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Infrared Microbolometer: Design, Development and Characterization

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Abstract: In the present paper, an uncooled 32x32 pixels microbolometer array has been developed by surface micromachining technology, A suitable readout electronics was designed for reading the individual pixel value, Then array together with the electronics was characterized in front of the blackbody radiation source and results were discussed.

Keywords: Micromachining, Responsivity, MEMS, IR detectors, NEP (Noise Equivalent Power).

1. INTRODUCTION

Infrared system technology has been developed for various application including IR search and track, Medical examination, astronomy, forward looking infrared system missile guidance and other strategic equipment. Recently a dual use technology concept has been proposed which emphasizes the integration of commercial and military IR imaging system to meet both economic and defense challenges. This concept has led to the increasing research and development efforts in VLSI technology in the design of ir imaging system. In infrared focal plane array technology like detector material sensing structure, optics, coolers, readout electronics, image enhancement and intelligent signal processing results in the revolution of IR systems to new generation with significant performance improvement.

In generally Infrared FPA (Focal Plane Array) can be categorized as two major parts namely detector array and readout electronics as compared to conventional discrete design, the IR FPA has the inherent advantage of larger packing density, lower cost, reduced harness complexity, high feasibility on–chip data processing, and high adjustability for integration of the system. In the high sensitivity applications, the IR FPAs are typically fabricated with narrow band gap photon detectors and cryogenic cooling [3] is required for this environment. Thus, very challenging technologies for detection materials and system interface are required. Moreover, high performance and low temperature mixed mode circuit designs are also required for the readout electronics. To achieve the optimal overall performance of the IR FPA's, suitable circuits of good performance, power dissipation, chip area, image resolution should be made. A number of readout has been developed for different system applications and concerns.

2. Microbolometer Development

Bolometers are thermal IR detectors that absorb electromagnetic radiation and thus increase their temperature. the resulting temperature increase is a function of the radiant energy striking the bolometer and is measured with resistive temperature sensing principle .The structure of bolometer is a small resistive material, suspended above the substrate, which will reduce the thermal mass and isolating the detector from the ambient to preserve heat in the detector .This can be achieved by making self supported microbolometer as shown in Figure 1,

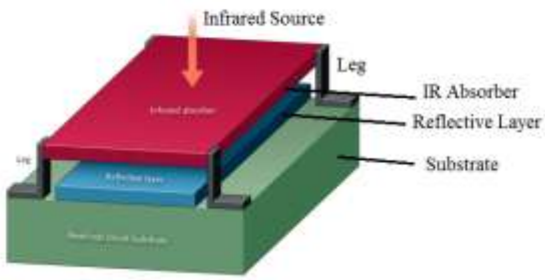

Fig. 1 Basic structure of microbolometer pixel[2]

As you can see in the Figure 2 an absorber is linked to a heat sink or substrate material through a low thermal conductance leg (G_{leg}) .When the absorber absorbs incident radiant flux (W) .The temperature increases, which causes a change in electrical resistance of the material. By measuring the resistance of a thermistor material placed on the absorber, one can find the amount of absorbed radiant flux [2]. The infrared radiation falling on the pixel is absorbed by the IR absorber, causing its temperature increase. Heat flows from the sensitive area by convection, radiation and conducts through support structures

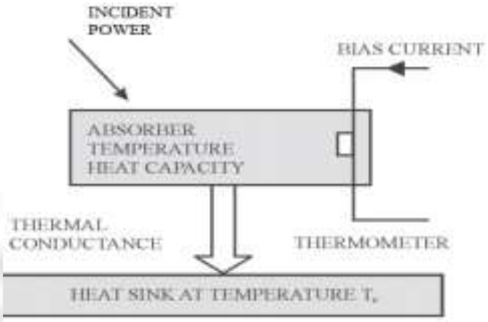

Fig. 2 Bolometer principle [4]

Being separated from the substrate not only reduces the thermal mass of the detector but also limits the loss of heat from the detector. The major paths for heat loss from the sensitive area to the ambient in this case of vacuum packaged microbolometer in the support structure which also serves as the electrical contact for measuring the change in resistance. The material for the support structure with low thermal conductivity [9] geometry dimension and evacuations of the air around the detector to operate the detector in vacuum greatly contribute to reducing the thermal conduction.

