Generation of mW Average Power in the sub-mm Wavelength Band by Pulsed Photoconductive Connected Array

Alessandro Garufo, Paolo Sberna, Giorgio Carluccio, Nuria Llombart, and Andrea Neto
Department of Microelectronics
Delft University of Technology
Delft, The Netherlands
{A.Garufo, P.M.Sberna, G.Carluccio, N.LlombartJuan, A.Neto}@tudelft.nl

Juan Bueno and Jochem J. A. Baselmans
Netherland Institute of Space Research (SRON)
Utrecht, The Netherlands
{j.bueno, j.baselmans}@sron.nl

Joshua R. Freeman, David R. Bacon, Lianhe Li, Edmund H. Linfield, and Alexander G. Davies
School of Electronic and Electrical Engineering, Institute of Microwaves and Photonics
University of Leeds
Leeds, United Kingdom
{J.R.Freeman, D.R.Bacon, L.H.Li, E.H.Linfield, G.Davies}@leeds.ac.uk

***Abstract*— A novel pulsed photoconductive THz source is presented that is able to radiate mW-level average powers, over a large bandwidth by exploiting both the optical and electrical properties of photoconductive sources and the ultrawideband properties of connected antenna arrays. An optical system composed of a micro-lenses array splits the laser beam into N x N spots that host the active excitation of the antenna arrays. An "ad hoc" network is introduced to bias the array active spots in order to implement a connected antenna array configuration. The array feeds a silicon lens to increase the directivity of the radiated THz beam. A dipole and a slot array are designed. Prototypes have been fabricated and measured. Power and spectrum measurements of the prototypes are in excellent agreement with the expected results. The proposed solutions achieve excellent power radiation levels by exploiting accurate electromagnetic design. Thus, they can offer enhancements to any active system relying on pulsed photoconductive antennas.**

Keywords*— *Photoconductivity, THz photoconductive antenna, THz radiated power, THz source, THz technology, THz time-domain measurement, connected array, ultra-wideband array.

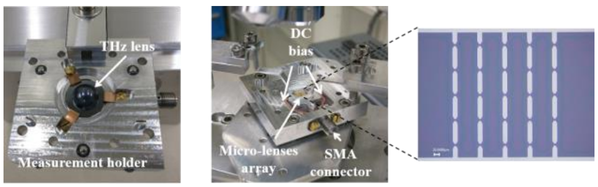
I. Introduction

The emergence of a large variety of applications, for THz technology in recent years has been driven by the availability of photoconductive antennas (PCAs) that have provided power up to THz frequencies at relatively low cost, thanks to several breakthroughs in photonics, and semiconductor technology [1]–[2]. PCAs are a combination of THz antennas and semiconductor materials driven by optical laser sources, that exploit photoconductivity to radiate power over large bandwidths, reaching THz frequencies. Currently, the power radiated by these device is limited by the high dispersivity and poor radiation efficiency of the existing PCA designs [3]. These bottlenecks render the integration time to detect the THz signal longer than really necessary and, as a consequence, these devices are limited to short-range applications (e.g. spectroscopy). The maximum power emitted by a single PCA is limited by: the maximum value of biasing voltage applied to the material, which can lead to the failure of the substrate material if it exceeds the voltage breakdown; and the maximum laser power that can cause a thermal failure of the device. Moreover, even before failure, large amounts of laser power and/or a high bias voltage lead to the saturation of the photocurrent [4], limiting the available power of the device. In order to increase the available radiated THz power, various PCA array structures have been proposed in the recent years [5]–[6]. However, all these technological solutions are electromagnetically inefficient when operate over wide bandwidths in a pulsed system. This is because they all rely on array arrangements of electrically short radiating elements, which are intrinsically narrow band.

