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BOLOMETRIC ARRAYS FOR MILLIMETER WAVELENGTHS

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RESUMEN

En años recientes, en el INAOE, se han desarrollado bolómetros semiconductores con películas delgadas de silicio amorfo hidrogenado dopado con boro. Estos dispositivos presentan características que los hacen atractivos para aplicaciones en instrumentos astronómicos, especialmente en arreglos bidimensionales. Con estos arreglos de detectores y el Gran Telescopio Milimétrico, será posible obtener imágenes astronómicas en longitudes de onda milimétricas y sub-milimétricas. Teniendo lo anterior en mente, nos hemos dado a la tarea de desarrollar un método de fabricación de arreglos de bolómetros que sea confiable y pueda llevarse a cabo en los laboratorios del INAOE. Hasta ahora se han obtenido arreglos de diafragmas de Nitruro de Silicio, que sirven como absorbedores de radiación electromagnética, de forma exitosa en diferentes tamaños. Aún falta probar la fabricación de los termómetros y los contactos metálicos. De forma paralela, se trabaja en el desarrollo de dos posibles configuraciones para la electrónica de lectura de los arreglos; una de ellas utiliza componentes comerciales, mientras que la otra es un circuito integrado diseñado para esta aplicación específica. Ambas versiones trabajarán a 77K o menos.

ABSTRACT

During last years, semiconductor bolometers using thin films have been developed at INAOE, specifically boron-doped hydrogenated amorphous silicon films. The characteristics shown by these devices made them attractive to be used in astronomical instrumentation, mainly in two-dimentional arrays. These detector arrays used at the Large Millimeter Telescope will make possible to obtain astronomical images in millimeter and sub-millimeter wavelengths. With this in mind, we are developing a method to produce, with enough reliability, bolometer arrays at INAOE. Until now, silicon nitride diaphragm arrays, useful as radiation absorbers, have succesfully been obtained. Sizes going from one to four millimeter by element in a consistent way; however we have not tested thermometers and metallic contact deposition yet. At the same time, we are working on two possible configurations for the readout electronics; one of them using commercial components while the other will be an integrated circuit specifically designed for this application. Both versions will work below 77K.

Key Words: instrumentation: detectors — instrumentation: miscellaneous

1. INTRODUCTION

Semiconductor bolometers, developed at INAOE, are made with a silicon nitride diaphragm suspended over a crystalline silicon frame. Over diaphragm is deposited a boron-doped hydrogenated amorphous silicon film, acting as thermometer. Main figures of merit are shown in Table 1 and a picture of two devices is shown in Figure 1.

The hypothesis we will test is that, it is possible to use an array of these bolometers and the LMT to obtain 1 to 4 millimeter wavelength astronomical images.

The main objective is to develop a bolometric detectors array for astronomical applications, including a readout circuit and a basic camera optics.

In order to fabricate the detector array, we shall know pixel size and pitch. We found 3 ways to determine pixel size:

1. First method is described by (Griffin et al. 2002). They made a comparison between bare pixel arrays and feed horn arrays, they found for a 75%

TABLE 1

FIGURES OF MERIT FOR INAOE'S MILLIMETRIC BOLOMETERS (Heredia (2004))

Figure of merit	Units	Value
NEP	$\frac{W}{\sqrt{Hz}}$	1.51×10^{-16}
TCR	%	106
D*	$\mathrm{cm}\frac{\sqrt{Hz}}{W}$	1.8×10^{14}
G_{TH}	$\frac{W}{K}$	2.3×10^{-11}
R_{BOL}	Ω	1×10^{12}
$\Re$	$\frac{V}{W}$	1×10^{11}

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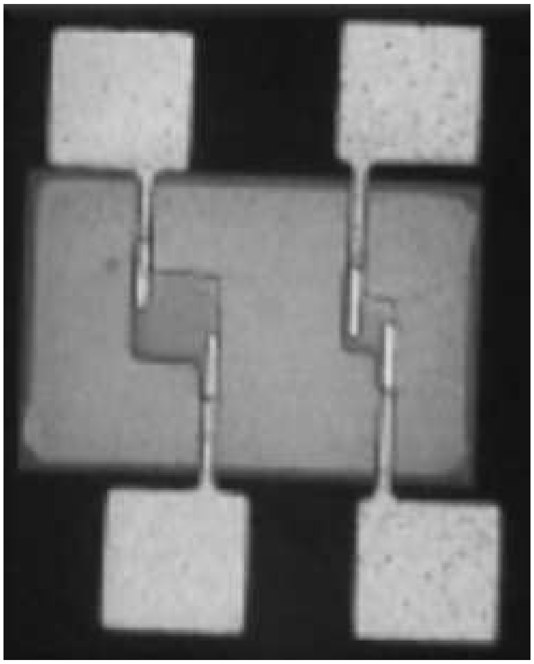

