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# Design and fabrication of a bidimentional microbolometer array for Terahertz detection characterized at different temperatures.

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**Abstract.** We present the design, micromachining and characterization of a bidimentional bolometer array for radiation detection in the 0.7-1.5 THz frequency range. The detector is based on a boron doped amorphous silicon film (a-Si-B:H). The film optimized for sensitivity enhancement was obtained using 500 sccm diborane flow with 95 nm thickness. The sensing layer was deposited using plasma enhanced chemical vapor deposition (PECVD) technique at low frequency on a 0.45 µm thick silicon nitride membrane sustained by a micromachined frame in crystalline silicon. The design consists of four 5x5 bolometer arrays made by conventional lithography. The bolometer active area is 660 µm x 420 µm and the detector will operate as a focal plane array. The current–voltage characteristics present an ohmic behaviour; the temperature coefficient of resistance (TCR) was obtained by measuring the bolometer performance from room temperature down to liquid nitrogen temperature. The responsivity was measured under illumination from a black body radiating at 300, 500, 700, 900 and 1100 °C, obtaining a value of R =1.17 x  $10^{-2}$  A/W with a dark current of 4.43 x  $10^{-9}$  A

Keywords: microbolometer, amorphous silicon, micromachining.

#### **1. Introduction**

The development of IR detectors starts with the development of thermal detectors. In 1821 Thomas J. Seebeck discovered the thermoelectric effect, since then many types of detectors have been used extensively in the far-infrared (FIR) and sub-mm applications, between 100  $\mu$ m and 1 mm [1,2]. Infrared sensors, thermopiles, pyroelectric devices and thermistor bolometers are examples of such detectors. Millimeter (mm) and sub-millimeter (sub-mm) astronomy is facing a revolution thanks to the development of new cameras based on transition edge sensors (TES) bolometer arrays. In particular bolometers are used for astrophysical application at millimeter wavelengths. Sensing and imaging using pulsed terahertz (THz) radiation have been widely recognized for reconstructing three-dimensional (3-D) images of objects [3-4]. Recently published works show implemented systems which operate at frequencies below 1 THz. There are two reasons for this: first, humidity interferes with the image due to its high absorption above 1 THz and, second the ability to find something covered by cloths. THz falls between the radiofrequency (RF) and infrared (IR) bands, and is a largely

unexplored region of the electromagnetic spectrum with wavelengths ranging from 100 GHz to 10 THz. The technology for this frequency range has been used recently in biology, medicine, and nondestructive control of materials [5]. Vanadium oxide (VOx), polycrystalline silicon, germanium and hydrogenated amorphous silicon (a-Si:H) are materials commonly employed for micro-bolometer sensors [6-7], most of them present a very high resistivity. One key issue for obtaining low-cost detectors using monolithic construction is their easy integration and compatibility with the CMOS technology. In this work we present the fabrication process and characterization of a 2D array of bolometers made of boron doped hydrogenated amorphous silicon (a-Si-B:H) as material sensor.

## 2. Bolometers

A composite bolometer follows the design of a micro-calorimeter as a thermal detector, which employs electrical resistance variations to determine a change in temperature due to the absorbed radiation. The absorbing film is connected to a heat sink through a weak thermal link kept at very low temperature. When electromagnetic radiation is absorbed (figure 1), its energy is transferred to the absorber whose temperature will increase. An ultra-sensitive thermometer (thermistor) transforms the temperature variations of the absorber in electric signals, consequently amplified and digitally processed by computers. In general three parameters are important for determining the performance of a bolometer: responsivity (S), noise equivalent power (NEP), and response time constant ( $\tau$ ).



