MEMS Technology Based Sensors for Payload Instruments and Attitude Control for Small Satellites

Alan Doctor -Barnes Engineering (Subsidiary of BF Goodrich Aerospace)

Abstract

The application of high performance low cost linear arrays of thermal detectors for use in small spacecraft is now becoming possible due to the availability of MEMS (Micro Electronic Machined Structures) technology. Large pixel count devices are now practical and affordable. MEMS based thermal sensors allow integration of the focal plane, electronics and optics within the sensor package paving the way for smaller, more affordable and better performing payload instruments such as hyperspectral radiometers, cloud mappers, as well as attitude sensors such as Earth sensors and horizon crossing indicators.

Prior to the use of MEMS technology, arrays of thermal detectors were difficult and expensive to produce and required larger geometry, pixel spacing and fill factors. MEMS produces higher performance devices (D*), reduced crosstalk between pixels and better thermal management.

Several new sensor designs have been developed and produced using MEMS technology. The improvements in cost and performance are discussed as well as new designs which are appropriate for use in payload instruments.

Introduction

The infrared optical spectrum has been used for many years to study the atmosphere, weather, geology and many natural phenomenon. IR technology is also employed in the most commonly used technique for spacecraft attitude determination (Pitch and Roll) relative to the Earth. All of these systems employ IR sensors of various types. In particular when broad band or long wavelength performance is desired the thermal sensors (bolometers, thermopiles and pyroelectrics) have been the sensors of choice. These have been produced using processes that did not lend themselves easily to high-density packaging, high performance, and are very labor intensive and thus costly.

Essentially the MEMS (Micro Electronic Machined Structures) technology advantage essentially allows the high volume production of close packed thermal isolation structures required of high performance thermal detectors. The application of high performance low cost linear arrays of thermal detectors for use in small spacecraft is now becoming possible due to the availability of MEMS technology. Large pixel count devices are now practical and affordable. MEMS produced thermal sensors allow integration of the electronics within the sensor capsule thus making smaller, more affordable and better performing payload instruments such as hyperspectral radiometers, cloud mappers, and attitude sensors such as Earth sensors and horizon crossing indicators.

IR Detectors for Space Applications

The three basic types of thermal detectors are described below along with their MEMS analog. The performances are also detailed in Table 1.

Thermistor Bolometers

Thermistor bolometers (in several different forms) have been used for many years as the primary sensor in horizon crossing indicators, scanning Earth sensors and payload instruments such as ERBE, CERES, HALOE and others.

These are basically thermistors, which are made from a material with a very high temperature coefficient of resistance (TCR.) In order to maximize the IR signal these are made with very small thermal capacitances and low thermal conductance to maximize the change in temperature of the element due to the absorbed IR radiation. The response time is also controlled by the thickness of the adhesive layer between the mounting substrate and the element. When produced by the traditional methods the thickness (thus their performance) and the center to center spacing of the elements is limited by the skill of the operator.

MEMS produced thermistor bolometers can provide high density packaging (X,Y Matrix arrays) with minimal center to center spacing and excellent fill factors . Figure 1[1] below shows a typical thermistor bolometer array used in an imaging application.

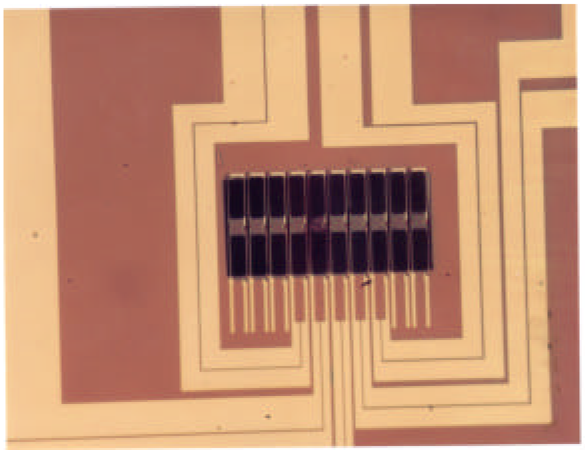

Figure 1

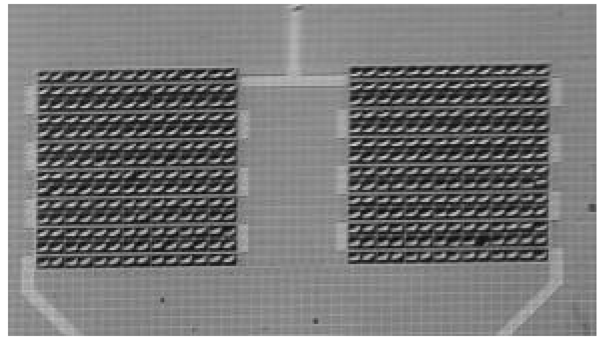

Figure 2(a)