Fig. 1. Picture of two bolometers over a Silicon Nitride diaphragm developed at INAOE (Heredia 2004).

efficiency of a square detector, pixel size should be 1.5Fλ and pixel sepparation of 5% of pixel size, where F is f number of final optics system.

2. Second method is described by (Chuss et al. 2008). In this work a diffraction analysis is performed, to obtain a diffraction cross-talk between 2% and 13% around a square pixel, its size should be 2λ.

3. For the third method we apply sampling theorem to the beam size at focal plane and using beam size @ λ=3mm of 5mm, pixel size should be 2.5 mm. This data were obtained from an F4 focal reducer for LMT designed by (Vazquez y Montiel 2005, personal comm.).

Also, there are some fabrication process restrictions, mainly:

- Waffer size 2 in.
- Waffer orientation (100) front and (110) edge.
- Maximum fabrication area is 35 mm × 35 mm.
- Lithography process resolution is 50 micron.

2. METHODOLOGY

Manufacturing process is explained in (Heredia 2004). I include a very brief explanation of it:

1. Growth thermal Silicon Oxide by one side of waffer.

2. Growth Silicon Nitride on the other side of waffer by LPCVD[2].

TABLE 2

PIXEL SIZES FOR DIFFERENT METHODS AND WAVELENGTHS. (Castillo 2008). ALL DIMENTIONS ARE MILLIMETERS

λ	Griffin	Chuss	Nyquist
1	6	2	0.83
2	12	4	1.67
3	18	6	2.5
4	24	8	3.33

3. Remove selectively squares of Silicon Oxide for micro machining.

4. Micro machinning using KOH at 30% by several hours (6 or more) until entire waffer thick is removed at squared holes.

5. Next step consist in to deposit Boron doped Hydorgenated amorphous Silicon by PECVD[3].

6. Final step consists in to deposit aluminium contacts and pasivate all waffer.

In Table 2 is a resume of three way we use to calculate optimum pixel sizes at different wavelenghts.

Final pixel size we choose is 3mm *times* 3mm and arrays size is 8 × 8 elements but, also, test waffer includes an 8×8 elements of 1mm by side pixels. Actual sizes were determined to use same detectors array for different wavelegths and to test wich size is more efficient as a wavelength function.

Previous to the fabrication of final detectors array, we have several question to answer:

- Will diaphragms support their own weight?
- Which is expected dispersion in merit figures for all detectors?
- Which is the Aluminum behavior at 4.2K?
- Is contact resistance significant?
- Could the electrical resistance be reduced?

In order to answer these questions a couple experiments were design. First experiment consist on to fabricate diaphragm arrays from 1 to 4 millimeters by side. The second experiment consist in manufacture general bolometers with different contact geometry; a 8 × 8 elements array of 1 millimeter bolometers; several thermo-sensing films crosses; some thermo-sensing films strips crossed by Aluminum lines and Aluminum lines of different lengths.

It is necessary a readout electronics. There are two versions proposed, first one is a custom made integrated circuit and second one will be made with commercial components.

[2]Low Pressure Chemical Vapour Deposition.

[3]Plasma Enhanced Chemical Vapour Deposition.

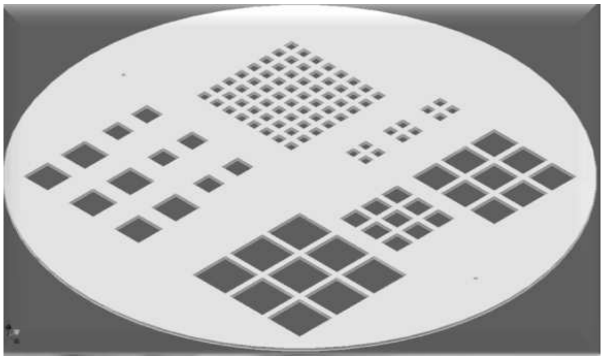

Fig. 2. 3D model for waffer micromachining structure.

