A Monolithic Visible, Infrared and Terahertz 2D Detector

Matteo Perenzoni[a], Nicola Massari[a], Stéphane Pocas[b], Jérôme Meilhan[b], François Simoens[b]
[a] Fondazione Bruno Kessler, Povo (Trento), 38100 Italy
[b] CEA Leti-MINATEC, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France

Abstract— **A monolithic multispectral detector for imaging in the visible (VIS), infrared (IR) and terahertz (THz) ranges has been designed for operation at room temperature. This sensor is composed of a CMOS readout integrated circuit (ROIC) housing visible photodiodes and of IR and THz microbolometer pixels processed above the CMOS wafer. Without package- and system-level issues, targeted individual pixel sensitivities are respectively an 80dB dynamic range for VIS photodiodes, a NETD=50mK @f/1 for IR and a THz NEP smaller than 10pW. Prototyping chips will be integrated in tri-spectral imaging and THz spectroscopy demonstration systems.**

I. Introduction And Background

MULTISPECTRAL imaging offers great potentiality in extracting additional information and is commonly applied in remote sensing systems for astronomy, agriculture, oceanography, pollution monitoring, etc. In particular THz technology looks like a promising complementary technique to VIS and IR sensing for multispectral analysis, as illustrated by several studies analyzing works of arts[1].

Compact solid-state focal plane arrays combining visible, infrared and terahertz detection with per-pixel correspondence of the retrieved images from the different bands would surely suit many fields, such as arts study but also surveillance field, production control or scientific research for example.

Visible imagers, either CDD or CMOS, are applied in countless domains. A multispectral sensor would undoubtedly benefit of high dynamic visible pixels, which would make it poorly affected by strong light source.

IR detector market also satisfies a wide applications range, from building insulation thermal diagnosis to temperature survey of bird-flu carriers in airports. Uncooled infrared microbolometer 2D arrays meet a growing demand driven by their compactness, reliability, low cost and high sensitivity.

Terahertz imaging has great potential and recent threats in airport increased the market of body scanners technology operating in the millimeter waves range. However, research still has to push further with real-time operation and spectroscopy capabilities at higher frequencies.

In this paper the efforts to realize a new detector capable of covering all cited main requirements will be described. This work has been funded under the EU 7th Framework Program (http://www.mutivis-ict.eu).

II. Concept and Technology

The detector technology choice has been driven by the objective of the realization of a monolithic detector integrating VIS, IR, and THz sensing capabilities with low-cost assets both in fabrication and in operation.

The first feature has motivated the design of a sensor where all the pixels are fully standard CMOS technology compatible. The VIS pixels are based on photodiodes integrated in a CMOS read out integrated circuit (ROIC) substrate. Both IR and THz pixels integrate amorphous silicon based un-cooled micro-bolometer technological stacks developed since 1986 by CEA-LETI[2]. Unlike IR pixels that benefit from robust standard 25µm pitch structure, THz pixels consist in bolometers coupled to 50µm pitch antennas that collect the THz radiation, sensor that are being developed at CEA-LETI for several years[3 & 4]. Both IR and THz pixels will be collectively fabricated above the ROIC with standard microelectronics processes, with VIS PDs located below IR pixels where there is no shadowing by the suspended structures (see Figure 1).

Low-cost operation objective is satisfied by sensor working at room temperature where only a Peltier module will help in stabilizing the substrate temperature.

III. Detector Design

The main technological breakthrough is to define appropriate IR and THz pixel layers that will be collectively processed above the CMOS. First pixel pitches and technological stacks have been optimized according to IR & THz spectral absorption, technological maturity and collective process constraints.

It came out of this study the choice of 50µm pitch THz pixel that exhibits spectral absorption on a wide bandwidth (about 55% around 2 THz, with a Half-Bandwidth of 2 THz;). That feature is a necessary requirement in the framework of a system aiming at spectroscopy using a tunable source.

For IR micro-bolometer pixels, the choice of 25µm pitch has been driven by considering technological robustness and compatibility with THz pixels. It ends up with a 4x4mm^2 sensitive region of 160x160 IR & VIS pixels, whereas 32 x 32 pixels THz are located in the centre of the focal plane array (Figure 2). The 1/4 surface ratio between IR and THz pixels ensures homogeneous topology floor plan that is requested for secured technological collective process.