2.1 Design features

Higher Absorptivity

For getting good signal the incident infrared radiation must be absorbed by absorbing material, So it should have a high absorptivity. For increasing the absorptivity, most of the current bolometers have quarter – wavelength cavities[9] to reach absorptivities η close to 80% in the 8-14 μ[6] band .therefore only little could be gained from increasing the absorptivity.

Wider bandwidth

One could think of using materials with absorptivities high enough to not require cavities. The 3-5 μm band could then be used in conjunction with 8-14μm band. However, the NETD (Noise Equivalent Temperature of Resistance)[3] would only be marginally improved because of the low existence of blackbody sources in this band.

Change in Resistance Due To IR Radiation

The temperature sensing material is the most important element in a microbolometer. The increment in temperature in the sensing material causes a change in some temperature dependent parameter. In the case of a microbolometer that parameter is the resistance. The thermo-sensing material should have a large temperature coefficient of resistance, TCR [13] α(T) which is given in the Eq. (1)

$$\alpha = Ea/kT^2 \tag{1}$$

Where
E_a is the activation energy,
K is the Boltzmann constant and
T is temperature

Responsivity

The performance of microbolometer can be enhanced by achieving high infrared absorption at specific spectral wavelength window. Selecting IR sensing material that has high TCR and low 1/f noise. The responsivity R_v given in the Eq. (2) for a microbolometer is defined as the output voltage of microbolometer pixel per radiant power falling on the pixel. In other words it is the amount of output seen per watt of input radiant optical power,

$$R_v = \varepsilon\alpha R V_b/(G_{th}(1+\omega^2\tau^2)^{1/2}) \quad (2)$$

Where V_b is the bias current, R is the resistance of bolometer, ε is the absorptivity, G_{th} is the thermal conductance, ω is the radiation modulation frequency, τ is the thermal time constant and α is the temperature coefficient of resistance.

Thermal Time Constant

The thermal time constant τ is defined as the ratio of heat capacitance to the thermal conductance and is given in the Eq. (3). If C is the thermal capacitance and G is the thermal conductance, then.

$$\tau = C/G \quad (3)$$

Conduction mechanisms

Conduction occurs when the heat flows from the thermo sensing area along the supporting legs to the substrate. Conduction is critical when the pixels are very close, since the heat can flow from one pixel to a neighbor pixel.
Conduction loss is given in Eq. (4)

$$G_c = K(A/L) \quad (4)$$

Where,
K= thermal conductivity ($Wcm^{-2}K^{-1}$)
A= cross section area of connecting element (cm)
L= Length of the loss path.

Detectivity D*

Detectivity is defined as the root mean square value of signal to noise ratio of 1 Hz bandwidth per unit RMS incident radiant power per square root of microbolometer area. The detectivity gives information that is similar to NEP (Noise Equivalent Power). D* in Eq. (5) is the measure of signal to noise ratio normalized with respect to detector active area

$$D^* = ((A\ \Delta f)^{1/2})/NEP \quad (5)$$

where,
NEP is Noise Equivalent Power,
A is the Detector area
Δf is the Noise Bandwidth (Hz)

Noise Equivalent Power

An important figure of merit of a detector is its noise equivalent power. The minimum IR signal that can be detected by a bolometer is limited by the noise in the output signal, the noise equivalent power is defined as input power necessary to give a signal to noise ratio of unity, i.e. the incident infrared power on the bolometer pixel that generate a signal output equal to the rms value of its noise. NEP for microbolometer is given by the Eq. (6)

$$NEP = \Delta V_n/R_v \quad (6)$$

Noise Equivalent Temperature Difference

The most relevant figure of merit for bolometers used for thermal imaging is the Noise- Equivalent Temperature Difference (NETD). It is the smallest temperature change on a target that one can measure using said bolometer.