Because the working temperature of readout circuit is necessary to perform an experimental characterization for commercial components version. Operational amplifiers of ultra low bias current were chosen. First experiment part includes current to voltage high gain amplifier. Second part includes instrumentation amplifiers done with same commercial parts. And third part includes tests for analog multiplexers.

All parts must be characterized at 300, 77 and 4.2K.

Moreover of detectors and readout circuit, it will be fabricated a protective case and external package.

3. PRELIMINARY RESULTS

Some 3D models for detectors in waffers were done, final wished results after micromachining are shown in Figure 2.

Figure 3 shows a simulation of micromachining of diaphragms array. There are two versions of final grid, one is obtained from sqare masks aligned with (110) edge planes and other one is rotated 45° respect same (110) edge plane. Main difference is an octagonal pattern with 4 vertical walls and 4 inclined 54.7°. Vertical walls helps to reduce thermal mass and that reduction helps to improve total sensitivitty of detector. Unfortunatelly it is not possible to use due large mass located in corners.

Experimental results for 45° rotate masks are shown in Figure 4, there are some vertical walls but there are too large masses in corners of diaphragms unabling this structure for improve sensitivitty of detectors. Full results were reported in (Castillo et al. 2008). Central breakage is due unexpected lithographyc process failure.

Figure 5 shows a picture of non rotated mask. We can see a full 8×8 elements grid. All walls are inclined 54.7°.

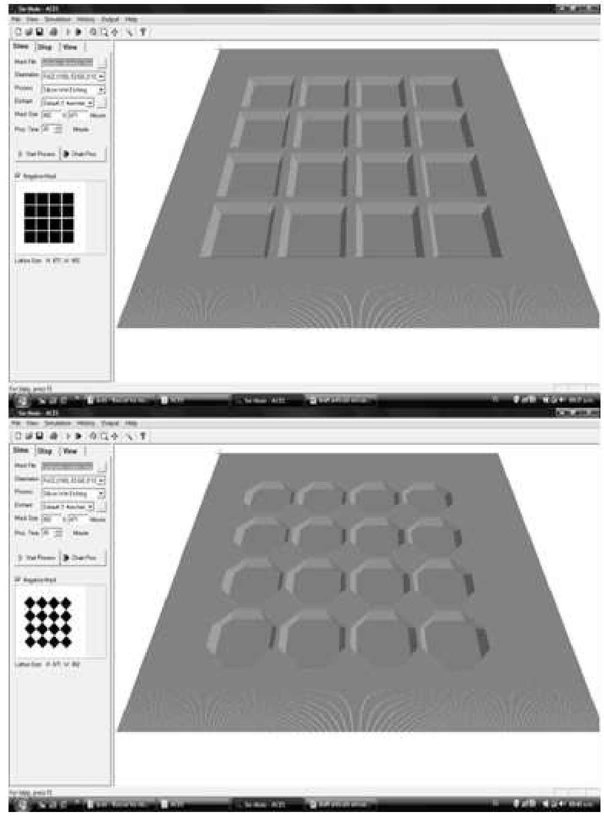

Fig. 3. 4×4 elements micro machined array simulation made with ACES with (110) planes parallel to masks (up) and rotated 45° respect same plane (bottom).

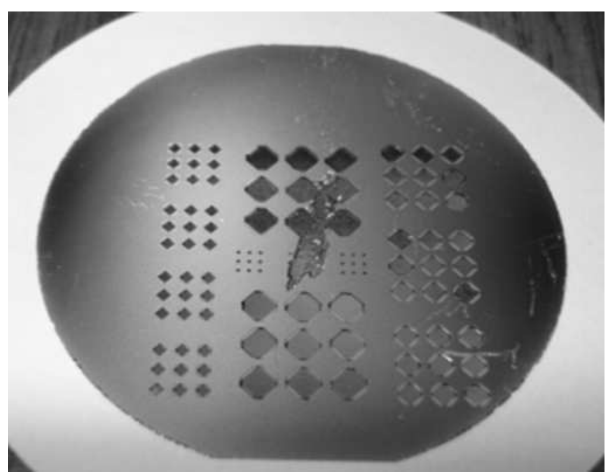

Fig. 4. Picture of 45° rotate masks waffer experimental micromachining results. All diphragm support their own weight.

