC-PDs the onset of the space charge effect is at higher power [1]. Using our design tool we expect saturation to occur around 10 mA photocurrent with a -2V bias and a power of 1 mW, for a 3x10 μm^2 active area device. In figure 2, we show some saturation measurements at 100 GHz using a calibrated W-band power meter. For this measurement we have used a 3x10 μm^2 active area device with an optical responsivity of 0.18 A/W and a -3dB bandwidth of above 67 GHz. The optical power was pulsed with a duty cycle of 1% to avoid thermal effects. In the figure the power showed is the equivalent continuous wave power and current.

As can be expected, the onset of space charge effect is bias dependent, but at higher bias the device does not saturate at the highest optical power and shows an output power of 2 mW, while similar devices have been demonstrated with power up to 10 mW.

With such output power, these devices have attracted a strong interest in a number of applications ranging from millimeter wave to terahertz. For the purpose of this abstract, we will focus on short range communication in the millimeter wave. In that case, it is essential to develop devices integrated with antenna [2]. In such devices the key is to develop a good match between the device and the antenna within the frequency range of interest as discussed in [4].

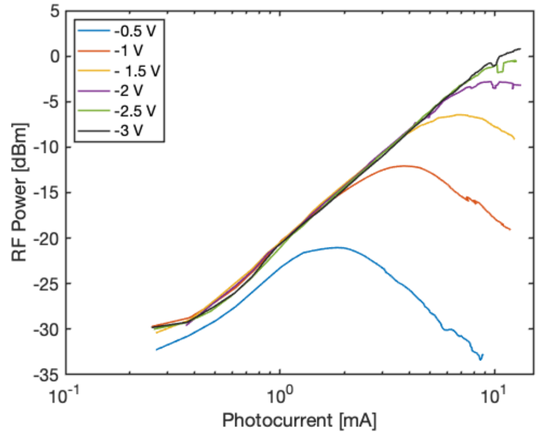

Fig.2. Output power saturation at 100 GHz for a 3x10 μm^2 active area CPW integrated UTC PD at varying reverse bias voltages. Recorded using a calibrated W-band power meter.

In figure 3, we can show the strength of good modeling schemes using a full wave model (CST studio) of the device that was constructed to account for the complex device impedance as described in[4]. For that purpose, using the model, we designed a UTC-PD integrated with a slot dipole antenna. That particular antenna was designed to have a strong resonance centered around 320 GHz which is a window of interest for communication (blue curve in fig.3). For the simulation, the radiated power of the antenna on a 6 mm silicon lens was calculated and a scaling factor for the transit time effects was applied.

The fabricated device (Fig.1) was mounted on a 6 mm silicon lens and evaluated using a calibrated Thomas Keating Power meter (red curve Fig. 3). The device photocurrent was 10 mA (unsaturated). The output power was measured at 1.2 mW at 100 GHz and 25 μW around 300 GHz. The Radiated power collected by the solid angle of the Thomas Keating detector window was also accounted for. While There was good agreement with the measured results at 100 GHz and a clear increase of power at 300 GHz, the measurement showed a clear drop in power around 200 GHz compared to simulations. However, we believe that it clearly demonstrates that the model and design tool are a good predictor of future performance of the developed devices.

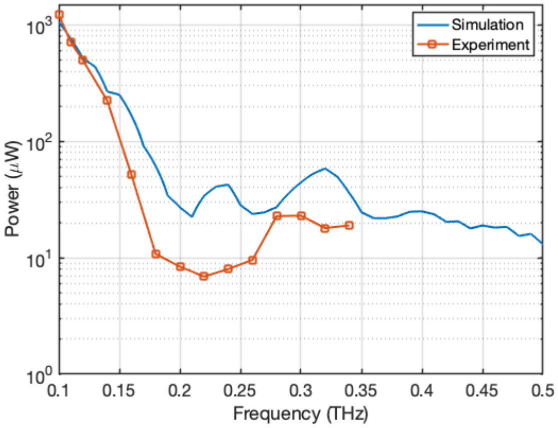

Fig.3. Comparison between full wave modelling and measured output power of a slot dipole antenna integrated UTC PD with 3x15 μm^2 active area. THz power was recording using a calibrated Thomas Keating power meter.

3. Conclusions

While UTC-PDS, have been demonstrated as efficient convertor for photomixing [2,3], the development of design tools that would allow to predict precisely the expected performances of the device has been lacking. Within this abstract we have shown, that developing a good full wave model, combined with a model of the complex impedance of the device to design the device architecture and electrodes will offer a good prediction of the device's performances. In particular the device integrated with antenna showed differences of less that 3dB between predicted and measured power at 100 and 300 GHz.

4. References

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