CTIA in Read-Out Integrated Circuit with PIN Photodetector

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Abstract — **This paper presents experimental and simulated results of a photodetector (*InGaAs P-I-N* photodiode) coupled to a Capacitive Transimpedance Amplifier (*CTIA*) circuit (*CMOS* 0.35 µm) used as a Read out integrated circuit (*ROIC*). The experimental results show the compatibility between these two structures for different irradiance values in the infrared spectral band.**

Keywords – CTIA, Photodiode, Infrared, Optical Sensor, ROIC, CMOS, Ingrated circuits

1. INTRODUCTION

The *P-I-N* junction photodiode has use as a light sensor in the visible and near infrared spectral bands, and has various applications, such as on the development of environment and coast monitoring devices [1]; on telecommunication sector [2] and for biomass. These photodiodes are also used as image sensors on neutron-based images [3]. The *P-I-N* used for the experiment presented in this paper is built from *InGaAs*, and has lower electronic noise than the silicon photodiode (*Si*) [4].

The Active Pixel Sensor (*APS*) is commonly used as Read-Out Integrated Circuit (*ROIC*) [5] for imagers in the visible spectrum. For infrared sensors, however, the Capacitive Transimpedance Amplifier (*CTIA*) *ROIC* is a usually deployed alternative with a simple signal conditioning or signal amplifier circuit.

The presented experimental results in this paper show the electronic compatibility between *CTIA ROIC* in *CMOS* technology (built in Silicon) and *InGaAs PIN*.

2. Read-Out Integrated Circuit – *CTIA* AND PHOTODIODE

Externally coupled and *PIN* structures were used in the experiments. The Semiconductors Laboratory, *LabSem*, at *Pontifícia Universidade Católica do Rio de Janeiro* (*PUC-RJ*), developed the *PN* junction with intrinsic layer photodiode (which can be seen on Figure 1). The Indium Phosfide (*InP*) substrate is 350 µm thick. The upper contact layer is P-type, made of *InGaAs:Zn* compound, with $1.5\text{x}10^{19}$ cm^{-3} of dopant concentration and 200 nm thickness. The lower contact layer is N-type, made of *InGaAs:Si* compound with $2\text{x}10^{18}$ cm^{-3} of dopant concentration and 600 nm thickness. The intrinsic layer has 2 µm thickness.

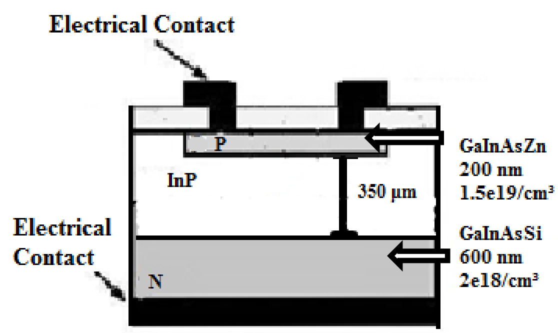

Figure 1 - InGaAs photodiode shape that was used, enhancing its layers and its size descriptions.

The *CTIA* – Capacitive Transimpedance Amplifier – is a circuit, designed at *OptMA_lab, Universidade Federal de Minas Gerais* (*UFMG*), and operates on voltage mode, Figure 2 shows the circuit draft. The current is photogenerated by the photodetector due to its voltage-applied polarization. This polarization occurs when there is a voltage signal on the *CTIA* Operation Amplifier non-inverting input, granted by feedback. Ideally, this voltage polarization should be null, since the positive feedback node is connected to the ground (*gnd*). However, imperfections of the real circuit create a little offset voltage signal, which produces a polarization voltage. Incident photons over the semiconductor material excite the charge carriers, that moves through the formed electric field, creating a photogenerated current. The Operation Amplifier setup with a 10 pF capacitor is known as integrator circuit. The output voltage is proportional to the input current (the photogenerated current), which is proportional to the incident light. Therefore, when the Reset Transistor (Figure 2) is off, we get the integrator circuit. In that way, to a constant light intensity, the output voltage (as an outcome of a constant integration) will result in a growing straight line (Figure. 3). As the experimental result is not ideal, the graph cannot be a straight line, and approximates to an exponential curve. The capacitor charging time (integration time of the pixel) depends on the capacitance and the photogenerated current [6].

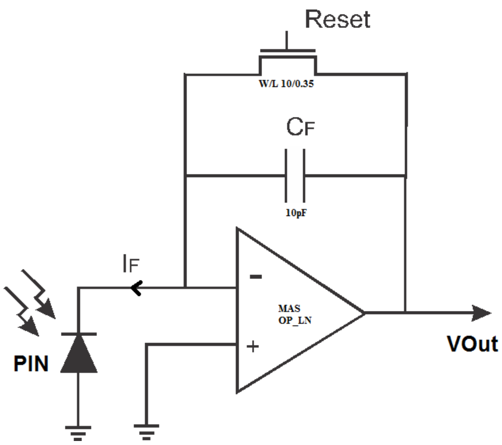

Figure 1. ***CTIA*** **circuit scheme.**

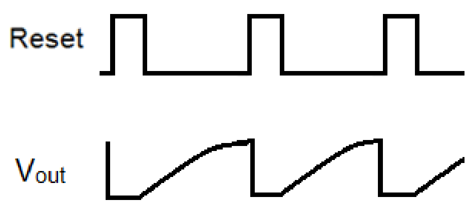

Figure. 2. Reset gate and V_{out} **signals**

3. SIMULATIONS

CTIA with 10 pF capacitor, coupled with a photodiode was simulated with SPICE, using models BSIM3v3. The photogenerated current is modeled as an ideal current source, with amplitudes variations shown at Table 1.