In this work, we describe the design and the analysis of connected array of photoconductive sources (PCCA), which was presented for the first time in [7]. A connected array of photoconductive sources can be viewed as a modification of a connected array antenna, which is characterized by an intrinsic wideband radiation performance. This property makes connected array of sources suitable to efficiently radiate the wideband pulses generated in the optically pumped photoconductive gaps. The designs, presented in this paper, target at large submillimeter wavelength bandwidth (the measured energy spectrum covers a bandwidth at -5dB from 0.1 THz to 0.6 THz, radiating mW-level average power.

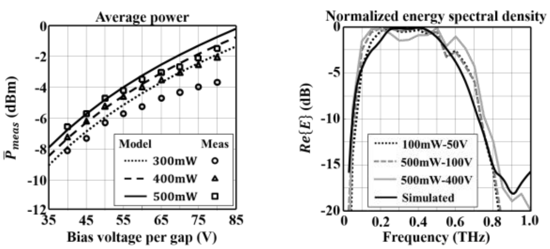
II. Section

The design of a pulsed PCCA source involves two components: the connected array which includes the biasing network; and the optical system used to excite the photoconductive gaps of the array cells. The optical system consists of a micro-lenses array, which splits the laser beam, and focuses a portion of the beam on each gap of the array. The connected array structure has two functions: biasing and wideband radiation at THz frequencies. For the biasing, it uses a connected biasing network that feeds the gaps in series, providing the bias voltage at each array cell to accelerate the free carriers excited by the optical pulses absorbed in the semiconductor. Fig. 1 shows a manufactured prototype.



(a) (b) (c)

Fig. 1. Prototype of the PCCA: a) view of the THz lens (Top view): b) view of the chip, and PCB for biasing the array (Bottom view); c) picture at the microscope of the dipole connected array on the semiconductor chip.



(a) (b)

Fig. 2. Measurements versus model: a) measured average power as a function of the applied bias voltage; b) measured spectrum for different laser excitation and applied bias voltage.

Fig. 2(a) shows the comparison between the measured power of the prototype and the detected average power P_{meas} estimated by the model [8], [10], as a function of the applied voltage and for different laser excitations. TABLE I summarizes the power budget of the PCCA prototype for 500mW laser power excitation and for different biasing voltages. The table shows that the available power $P_{available}$, when the antenna is ideally matched on the entire bandwidth, the generated power P_{source}, the actual power generated by the, and the power radiated outside the lens P_{lens}, are in the order of the mW, when the applied bias voltage is 400V. An excellent agreement between the detected power estimated by the model and the measured power of the prototype is shown.

TABLE I. TABLE TYPE STYLES

		Estimated Power				Measured Power
P_{laser}	V_{bias}	$P_{available}$	P_{source}	P_{lens}	P_{meas}	
500mW	200V	1.76mW	451 µW	268µW	214µW	221µW
	300V	3.96mW	1.01mW	603µW	482µW	448µW
	400V	7.04mW	1.80mW	1.07mW	857µW	712µW

The normalized amplitude spectra of the measured pulses radiated by the PCCA prototypes, for different laser power excitation and bias voltages, are shown in Fig. 2(b), where they are also compared against the estimated normalized energy spectral density radiated by the reflectors system, used for measurements, which were carried out by using Electro-Optic (EO) technique. The qualitative comparison shows an excellent agreement between the measurements and the estimation of the model for low laser power excitation and bias voltages, thus validating the dispersion analysis performed using our proposed EM model of the QO channel.

III. CONCLUSION

In this work, a novel architecture for pulsed photoconductive antennas, which allows high power radiated over a large bandwidth is presented. The solution realized a connected array of sources, by implementing an “ad hoc” bias voltage structure, and an optical system to excite the devices. A prototype has been designed and fabricated to maximize the power radiated on a selected bandwidth from 0.1THz to 0.6THz. The prototype have been characterized by power and spectrum measurements, thus validating the effectiveness of the proposed solution for the enhancement of the radiated power for PCAs. The maximum THz average power generated reaches the order of mW. The demonstrated power levels are obtained only optimizing the antenna architectures and the relevant modelling. More details will be discussed during the conference.

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