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UNCOOLED INFRARED IMAGING MICRO-CANTILEVER PIXEL BI-MATERIAL STRUCTURE WITH OPTICAL READOUT[+]

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ABSTRACT

In this presentation, we propose a novel uncooled IR imaging micro-cantilever pixel bimaterial structure (MCPBS) based on the structure invested by ORNL and Multispectral Imaging Inc. The proposed MCPBS is a thermal compensation structure and has nulling out any substrate temperature induced motion in the cantilever paddle. The new deflection induced by the temperature change has been modified by taking into account of the length of the paddle. The measurement of the deflection will be sensed by an interferometric optical readout. The analytical relationship between interferometric intensity $I(t)$ and the temperature change ΔT has been derived for the first time by using Fourier series. The relationship has taken into account the dynamical response of structure due to the change of the temperature change ΔT.

Key words: Uncooled IR Imaging, Micro-Cantilever Pixel, Bimaterial Structure, Optical Interferometric Readout

1. INTRODUCTION

Infrared imaging sensors that operate without cryogenic cooling have the great potential to provide commercial and military users with exceptional night vision capabilities. Considerable progress has been made in recent years reducing the pixel size while improving the imaging sensitivity by using micro-cantilever type structure technology.

There are several advantages for un-cooled infrared imaging systems using optical readout, such as, eliminating electrical interconnects that are required on each pixel for electrical readout. The absence of highly thermally conductive interconnects leads to better thermal isolation of the pixels and a simpler micro fabrication process. Hence, the uncooled infrared imaging system with optical readout provides an inexpensive, high performance, low-power consumption and light-weight solution.

A micro-cantilever based sensor can detect extremely small external stimuli that include temperature and surface stress changes. It has been successfully applied to thermal and infrared sensing. In all these cases, the cantilever produced either a static or its resonance frequency changes. Deflection sensing methods can be divided into two categories: electrical and optical. Although the electrical method, including capacitance and piezo-resistive sensing, is promising due to its compatibility with electric signal processing, it is limited due to lack of thermal isolation and Johnson noise. Furthermore, for piezo-resistive sensing, there are technological limits in fabricating a thin, highly sensitive cantilever. The most common readout techniques for cantilever motion are optical including optical lever and interferometric methods. These optical methods can detect cantilever motion with sub-Angstrom resolution limited only by thermal vibration noise.

In this paper, based on the work of [1], we extend its design to a microcantilever with a mirror to form a novel optical readout. In this presentation, we propose a novel uncooled IR imaging micro-cantilever pixel bimaterial structure (MCPBS) based on the structure invested by ORNL and Multispectral Imaging Inc. The proposed MCPBS

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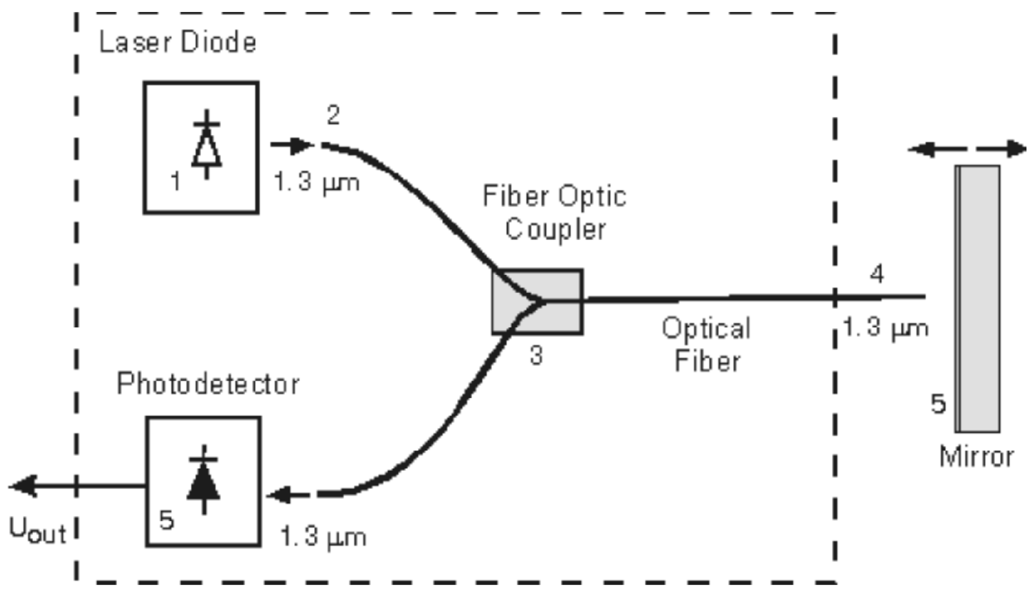
is a thermal compensation structure and has nulling out any substrate temperature induced motion in the cantilever paddle. The new deflection induced by the temperature change has been modified by taking into account of the length of the paddle. The measurement of the deflection will be sensed by an interferometric optical readout. The analytical relationship between interferometric intensity $I(t)$ and the temperature change ΔT has been derived for the first time by using Fourier series. The relationship has taken into account the dynamical response of structure due to the change of the temperature change ΔT.