Table 1. Photogenerated current values shown in Figure 4

Curves	Simulated Current
Curve 1	9.6 µA
Curve 2	4.8 µA
Curve 3	2.4 µA
Curve 4	1.2 µA
Curve 5	600 nA

The simulation resulted on a response curve, plotted on Figure 4. Photogenerated current values were approximated by the experimental results, which were obtained and will be shown later.

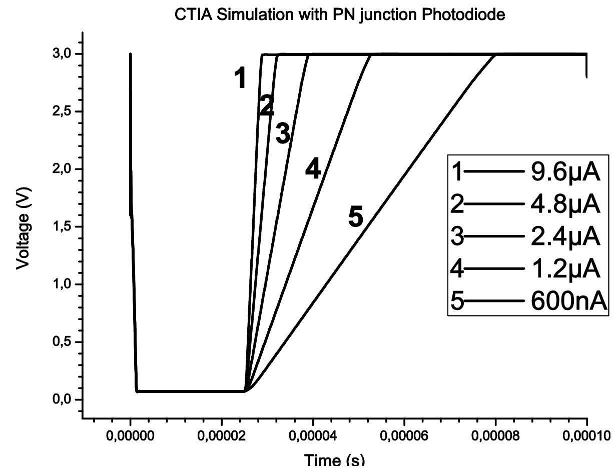

Figure 3. ***CTIA*** **simulation curve with different current values.**

4. EXPERIMENTAL RESULTS

The encapsulated chip (Figure 5), that contains the signal reading circuit *CTIA* (Figure 6) were put in a Printed Circuit Board (*PCB*) along with the encapsulation containing the *PIN* photodiode (Figure 7).

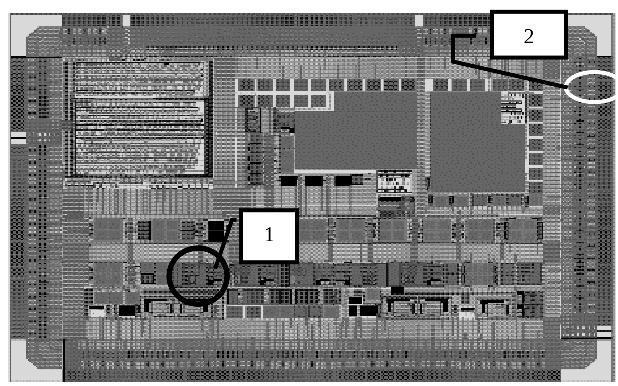

Figure 4. Chip designed by OptMA Lab rebouding CTIA (highlight 1) and the communication pad (highlight 2).

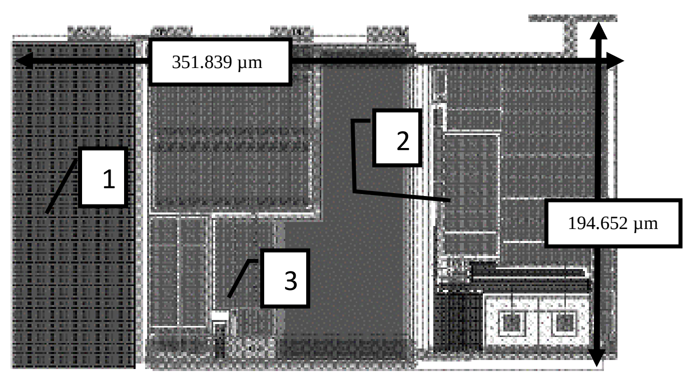

Figure 5. CTIA layout in the chip. It is possible to identify a capacitor (highlight 1), a Reset transistor (highlight 2), and the amplifying circuit (highlight 3).

The electrical connection between the photodiode and the *CTIA* (Figure 2 – highlight 1) is possible due to an available pin (Figure 5) in the chip, which is capsuled through a bus that interconnects the *PAD* of the chip (Figure 5 – highlight 1) to the photodiode of the *CTIA* (Figure 5 – highlight 2). The connection between this input and the *PIN* photodiode and the *CTIA* control/out are made through a terminal of the Printed Circuit Board (*PCB*) could be seen in the Figure 7.