$$NETD = (8F^2T\sqrt{(kBG)})/n\tau A(\Delta P/\Delta T) \quad (7)$$

where, B= Bandwidth
$F^2 = (4F_{no.}+1)/4$
$F_{no.}$= Focal number

2.2 Fabrication Processes

MEMS technology is based on a various tools and methods [13] which are used to make small structures with dimension in the micrometer scale, in this almost all devices are built on silicon wafer and the structure are realized in thin film of materials. They are patterned using photolithographic methods. There are three main aspects to be considered in MEMS technology [13], which have the capacity to deposit thin film of materials on a substrate, to image a patterned mask on top of the film by photolithography, and selective etch the films to the mask. A MEMS process is a structured sequence of operations to form actual devices.

- Deposition Processes
- Lithography
- Etching Process

Sputter Deposition is a physical vapor deposition (PVD) method of depositing thin films by sputtering. This involves ejecting material from a "target" that is a source onto a "substrate" such as a silicon wafer. Resputtering is re-emission of the deposited material during the deposition process by ion or atom bombardment.

Lithography: It's a process where the photosensitive material used is usually a photoresist (also known as resist, other photosensitive polymers are used too). When resist is exposed to a radiation of a specific range of wavelength, the chemical resistance of the photoresist to reducing agent changes. If the resist is placed in a reducing agent after exposing selectively to a light source, it will remove one of the two regions (exposed or unexposed) by etching. If the exposed material is etched and the unexposed region is resistant, then the material is said to be a positive resist. In the other hand if the exposed region of the material is resistant and the unexposed region is removed away, then it is said to be a negative resist.

Etching Process: In order to build a working MEMS structure on a selected substrate, it is prerequisite to remove the thin films deposited before and the substrate itself by etching. Generally, etching processes is classified into two classes:

- Wet etching is a process where the resist is dissolved when immersed in a chemical reagent.
- In dry etching, etchant gasses remove the layer of substrate material. The reaction which that takes place can be carried out using high kinetic energy of particle beams, chemical reaction or by combining both.

3. Readout Electronics

The read out circuit for 32 x 32 2-D microbolometer array is to be fabricated in the underlying Si substrate, providing an IR- sensitive focal plane. The basic function of read out circuit is to apply a short bias pulse to each microbolometer pixel in an array in turn, while simultaneous measuring the signal from that microbolometer. This is quite efficient method.

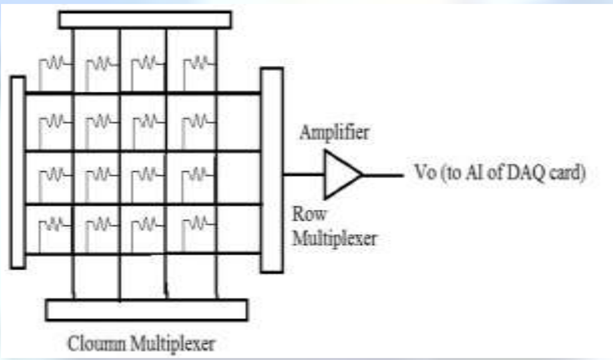

Fig 3 Pixel arrangement [16]

Addressing a pixel is carried out in such a way of that only one pixel at a time is selected, Data acquisition card is used for addressing where in the digital line to be enabled is provided with 5V internally. The bias voltage is given to the column multiplexer to enable the entire column. Multiplexer enables one of the column and similarly, addressing the row multiplexer enable one of the row. Collectively addressing both multiplexers creates the proper path so that only one pixel is active at a time.

The measured signal is branched where one is supplied to the external multiplexer (placed on PCB) which serves as a bias voltage for compensating pixels at the corners of the microbolometer array and the other one was amplified and probed to analog input of the DAQ Card which is processed as shown in the Figure 4. The multiplexers (MUX) inside the card, route one AI channel at a time to the ADC through the NI-PGIA.