Fiure 1. Layout of a simplified bolometer

#### 3. Experimental details and bolometer structure

The fabrication process is summarized as follow: the microbolometer array was fabricated on p-type crystalline silicon wafer (c-Si) in which l  $\mu$ m thick SiO<sub>2</sub> layer was thermally grown (figure 2). A 0.4  $\mu$  thick silicon nitride (Si<sub>3</sub>N<sub>4</sub>) was deposited on both faces of the substrate using low pressure chemical vapor deposition. The Si<sub>3</sub>N<sub>4</sub> also works as IR absorbing material, mechanical support and protective layer. A mask is used to define the diaphragm by removing the c-Si by wet chemical etching in a bulk-micromachining process (figure 3).



Then the a-Si:B:H thermo sensing layer was deposited using low frequency PECVD. Electrodes were deposited by electron beam evaporation. Patterning was performed by photolithography and a combination of wet and RIE etching (figure 4). Finally we packaged a 5 x 5 array of bolometers for measurements in a liquid nitrogen cryostat (figure 5). Conditions for the sensitive layer deposition are shown in table 1.



Figure 4. Deposition of a-Si:B:H sensitive layer and aluminum electrodes



**Figure 5.** Encapsulated 5 x 5 microbolometer array

Table 1.	Parameters	for the c	deposition	of B-dope	ed <b>a-Si:H</b> b	v PECVD.
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Temperature	Time	Frecuency	Power	Flow of	Flow of	Flow of		
Deposition (K)	(min)	(KHz)	(W)	Ar (sccm)	$SiH_4$	$B_2H_6$		
					(sccm)	(sccm)		
540	30	110	300	100	50	500		

#### 4. Results and discussion

The performance of the bolometer depends strongly on the TCR, which is related to the activation energy, equation 1. Therefore, by measuring the layer resistance as a function of temperature we can calculate the Ea.

$$TCR = \frac{E_a}{KT^2} \tag{1}$$

Where Ea is the activation energy, T the temperature and K the Boltzmann's constant. In previous work [8] we estimate de TCR values for this sensitive layer at different temperatures and the best behavior was found in the vicinity of 150 K about 0.085 K<sup>-1</sup>. The characterization of each bolometer (labeled as B, C, H, I, L and K) was conducted using a blackbody radiation operating at 300, 500, 700, 900 and 1100 °C; the operating temperature in the cryostat was set to 77 K as shown in figure 5. We measured the current - voltage (I-V) characteristics of the devices, using a voltage bias in the -10 V to 10 V range under irradiation from the black body at 300 and 1100 °C as shown in figures 6 and 7, respectively. The graph showed some differences in their I-V curves. The reason might be attributed to the stress appearing in the thermo-sensing films deposited on the Si<sub>3</sub>N<sub>4</sub> and a-Si:H a amorphous films, consequently their electric properties are slightly different depending on their location.





Figure 6. Measured current-voltage characteristic at 300 °C for black body radiation

Figure 7. Measured current-voltage characteristic at 1100 °C for the black body radiation

An ohmic behaviour is observed for absolute values of voltage below 3V, in which the I-V curve slope is almost constant. At higher voltages, and thus higher power consumption, the resistances start self-heating, leading to a non linear characteristic. The I-V curves measured at 500, 700 and 900 °C black body radiation have a similarly behavior. We calculated the current values for different temperature of the black body radiator and observed that presents a lineal dependence on power. In Figure 8 we have used an average I-V curve which is representative for all the bolometers for each temperature of the black body radiation, whereas the cryostat was maintained at 8 mtorr of pressure. From these plots the responsivity (R), determined as the ratio of output signal on the input signal, was estimated as R =1.17 x  $10^{-2}$  A/W with a dark current of 4.43 x  $10^{-9}$  A at 7 V bias voltage.



**Figure 8.** Measured current-power curves under different temperature for the black body radiator

### 5. Conclusions

We developed, characterized and encapsulated a thermistor microbolometer array. The fabrication process included a micro-machining technique that is fully compatible with the CMOS standard fabrication process. We used an a-Si:B:H film as the sensitive layer. The bolometers present a high TCR, and showed a responsivity of  $R = 1.17 \times 10^{-2} \text{ A/W}$  at 7 V dc.

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