Micromachined and Characterization of Cooled a-Si:B:H Microbolometer Array in the Terahertz Region

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Chapter 16
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A. Orduña, C.G. Treviño, A. Torres, R. Delgado, and M.A. Dominguez

Abstract This work presents the fabrication and characterization of microbolometer array operating in the Terahertz region. The detector is based on a boron-doped hydrogenated amorphous silicon film (a-Si:B:H) employed as a thermosensor layer in bolometers arrays. The sensitive layer was deposited on the micromachined silicon wafer by the plasma-enhanced chemical vapor deposition technique. The array was fabricated using conventional lithography. The 5×5 microbolometer array was characterized at a base temperature of $-196\,°C$, using liquid nitrogen, under black body radiation from 0.1 to 10 THz frequency range. The responsivity value of 0.187 A/W is obtained at 3 V.

Keywords Bolometer • Micromachined • Radiation • Terahertz frequency • Responsivity

16.1 Introduction

For many years, thermal detectors have played an important role in the exploration and exploitation of infrared radiation, operated at room temperature and with cooled thermal detectors. Infrared radiations are the electromagnetic waves in the wavelength, from 0.75 to 1000 μm or 1.65 eV–1.24 meV. A wide variety of applications are used, and new applications are constantly being developed. The advances in

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detector fabrication technology and microelectronics process technology have led to the development of a large format array of IR detectors [1]. These detectors have been developed for infrared (IR) spectroscopy, medical examinations [2, 3], security systems [4], scientific applications, using nanostructural materials [5], and many consumer products. Detection mechanisms of infrared may be classified into two groups: thermal detection and photon detection. Thermal detectors convert radiated power into a more readily measured parameter; three types exist: thermopile detectors [6], pyroelectric detectors [7], and resistive bolometers [8, 9]. All thermal detectors convert incident radiation into heat, thereby raising the temperature of the detector element. This change in temperature leads to a change in the measurable property of the material, such as the electrical resistance (bolometers) or spontaneous polarization (pyroelectric detectors).

Bolometers employ an electrical resistance thermometer to measure the temperature of the radiation absorber, heated by incoming radiation usually in the infrared and microwave regions of the electromagnetic spectrum and cooled by thermal conduction through its electrical lead wires. Bolometers are discrete semiconductor or superconductor elements used to measure temperature; their performance is characterized by the temperature coefficient of resistance (TCR), typically IR absorbing areas are formed by a micromachined membrane suspended usually by two or more arms in the same plane over etched pits on the substrate. An efficient good thermal insulation is usually obtained by micromachined, depositing a film resistor onto a thermally and electrically insulated membrane, obtaining an increment in the detectivity of detector. Typical membrane materials are silicon nitride or silicon oxide. In this paper, we describe the design, micromachined, and characterization of 5×5 cooled microbolometer array, based on hydrogenated amorphous silicon thermo sensing layer boron doped to reduce the high resistance, obtaining the result of principal figures of merit from 0.1 to 10 THz frequency range.

16.1.1 Terahertz Applications

Terahertz range is broadly applied to submillimeter-wave energy that fills the wavelength range between the radiofrequency (RF) and infrared (IR) bands, a largely unexploited region of the electromagnetic spectrum. THz rays are non-ionizing and present an alternative in comparison to X-rays for imaging through paper, cloths, and many plastic materials. In particular, THz imaging holds large potential in the field of nondestructive testing, different types of detectors for the THz-IR radiation have been researched and are already used in industrial applications for THz systems [10] and microbolomter [11]. For many years, thermal detectors have played an important role in the exploration and exploitation of infrared radiation, operated at room temperature and cooled thermal detectors. Infrared radiation are the electromagnetic waves in the wavelength, from 0.75 to 1000 μm or 1.65 eV–1.24 meV. They are used in a wide variety of applications, and new applications are constantly being developed. The advances in detector fabrication technology and microelectronics process technology have led to the development of the large format array of IR detectors [1]. These detectors have been developed for infrared (IR) spectroscopy, medical examinations [2, 3], security systems [4], scientific applications, using nanostructural materials [5], and many consumer products. Detection mechanism of infrared may be classified into two groups: thermal detection and photon detection. Thermal detector converts radiated power into a more readily measured parameter; it has three types: thermopile detectors [6], pyroelectric detectors [7], and resistive bolometers [8, 9]. All thermal detectors convert incident radiation into heat, thereby raising the temperature of the detector element. This change in temperature leads to a change in the measurable property of the material, such as the electrical resistance (bolometers) or spontaneous polarization (pyroelectric detectors).