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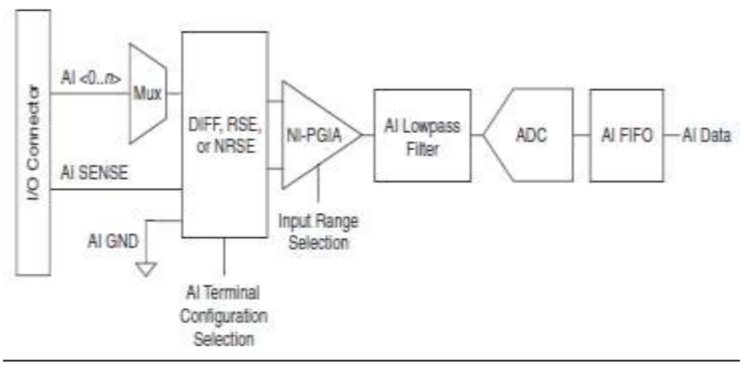

Fig 4 Analog Input Circuitry

The NI-PGIA[15] (NI Programmable Gain Instrumentation Amplifier) can amplify or attenuate an AI signal to ensure that one uses the maximum resolution of the ADC. Further a lowpass filter attenuates signals with frequencies above the cutoff frequency while passing, with minimal attenuation, signals below the cutoff frequency. Then an analog-to-digital converter (ADC) digitizes the analog input by converting the analog voltages into series of zeros and ones.

Further AI FIFO block shown in the Figure 4 can perform both single and multiple A/D conversions of a fixed or infinite number of samples. A large first-in-first-out (FIFO) buffer holds data during AI acquisitions to ensure that no data is lost. Devices can handle multiple A/D conversion operations with DMA, interrupts, or programmed I/O. Then AI data is displayed on remote PC using suitable tool.

4. Characterization

A series of experiments were carried out to measure the responsivity of the detector by keeping it in front of a black body IR radiation source. The device output was measured using data acquisition card and the signal plot was observed using matlab.

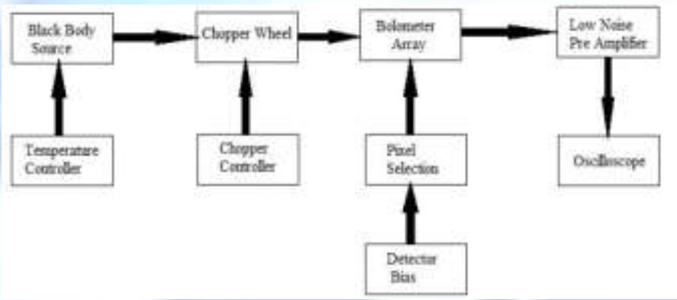

Fig. 5:The responsivity measurement setup

The radiation source is a cavity of blackbody at temperature and a filter wheel of 8 different filters. A chopper wheel with a chopper controller can modulate the radiation with variable frequency. The detector was placed in front of the blackbody without focusing and connected in bridge configuration for biasing with a voltage of 2.46V dc. The signal from the detector was amplified by a low noise pre amplifier with a gain 100 . The plot in the Figure 6 shows the response of bolometer of blackbody at 550 ^{0}C and chopper frequency of 10 Hz. The output voltage was approximately equal to the standard bolometers at similar condition

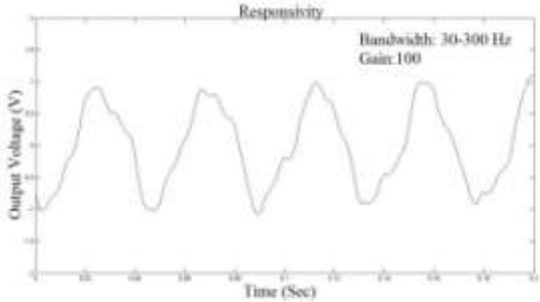

Fig 6: Output Voltage of microbolometer pixel

4.1 Spectrum Analysis [10]

The detector was placed in front of a blackbody radiation source with body temperature 70^{0}C , bias voltage 9 V was given as a input to the detector and the output is given to a low noise preamplifier with a changeable cut off frequencies ranging from 1 to 1000 Hz , then the amplifier output is given to a digital oscilloscope and to a network analyzer .

