Recent advances in modelling and characterization of uncooled antenna-coupled bolometer arrays

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***Abstract*—The CEA-Leti THz uncooled imaging arrays rely on a dedicated pixel architecture where a resonant dielectric cavity combined to antennas processed above the CMOS read-out-circuit ensure the optical coupling. Performance improvements of the prototyped designs are presented through modelling and characterizations in the range above and below 1 THz.**

I. INTRODUCTION

OWING to its advanced know-how in thermal infrared bolometer sensors, CEA-Leti has designed and prototyped proprietary QVGA THz bolometer array architectures [1]. This paper reviews the latest modeling and characterization works that target performance improvements and addition of functionalities.

II. NEW PIXEL DESIGNS FOR FASTER / POLARIZATION SENSITIVE IMAGING

The THz bolometric pixel architecture relies on the separation between electromagnetic absorption and the thermometer that is provided respectively by antennas associated to a resonant cavity and a micro-bridge supporting a thermo-resistive layer.

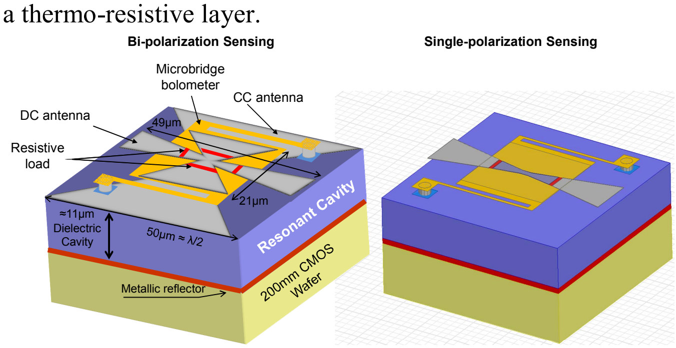

Fig. 1. Pixel architecture versions for bi or single polarization sensing.

The use of antennas brings versatility in optical absorption features [1]. In particular, two-storied bow-tie antennas architecture has been designed (Fig 1., left) and the tested prototypes have confirmed very high and independent absorption of the crossed polarizations [2].

Design with one of the 2 bow-tie antennas being suppressed has been studied (Fig 1., right). A single antenna design – keeping here the so-called DC bow-tie antenna - has been implemented in a 3x3 pixel micro-arrays and spectral response measurements of the device have been performed. An impinging optical wave is considered at normal incidence and with linear polarization along the antenna axis direction. Measurements exhibit overall consistency with simulation: they show a significant broadening of absorption that is consistent with single element bowtie antenna frequency behavior while orthogonal polarization (CC direction on Fig 2) has null absorption. However a shift in absorption peak (Fig 2.) is noticed and may arise from simulation conditions as periodic boundaries conditions are applied on the simulation setup whereas the tested device is a finite array.

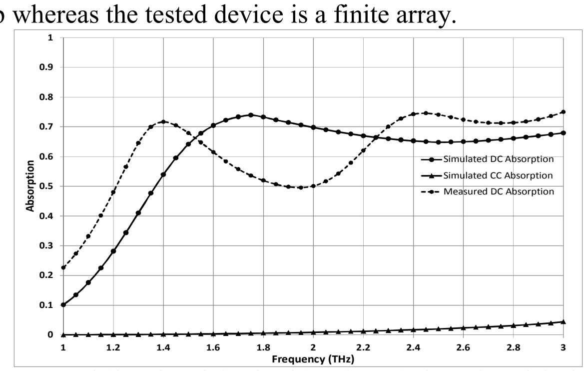

Fig. 2. Measured (dotted) and simulated (continuous) absorption of single DC polarization antenna bolometer.

Coupling of antennas to the micro-bridge adds up material to the structure that increases its thermal capacitance and therefore can hamper the device time response. Single polarization antennas pixels are a way to mitigate this degradation. An alternative design can also ensure both fast response time and cross-polarization sensibility. It consists in a novel antenna structure where most of the central metallic part is removed (Fig 3.).

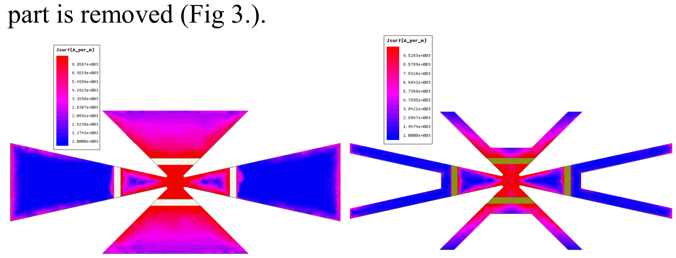

Fig. 3. Surface current density of standard crossed antenna design and lightened V-shaped design

Simulation of the current density in the suspended antennas (Fig 3., left) for a plane wave polarized along the CC bow-tie shows that most of the current is located along the edges of the antenna. Current density within the central area is much lower and its removal should not impact significantly the antenna behavior. It allows optimization of the antenna area that is reduced by more than 60% and leads to a V-shaped surface (Fig 3., right) on which current density presents levels similar to the standard design.