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16.1.2 Principles of Bolometer Operation

Bolometers are usually used for astrophysical applications at millimeter wavelengths and infrared imaging systems. The original bolometer was developed by Lanley in 1878. Thermosensor layer is formed by a micromachined membrane, usually suspended by arms in the same plane over etched pits on the substrate. The incident power induces an increase of the temperature of a sensitive layer absorber that is connected to the thermal bath through supports having a thermal conductance (GTh), as is shown in Fig. 16.1. The resistor should have a large temperature coefficient of resistance, defined as TCR, a small temperature increase gives rise to a significant change in the bolometer resistance. CMOS terahertz [12] and development are motivated by biology [13], astronomy [14], telecommunications [15, 16], and other disciplines. For infrared or Terahertz range, bolometers are among the most sensitive detectors available.

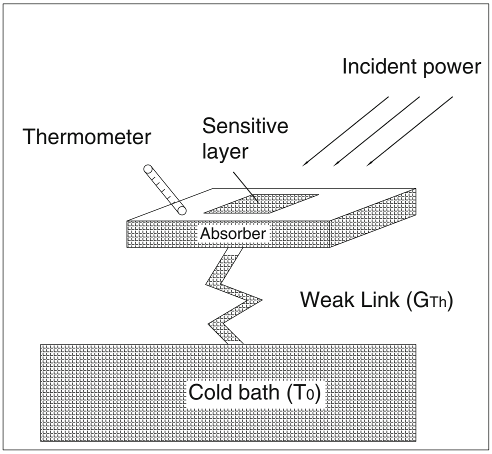


Fig. 16.1 Simplified bolometer layout

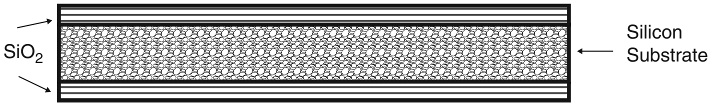


Fig. 16.2 SiO_2 thermally grown by CVD on the c-Si wafer

16.2 Experimental

The array was fabricated of 5 × 5 bolometers. The fabrication process is summarized as follow: The wafers used were cleaned in trichloroethylene, followed with acetone in an ultrasonic bath, both for 10 min of process time. Later, the samples were cleaned with the RCA1 and RCA2 solutions. The microbolometer array was fabricated on p-type crystalline silicon wafer (c-Si) in which 1 μm thick SiO_2 layer on both faces was thermally grown, as is shown in Fig. 16.2. Figure 16.3 shows a 0.4 μ-thick silicon nitride (Si_3N_4) deposited on silicon oxide layer using the low pressure chemical vapor deposition technique (LPCVD). The Si_3N_4 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. We used the Hydrogenated amorphous silicon (a-Si:H) as a thermo-sensing film, showed high activation energy (Ea) and consequently a high value of thermal coefficient of resistance (TCR), necessary for the performance of the microbolometer, the material was deposited using plasma enhanced chemical vapor deposition technique (PECVD) at low frequency. The parameters for the a-Si:H deposition was described in previous work [17]. Finally, the electrodes were deposited by electron beam evaporation and patterning was performed by photolithography obtaining the microbolometer structure, as is shown in Fig. 16.4.

Figure 16.5 shows the packaged 5 × 5 array of bolometers, for measurements in a liquid nitrogen cryostat.