The Table1 shown below gives the output voltage for decreasing bandwidth. This implies that the maximum output is obtained at wider bandwidth.

Table 1

Bandwidth	Output voltage
3-300 Hz	5.25V
10-300Hz	4.70V
30-300Hz	3.17V
100-300Hz	1.54V

.

4.2 Noise Analysis

The setup was prepared to test the noise of the bolometer, which includes SR560 (Low Noise Pre Amplifier) and SR 770 (Network analyzer). The setup shown in the Figure 7 consists of a bolometer with bias voltage block, low noise pre amplifier and network analyzer, the amplifier was set with a constant gain 20000. The bias voltages applied to the pixel of the bolometer to obtain the noise voltage, which is amplified by low noise pre amplifier. The amplified signal is fed to network analyzer which is remotely controlled by a personal computer running a matlab program [17]

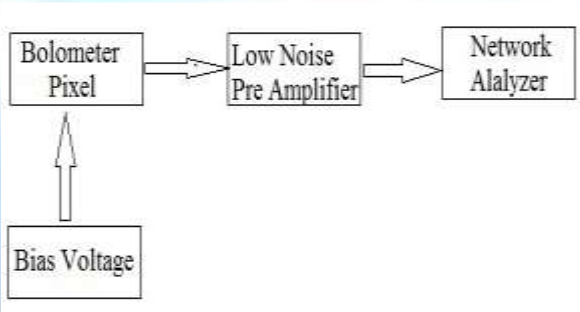

Fig7 Noise Analysis Setup

4.3 Experimental Results of Microbolometer Noise

Noise signal of two different pixels of Bolometers gain @ 22000, bias voltage 9V for two bandwidths are shown below in figure 8,9 Power Spectral Density of noise signal was plotted in log scale.

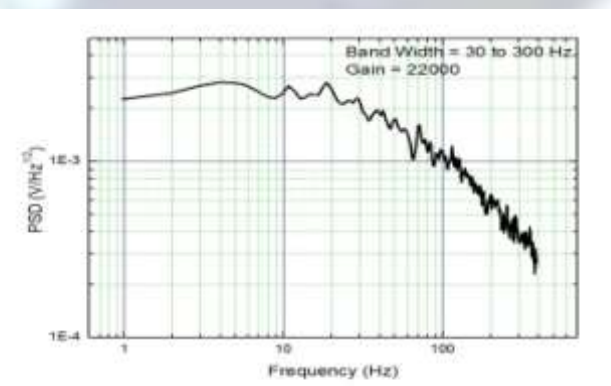

Fig 8 Noise signal for 9V bias in 30 – 300 Hz bandwidth at 22000
span 1-400 Hz measured using Network Analyzer SR 770

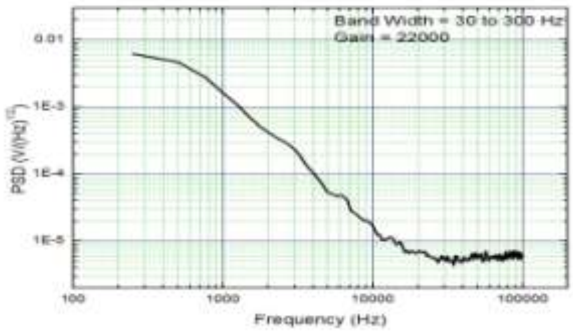

Fig 9: Noise signal of second pixel at 9V bias in 30 – 300 Hz bandwidth at 22000 span 250-100K Hz measured using Network Analyzer SR 770

Conclusion

This paper discussed the design and development of front end readout electronics for 32x32 microbolometer array. Responsivity, noise analysis was carried out successfully. The pixel output at gain 22000 in 30-300 bandwidth was found $\pm$2.4V and TCR for the chosen material is -4%K^{-1}. It's observed that the responsivity of the detector was increased as function of bandwidth. The noise analysis of the detector pixel was successfully carried out and obtained higher noise at lower bandwidth. Observed the presence of 1/f noise, Johnson noise and thermal fluctuation noise and also seen that at higher frequencies 1/f noise disappears in Johnson noise.