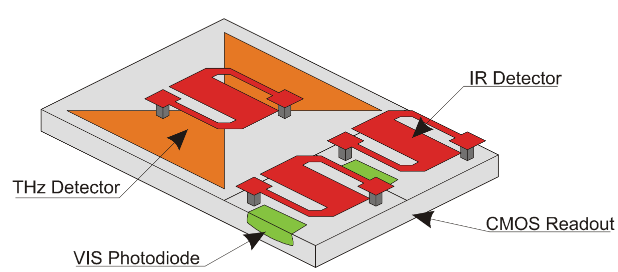

Figure 1. Principle of the multispectral detector

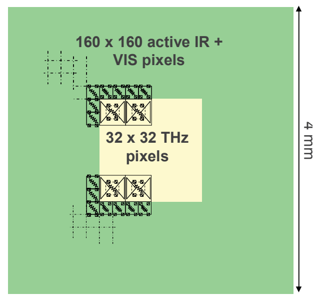

Figure 2: sensitive region of the detector

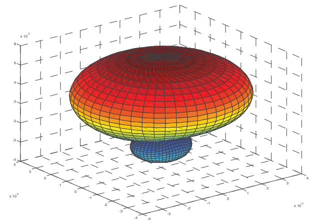

Figure 3. Antenna pattern at 1.5THz.

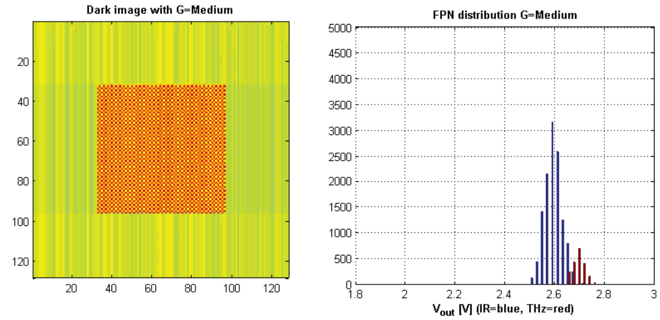

Figure 5. IR/THz electrical emulation image (left) and distribution (right)

In addition to layout design, many specific simulations have been run verify the detector electromagnetic and optic suitability to the system level requirements. For example to optimize the matching between optics and detector the antenna pattern at various wavelengths of interest has been simulated. As an example, Figure 3 shows the antenna pattern at 1.5THz, with substrate on the lower side, exhibiting a lambertian-like radiation diagram.

One other significant challenge lies in the readout circuit design that has to drive the 3 channel signals reading. The visible imager is designed to have an extended dynamic range[4], while the bolometers readout shares the integrating channels among the different kinds of sensors, with flexible addressing to allow binning and random access.

IV. Readout Circuit Results

A first prototype of the ROIC has been designed and fabricated in a standard CMOS technology, with operational VIS detectors and on-chip emulation of bolometers, to extract the circuit performances even before the above-IC fabrication process. The chip micrograph is depicted in Figure 4.

Experimental results of the first ROIC prototypes have been extracted. Wide dynamic range operation has been verified through electro-optical measurements, reaching more than 80dB of double slope characteristics.

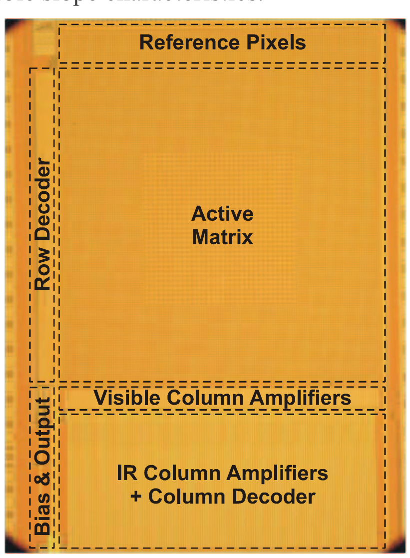

Figure 4. Chip micrograph

Measurements of IR/THz imager have been performed using the integrated resistors to emulate bolometers, showing a very good noise performance. Together with three selectable channel gain, these results will allow to achieve the targeted performance of 50mK NETD for IR, and 10pW NEP for THz sensors. Non-uniformity of readout channels is of about 1.65% of the whole range, as visible in Figure 5, which is equivalent to an electrical offset of less than 2.9mV without any calibration.

V. Conclusions

A multispectral monolithic detector based on the convergence of CMOS visible imaging, uncooled infrared imaging and antenna-coupled THz bolometers has been designed and simulated in all its components. The readout circuit containing the visible photodiodes has been validated with a preliminary fabrication. Near future developments are about fabrication of the detectors with an above-IC process to achieve a first prototype.

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