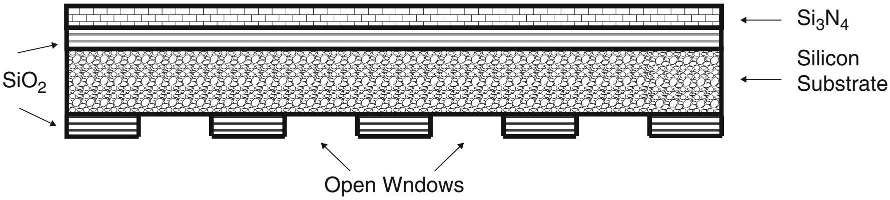


Fig. 16.3 Deposited Si_3N_4 layer and opening the window of SiO_2 by micromachined

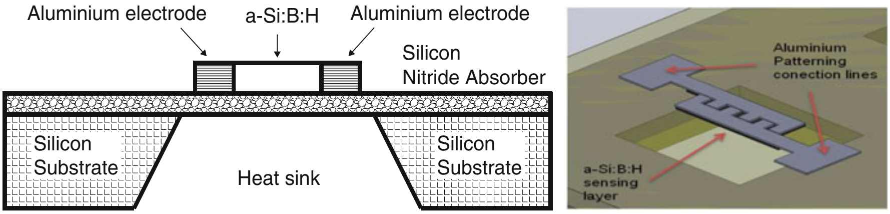
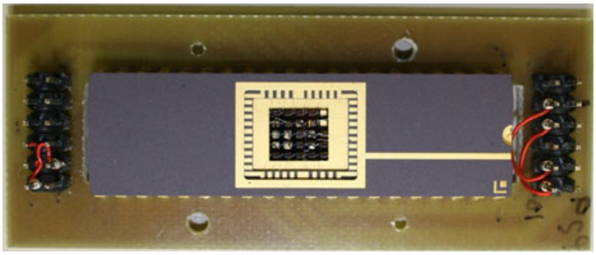


Fig. 16.4 Microbolometer structure, obtaining the deposition of a-Si:B:H sensitive layer and aluminum electrodes

Fig. 16.5 Package of microbolometers array



16.3 Results and Discussion

The bolometer array was set in a vacuum cryostat operating at liquid nitrogen temperature of 77 K. Normalizing the signal with respect to the detector area and illumination source bandwidth, we obtain the detectivity, which gives us information about the performance of the bolometer. The characterization of the bolometers array was performed using a commercially available black body (Mikron M300), operating at 573, 973, 1173, and 1373 K from 0.1 to 10 THz frequency range.

The response of black Polyethylene (R_{BPoly}) and Gore-Tex (R_{GTex}) were incorporated and set in front of the detector as band pass filters [18, 19] to determine the power falling in the microbolometer array, we must consider a geometrical correction defined by the detector solid angle (Ω_{det}) viewed from the black body and the black body area (A_{BB}). Therefore, the net power arriving to the microbolometer array (P_{abs}) is determined from the black body radiation ($B_{(\nu,T)}$), filters response, and geometrical correction are shown in Table 16.1.

Table 16.1 Black body emissivity and integrated power arriving to the bolometer considering geometrical correction and filter transmission

	Black body temperature (K)			
	573	973	1173	1373
Black body radiance (nW/m^2Sr)	42.29	82.43	102.71	124.07
Power incident on the bolometer (nW)	0.933	1.793	2.227	2.683

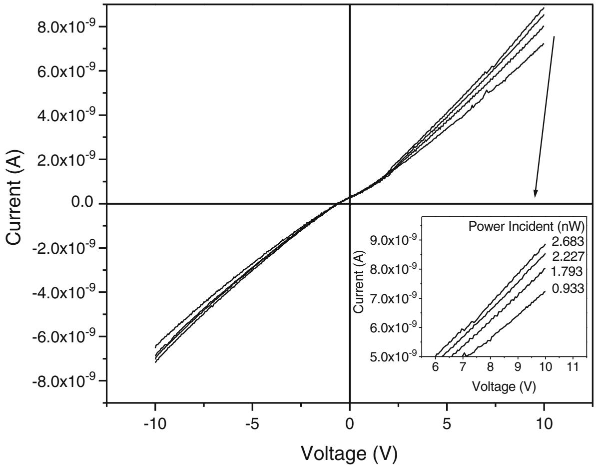


Fig. 16.6 Measurements of microbolometer current-voltage characteristics at 77 K and exposed to 0.933, 1.793, 2.227, and 2.683 nW filtered black body radiation power