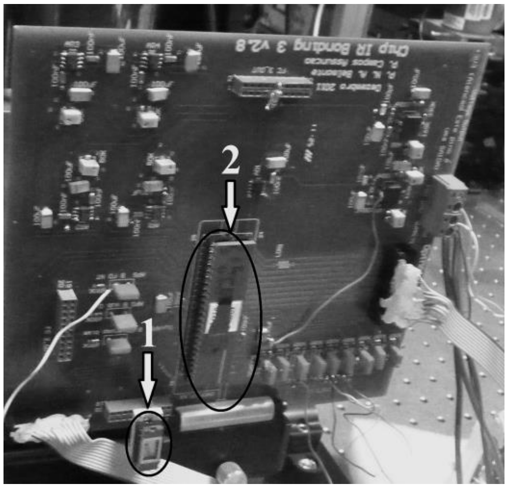

Figure 6. Encapsulated *PIN* photodiode *(highlight 1)* and encapsulated *CTIA ROIC (highlight 2)* in the PCB.

4.1. The Experiment

A black body – Mikron M305 – adjusted (1473 K) to transmit infrared radiation (λ_{max} = 1.97 μm) with different intensities was aligned with the *PIN* photodiode (connected to the *PCB*) at room temperature (295 K), as it can be seen at Figure 8.

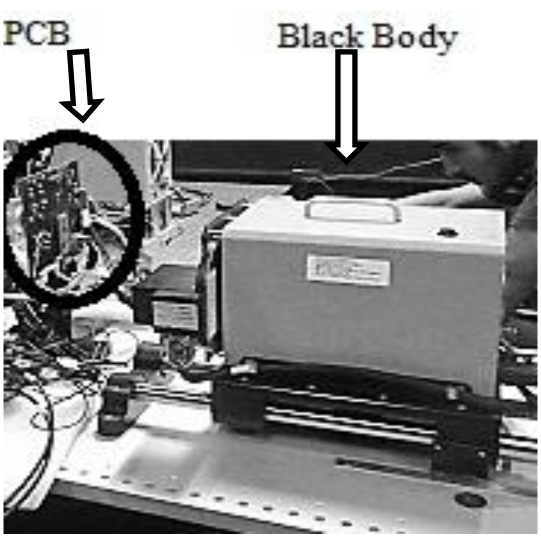

Figure 7. Alligned Black Body and *PCB* setup.

The variation of the beam intensity has been made through the distance and the size of the open diameter of the black body, using the Stefan-Boltzmann equation [7].

$$Ia = \frac{\sigma T_{cn}^4 A_{cn}}{\pi d^2} \qquad (1)$$

Ia is the black body irradiance on the sample; σ, the Stefan-Boltzmann constant; T_{cn}, the black body temperature; A_{cn}, the black body open area and *d*, the distance of the black body to the sample.

The *PCB* – with the *CTIA* structure – was connected to the oscilloscope Tektronix TDS2024B, where the pixel responses were read.

Four measures of the light irradiance coming from the black body at 0.225 m distance, and one measure at 0.425 m, and different open diameters were done, and are shown in Table 2.

Table 2. Black body and irrandiance over *PIN* values.

Measure	**1**	**2**	**3**	**4**	**5**
Opening width (m)	0.022 (Opened)	0.0127	0.0064	0.0032	0.0008
Distance (m)	0.225	0.225	0.225	0.225	0.425
Irradiance (W/m^2)	638.03	212.63	54.00	13.50	0.24

The results can be seen on the graph in Figure 9. It is possible to observe that, when bigger is the irradiance on *PIN*, faster is the output voltage variation of *CTIA*. This happens because the C_F capacitor, (Figure 2) loads faster due to the *PIN* photogenerated current increase, as verified on simulations (Figure 4).

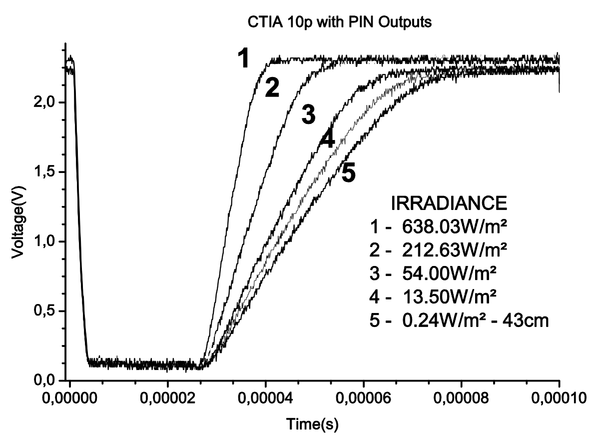

Figure 8 – Experimental Results: Voltage x Time in 5 different irradiance values on the sample.

The obtained response curve shows the low noise in the signal conditioning when using the *CTIA*. Besides, the experimental generated curve denotes a resemblance to the simulated curve (Figure 4).

5. CONCLUSION

The similarity between the simulated and experimental curves is a fact that validates the use of the *CTIA* as a good *ROIC* circuit, also with a photosensor capable of operation on the infrared spectrum band at room temperature (295 K). As it was said before, the curves that were simulated using pre-defined values shows that, probably, the photogenerated current values in the experiment of the *CTIA* with the *PIN* has a resemblance to the simulated values.

It is also important to highlight that the tested devices were both projected and developed in Brazil, and the initial results were promising and shows the availability of the integration of *CTIA ROIC* circuits together with *PIN* photodiodes, pointing to the real possibilities of project, development and constructing of infrared sensors, with fully national technology.

6. AKNOWNLEDGES

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