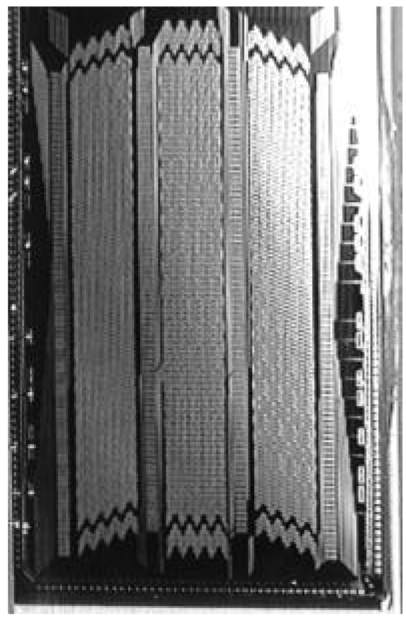

Figure 2(b)

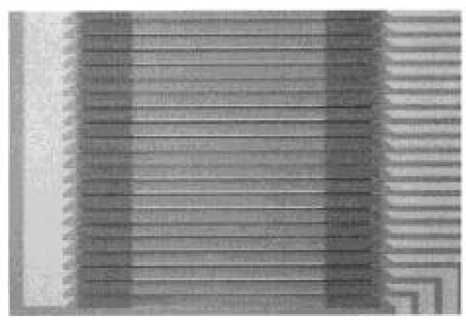

Figure 3

Thermopiles

Thermopiles have been used in many spaceborne applications where DC or staring performance is required. This is typical of Earth sensors that "ride" the horizon and respond to changes in the FOV due to a change in the "dip" angle.

Thermopiles are essentially interconnections of many small vacuum deposited thermocouples. The materials for the "couples" are selected for the highest work function differences. They produce voltages proportional to their absolute temperature. In practice "reference" junctions are placed in the detector capsule such that they do not receive IR energy thus providing an ambient reference which is subtracted from the voltage produced from the "active" couples. To maximize the signal these are thermally isolated from the mounting substrate to maximize the temperature change due to the IR signal. The performance limitations of the thermocouple are basically the choice of couples, the number and size of each couple and the thermal isolation of the active couples from the substrate mounting.

Several new instruments or radiometers have been designed and qualified using MEMS thermopiles. Figure 2(a) and 2(b)[2] show MEMS thermopiles used in a horizon crossing indicator (a) and a staring Earth sensor (b)

MEMS thermopiles have also been developed for use with diffraction grating and linear variable filter spectrographs. The spectral resolution can be greatly enhanced by the use of a large number of elements. In Figure 3[3] a MEMS linear thermopile array is depicted.

Pyroelectrics

Pyroelectric sensors are thermal detectors that respond to the rate of change of temperature. As such they are first derivative sensors and usually require that the scene be "chopped" or scanned. Although they are high output devices they are still presently produced from crystals or ceramics processed into thin plates and then mounted onto thermal isolation structures.

Currently there is much research in depositing these pyroelectric materials directly onto MEMS structures to gain the same cost/performance advantages as can be realized with thermistor bolometers and thermopiles.

Comparison of MEMS Technology and Conventional Manufacturing Techniques for IR Sensors

Table 1A Thermistor Bolometers

Parameter	Conventional	MEMS
Min.. Element Size and Spacing (mm)	0.1 x 0.1	0.025 x 0.25
Linear Array	0.1 -0.05	0.025 – 0.004 mm
Matrix Array	Not Practical	0.025 x 0.025 .010
D*	2 x 10e8	1 x 10e9
Integrated Electronics	Not Practical	YES
Cost	High	Low
NRE	Low	High

Table 1B Thermopiles

Parameter	Conventional	MEMS
Min.. Element Size and Spacing (mm)	0.1 x 0.1	0.025 x 0.25
Linear Array	0.1 mm -0.05 mm	0.025 mm – 0.004 mm
Matrix Array	Not Practical	0.025 x 0.025 .010
D*	1 x 10e8	2 x 10e9
Integrated Electronics	Not Practical	YES
Cost	High	Low
NRE	Low	High

Table 1C Pyroelectrics

Parameter	Conventional	MEMS
Min.. Element Size and Spacing (mm)	0.05 x 0.05	0.025 x 0.25
Linear Array	0.1 mm -0.05 mm	0.025 mm – 0.004 mm
Matrix Array	Not Practical	0.025 x 0.025 .010
D*	5 x 10e7	5 x 10e8
Integrated Electronics	Not Practical	YES
Cost	High	Low
NRE	Low	High

Conclusions

MEMS technology is making possible the development of many different types of thermal sensors for spaceborne instruments and operational hardware. These will be available with high performances and in the case of arrays (linear or matrix) make possible a new class of imaging and spectrographic instruments.

References

1. Private communication
2. Barnes Engineering Internal communication
3. Foote. M.C., Jones E.W, "High Performance Micromachined Thermopiles Linear Arrays" Proc. SPIE 3379 , Infrared Detectors and Focal Plane Arrays V, pp 192-197, 998