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Reference

[1]. A. Rogalaski and K. Charzanowski, "Infrared Device and Techniques", Institute Of Applied Physics, Institute Of Optoelectronics, Military University Of Technology, 2 kaliskiego Str, 00-908 Warsaw, Poland OPTO- ELECTRONICS REVIEW 10(2), 111-136 (2002).

[2]. P. W. Kruse, "Uncooled Thermal Imaging Arrays, Systems and Applications", SPIE Press Bellingham, WA (2002).

[3]. D. Murphy, M. Ray, R. Wyles, J Asborck , "High sensitivity 25 µm microbolometer FPA", Infrared Detectors and focal Plane arrayVII Proceedings of SPIE Vol. 4721(2002) c 2002 SPIE 0277-786/02.

[4]. Christoph Posch, Member, IEEE, Daniel Matolin, Rainer Wohlgenannt, Thomas Maier, and Martin Litzenberger "A Microbolometer Asynchronous Dynamic Vision Sensor for LWIR" IEEE SENSORS JOURNAL, VOL. 9, NO. 6, JUNE 2009.

[5]. A. H.Z. Ahmed and R Niall Tait, "Characterization Of Amorphous $Ge_xsi_xo_y$ Microbolometer Forthermal Imaging Application" IEEE Transaction on electron devices, 52(8).1900-1906 , (2005).

[6]. Frank Niklaus, Christian Vieider , Henrik Jakoben, "MEMS –Based Uncolled Infrred Bolometer Array" PROC. OF SPIE vol 68360D.2007.0277-786x/07 snd dol.10.11.17/12m.

[7]. F.N. Hooge, "1/f Noise Source" IEEE Transcriptions on Electron Device , vol 40 No 11,Noc 2004.

[8]. R.K. Bhan, R.S Saxena , C R. Jalwania, and S.K. Lomash, "Uncooled infrared microbolometer array and their characterization techniques" Solid State Physics Laboratory Delhi 110 054,Defence Science Journal Vol.59 no. 6, Nov. 2009, pp 580-589 c 2009, DESIDOC.

[9]. Jean-Luc Tissot, Sebastian Tinnes,Alain Durand, Christophe Minassian,Patrick Robert,Michel Vilain, **"**High-performance uncooled amorphous silicon video graphics array and extended graphics array infrared focal plane arrays with 17-µm pixel pitch" SPIE Digital Library Optical Engineering 50(6), 061006 (June 2011).

[10]. Mukti M Rana, Donald butler "Noise Reduction Os A Si-Ge-0 Microbolometer By Forming Gas Passivation" The University Of Texas, Department of Electrical Engineering Texas USA-76019. March 2008, Thin solid films 516 (2008).

[11]. J A Harley and T W Kenny " 1/F Noise Consideration For The Design And Process Optimization Of Pizoresistive Cantilevers" Dept. Of Mechanical Engineering, Stanford University, JMEMS , MARCH 2000.

[12]. Duy-Thong , Francois Simoens, Jean- Louis CEA Leti-MINATEC 17 rue des martyrs, 38054 Gernoble cedex9, France " Simulation And Measurements Of The Electromagnetic Response Of Broadband Thz Uncooled Anteena Coupled Microbolometer Array" MIKON 2012, 978-1-61284-1438-2/12/C 2012 IEEE.

[13]. Retrieved from: https://www.memsnet.org/material/.

[14]. Antoni Rogalski, "Infrared Detectors", Second edition ISBN 978-1-4200-7671-4 printed in USA c 2011 by Tylor and Francio group , LLC.
[15]. E L Deremik , G D Boreman, " IR detector system" published by John Wiley and Sons Inc c 1996 JWS Inc.
[16]. [Gordon R Hopkinsson,Teresa Goodman, Stuart R. Prince, "A Guide to the use and calibration of detector array equipment", published with Sira Technology ltd UK, SPIE Press USA, ISBN -0-8194-5532-6, Published by SPIE c 2004.