A 3D model for final detectors array, including diaphragms, thermo-sensing films and Aluminum lines is shown in Figure 6.

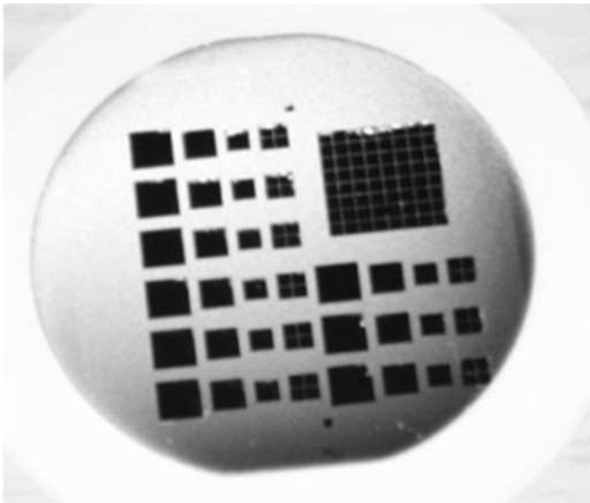

Fig. 5. Picture of 45° rotate masks waffer experimental micromachining results.

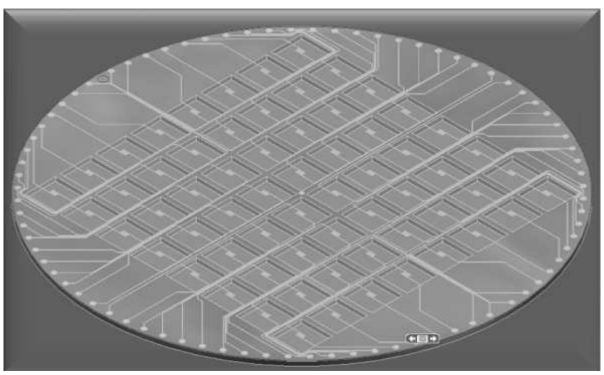

Fig. 6. 3D model for final 8×8 elements bolometer array of 3mm × 3mm.

Figure 7 shows a model for a detector package proposal, including cooper base and a Teflon® printed circuit board for external connections.

A thermo-sensing film was deposited and characterized but, only between 300K and 320K. Results obtained are similar to figures of merit in Table 1, except electrical resistance that is 25% lower. Full characterization was reported in Orduña-Díaz et al. (2008).

Also, there where some doubts abous Aluminium behavior at 4.2K, specially about its transition temperature to superconductor; but it is aroun 1.5K.

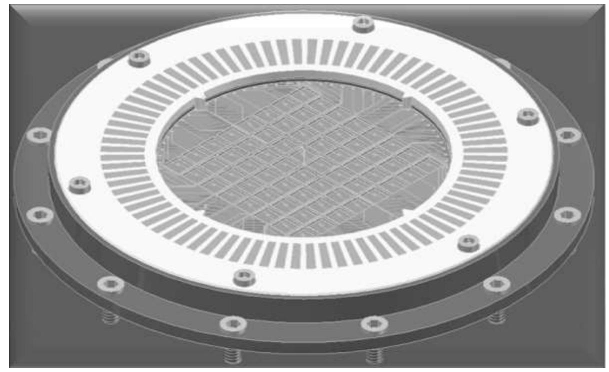

Fig. 7. 3D model for 8×8 elements bolometer, Copper base and Teflon® printed circuit board for electrical connections.

4. CONCLUSIONS

Until now, we tested that is possible to manufacture diaphragms of large sizes, up to 4 millimeters. Also we found a way to optimize thermo-sensing films, specially reducing electrical resistance, this will help to relax readout electronics specifications.

Readout electronics is on design stage and soon we will start construction and test stages. Main challenges are associated with huge resistance of detectors at low temperatures. Custom integrated versions will multiplex signals and then it will be amplify them while commercial version intend to amplify and then they will be multiplexed.

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