The absorption of the antenna-coupled bolometer structure for this type of antenna has been simulated and compared to previous results [1]. Frequency behavior of the structure is not disturbed by the size reduction for both CC and DC antennas, and locations of the resonance peaks are preserved (Fig 4.). However absorption efficiency is reduced and appears 15% lower than the standard structure.

This efficiency loss is counter-balanced by the improvement of the thermal mass of the structure. Thin layers that make up the bolometer bridge are similar to the matured IR a-Si bolometer technology and thermal capacitance of the stack can be estimated based on this know-how. It appears that the metallic antennas that top the bolometer membrane for standard design increases the thermal mass by 34% compared to a standard IR micro-bridge structure of similar dimensions. In the case of the lightened design the thermal mass rise is limited to 13%. The structure reaches thermal time constants close to 20ms, in the range of state of the art IR bolometers at similar pitch.

This new design offers a good trade-off between absorption efficiency and response time of the structure that are key parameters to achieve high performances and real-time imaging.

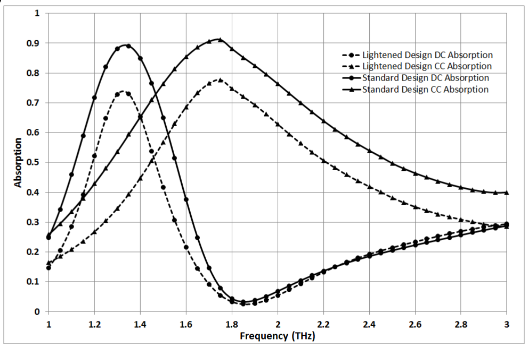

Fig. 4. Comparison of the modelled spectral optical absorptions of the lightened (dotted) versus standard (continuous) antenna designs

III. On-Going characterizations

Non uniformity correction is a challenge for THz imaging array due to the lack of uniform powerful source as pointed out in [3]. In order to improve the response uniformity it is mandatory to identify the sources of dispersion of the design. The antenna-coupled bolometer stack is derived from mature IR bolometers technology that are monolithically processed with standard Si microelectronics. Therefore it benefits from its industrial yield and reliability.

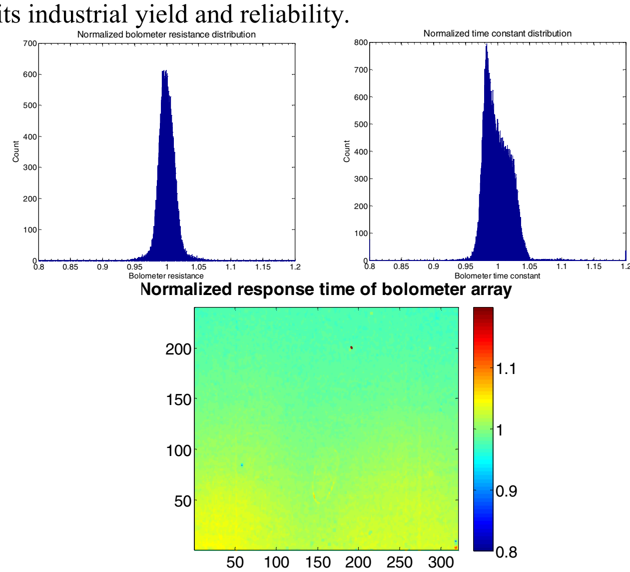

Fig. 5. Distribution histogram and dispersion map of antenna-coupled bolometer resistance and thermal time constant

As illustrated in Fig 5, the bolometer resistances exhibit standard deviation of the order of 1% (normalized to average value) comparable to results in IR and will have limited impact on the overall dispersion.

A setup that allows measurement of the pixel time constants within the array has been developed. It consists in a black-body and a shutter that allow phase controlled triggering of the array illumination and removal of low frequency drifts. The dispersion of the time constant turns out to be more important and its standard deviation reaches 3.4%. This value stands out when compared to IR bolometer achievements that are better than 2%. As IR and THz bolometers differ from the cross-antenna that tops the structure it reveals that the excess dispersion arises from this absorbing element. Slight variations on antenna geometry must induce variations on stack thermal mass and time constant. However this dispersion of the time constant is still moderate and will not affect seriously the array responsivity uniformity.

Further studies will aim at measuring the spectral response of individual pixels in order to be able to discriminate the dispersion of the different technological parameters of the device.

A new experimental set-up has been assembled for characterization of our existing arrays below 1 THz (Fig 6.).

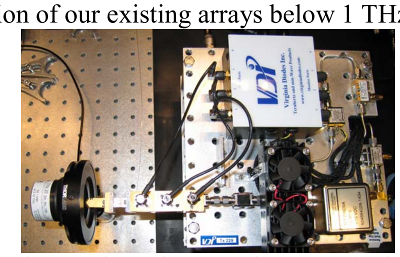

Fig. 6. Experimenalt set-up for performance characterization between 650 and 750 GHz

A calibrated power-meter is used in order to assess the impinging optical power. Measurements on various pixel designs in comparison to simulations are undergoing.

IV. Summary

New designs of arrays above 1 THz are modelled and characterized showing improved performances and functionalities. Characterization and experimental methods are being developed in order to extract the dispersion of the pixel parameters and the sensitivity below 1 THz.

References

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