2. MICRO-CANTILEVER PIXEL BIMATERIAL STRUCTURE (MCPBS) WITH MIRROR

The microcantilever sensor structure has been used for infrared detector arrays. The bi-material microcantilever pixel structure proposed in [1] is a quite good structure, which enable the sensor to be operated without a thermoelectric cooler to stabilize the sensor operating temperature.

A schematic diagram of a generic, optically sensed microcantilever sensor is shown in Figure 1. The microcantilever is attached electrically and mechanically to the substrate at one end by an anchor, and the cantilever end is free to bend under the influence of any changes in stress along the arm. [1]

The operation of a microcantilever structures as an infrared detector can be described as follows: Infrared radiation is absorbed by the microcantilever paddle using the absorption of the paddle materials along with a tuned resonant IR absorption cavity. The absorber region is composed of a SiO_2 / SiON substrate layer and a thin TiN layer used to match the free space impedance for the resonant cavity.



The absorbed radiation is converted to heat in the microcantilever structure and it is thermally isolated from the substrate by thermal isolation arms. The isolation arms are composed of SiO_2 / SiON dielectric materials that possess high thermal impedances, and over coated with thin layer of TiN to provide electrical continuity to the substrate electronics. The bi-materials beam is designed in such way that it deforms only “bending out”, rather than down into, the plane of the sensor. The bottom of the absorption paddle is coated in Al for the reflection of light.

During operation, when the microcantilever sensor is exposed to the IR radiation, the paddle moves up and tip deflection due to the change of temperature from T_0 to T can be calculated as:

$$\Delta Z = \tfrac{3L_P^2}{8t_{bi}} K_0 (\alpha_{bi} - \alpha_{subs})(T - T_0), \qquad (1)$$

where L_P is the length of the bi-materials section of the cantilever sensor, t_{bi} is its thickness (AL Alloy), α_{bi} and α_{subs} are the bimaterials (Al alloy) and substrate (SiO_2/SiON) thermal expansions, respectively, and the constant $K_0 = \frac{8(1+x)}{4+6x+4x^2+nx^3+(nx)^{-1}}$, $x = \frac{\mathrm{t_{subs}}}{\mathrm{t_{bi}}}$, $n = \frac{\mathrm{E_{sunbs}}}{\mathrm{E_{bi}}}$, t is the thickness and E is Younf’s moduli.

3. OPERATION OF MICRO-CANTILEVER PIXEL BIMATERIAL STRUCTURE (MCPBS) WITH MIRROR

The phenomenon of the interference of light underlies many high-precision measuring systems and displacement sensors. The use of optical fibers allows to make such devices extremely compact and economic.