$$P_{abs} = B_{(\nu,t)}\Omega_{det}A_{BB}R_{BPoly}R_{GTex} \tag{16.1}$$

The I–V characteristic curves were measured for different elements in the −10 to 10 V range and shown in Fig. 16.6. We tested microbolometers to account for edge, corner, and center response and obtained uniform response among the different elements. The I–V slope characteristics show a current increase with respect to radiation power incident as a function of bias voltage. It is important to note that the measurement was performed at 77 K. At this temperature, the DC current conductivity is generally expressed as:

$$\sigma = \sigma_0\left[-\left(\frac{\Delta}{kT}\right)^{\beta}\right] \tag{16.2}$$

where σ_0 is a characteristic value and β depends on the material and temperature range. For a-Si:B:H, β has values ranging from 0.5 at room temperature and a substantial drop down to 0.25 at low temperatures. The result is a very high

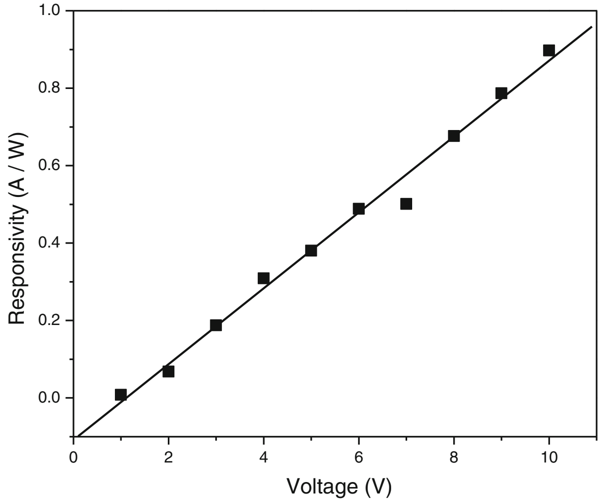


Fig. 16.7 Responsivity ($\mathfrak{R}$) of microbolometers as a function of the voltage

resistivity material in which it is difficult to obtain an Ohmic contact. The annealed aluminum metal electrodes induce crystallization in such a way that the barriers become near ohmic. The result is an Al-a-Si:B:H near Ohmic contact, which does not go through zero, but keeps the linear I–V response to be considered as a resistor.

The Responsivity ($\mathfrak{R}$) was determined by considering the ratio between generated current as a function of the incident power at a given bias voltage. The results are shown in Fig. 16.7.

From these measurements, we were able to determine a responsivity in the hundredths of milliampere per Watt range at liquid nitrogen temperature. In particular, a responsivity of 0.187 A/W is observed at 3 V. These values are large enough that the boron-doped amorphous silicon bolometer is a feasible candidate for Terahertz detection systems comparable [19, 20] with similar devices.

16.4 Conclusions

We presented the construction and characterization of a microbolometer array compatible with CMOS technology that can be used as focal plane detector in the THz region of the EM spectrum. The a-Si:B:H sensor film was prepared by PECVD, in order to obtain thermal isolation, the microbolometer was fabricated on a thick silicon nitride membrane, which was made on a p-type crystalline silicon wafer by micromachining techniques. The final array has 550 μm $\times$ 260 μm dimensions, and responsivity (from 100 GHz to 10 THz range) in the 10-1 A/W range at $-196\,^{\circ}$C was obtained. These values are large enough that the boron-doped amorphous silicon bolometer is a feasible candidate for Terahertz detection systems comparable with similar devices.

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