The radiation of the laser diode 1 is coupled into the fiber 2 and propagates through the coupler 3 to fiber 4. Then, one part of radiation is reflected from the end face of the fiber 4 and other part of radiation is flashed into the air, reflected from the mirror 5 and returned back into the fiber 4. The optical beam reflected from the end face of the fiber 4 interferes with the beam reflected from the mirror. As a result the intensity of the optical radiation at photodetector 5 is periodically changed depending on the distance x_0 between the fiber and mirror.

we shall consider the interferometric signal appearing as a result of the reflection of the light from the vibrating surface (resonator). When the resonator oscillates, the phase difference of interfering rays is varied as follows: $\Delta\varphi = \frac{2\pi}{\lambda}\Delta L = \frac{4\pi l_0}{\lambda} + \frac{4\pi}{\lambda}\Delta Z$, where λ is the wavelength, y is the amplitude of resonator vibration. This gives rise to the following modulation of the light intensity reflected from the interferometer cavity: $I(t) = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\left(\frac{4\pi l_0}{\lambda} + \frac{4\pi}{\lambda}\Delta Z\right)$, I_1 and I_2 are intensities of these two rays. It can be modulated as $I(t) \approx \cos\left\{\frac{4\pi l_0}{\lambda} + \frac{4\pi}{\lambda}\Delta Z\right\}$. Expanding it into Fourier series and Bessel function, then we have liberalized sensing equation as follows: $I(t) \approx -\frac{4\pi}{\lambda}\sin\left(\frac{4\pi l_0}{\lambda}\right)\Delta Z$. So we have

$$I(t) \approx -\frac{4\pi}{\lambda}\sin\left(\frac{4\pi l_0}{\lambda}\right), \frac{3L_P^2}{8t_{bi}}(\alpha_{bi} - b_{sunbs})(T - T_0)K_0 \tag{2}$$

or the temperature distribution can be sensing by detecting the light density:

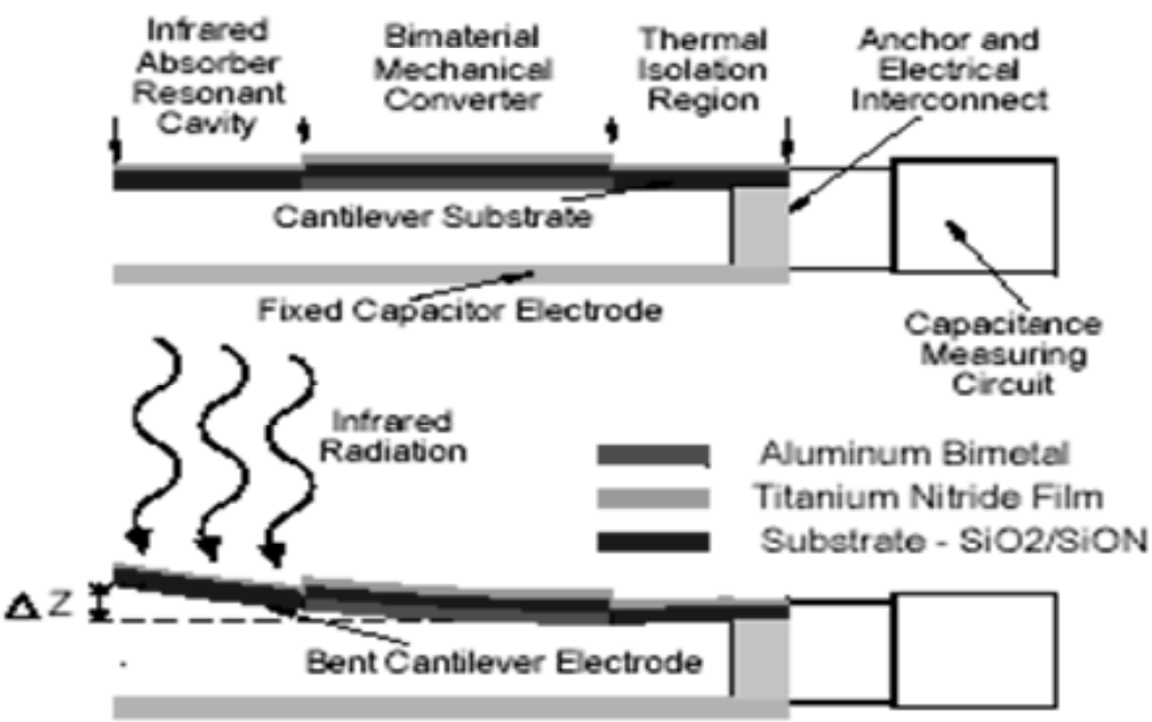


Figure 1: Schematic Diagram Schowing the Operating Principle of the Bimorph Microcantilever IR Sensor

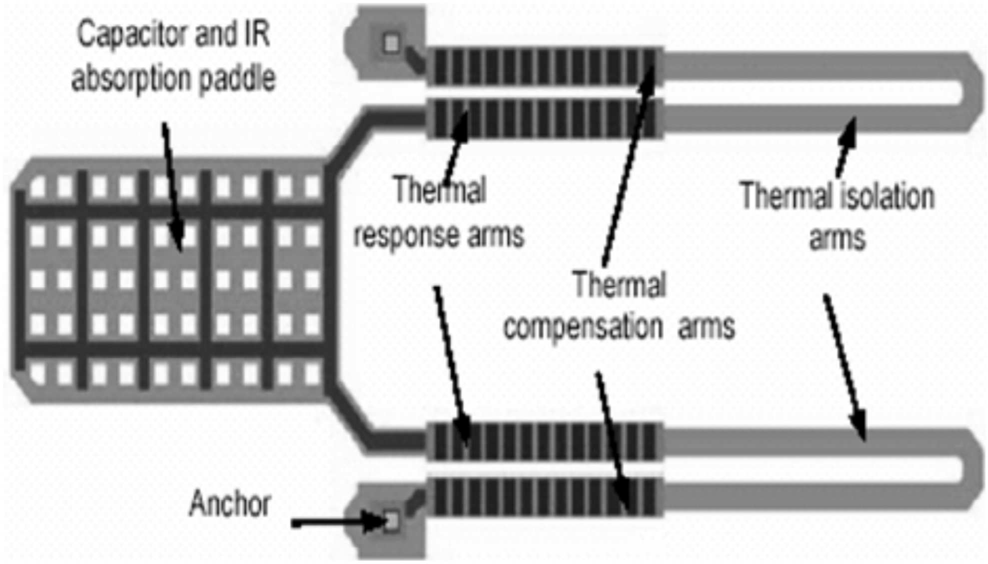


Figure 2: Schematic Diagram of the Thermally Compensated 25 µm Pixel pitch IR Sensor Structre

$$\Delta T = T - T_0 = -[\sin\left(\frac{4\pi l_0}{\lambda}\right)]^{-1}\frac{\lambda}{4\pi}\frac{8t_{bi}}{3L_P^2(\alpha_{bi}-\alpha_{sunbs})}I(t), \tag{3}$$

We can also define ration of temperature/density of the sensor is given by:

$$R_I = \Delta T / I(t) = -[\sin\left(\frac{4\pi l_0}{\lambda}\right)]^{-1}\frac{\lambda}{4\pi}\frac{8t_{bi}}{3L_P^2(\alpha_{bi}-\alpha_{sunbs})}, \tag{4}$$

4. CONCLUSION

The temperature distribution has been presented in linear of the light density will maintain good linearity. To get larger temperature sensitivity require longer wave length of light and shorter and thicker beam, and bigger difference of thermal coefficients.

References

[1] S. R. Hunter, G. Maurer, L. J. Jiang and G. Simelgor, High Sensitivity Uncooled Microcantilever Infrared Imaging Arrays, *SPIE Defense and Security Symposium*, April 19, 2006, SPIE XXXII, Vol. 6206.