Journal of Advance Research in Science and Social Science (JARSSC) ISSN: 2582-2004
Volume 02, Issue 01

BI METALLIC MICRO CANTILEVER UN COOLED IR SENSORS

Dr. Abdul Quayoum
Department of Physics, Amiruddaula Islamia Degree College, Lucknow

Abstract

Infrared imaging plays a critical role in many applications ranging from night vision, environmental monitoring, astronomy, biomedical diagnostic and thermal probing of active microelectronic devices. The development of un cooled detectors arrays started in the early 1980s. By the end of the last century, large focal plane arrays of resistive bolometer and ferroelectric devices.

***Keywords**: Infrared imaging, Night vision, detectors, IR video camera*

Introduction: Electromagnetic radiations play an important role in our everyday life. Out of these radiations, IR and MMW [1] are most important. Do we know that a page of paper at room temperature emits 13.5wattsof infrared energy and human body having area of say 2sq.m emits more than 90watts continuously. The sun emits 10^5 times more than human being. Out of this more than 50% of sun's energy lies in the infrared. After its discovery by Sir William Herschel in 1800, these radiations have found niche in our daily life like IR oven for cooking meals, drying paints, IR video cameras permit us to see in the dark, plot weather conditions from satellites, detect breast cancer and more than anything else has proved to be the lifeline of our armed forces since Second World War. Infrared imaging sensors that operate without cryogenic cooling have the potential to provide commercial and military users with exceptional night vision capabilities packaged in a device of extremely small size, weight and power. Infrared imaging plays a critical role in many applications ranging from night vision, environmental monitoring, astronomy, biomedical diagnostic and thermal probing of active microelectronic devices.

IR detectors could be divided in to two categories:

a) Photon/quantum detectors due to photon-electron interactions,

b) Thermal/square law detectors due to photon-phonon interactions.

Quantum detectors photons interact directly with electrons; therefore their response is proportional to the no of photons absorbed. Photon detectors usually have higher sensitivity& faster response but their spectral response varies with wavelength. Since they are based on low band gap (Eg~0.1ev) semiconductors, which make them highly susceptible to thermal noise and necessitates operation at about 80K.The added cost, weight and reliability problems of the required cryogenics have driven research towards un cooled photo thermal IR detectors. Infrared radiations falling on such detectors are absorbed by the material and raise its temperature. The heating effect produces a change in one of the properties of material such as electrical resistance (bolometric), spontaneous polarisability (pyroelectric effect) or expansion of gases leading to thermistor bolometer, pyroelectric & Golay cells type of detectors.

The development of un cooled detectors arrays started in the early 1980s. By the end of the last century, large focal plane arrays of resistive bolometer and ferroelectric devices with 320x240 pixels were available giving NETD values as low as 40mK Micro bolometer exhibited a NETD of 23mK at a 60Hzframe rate However the reported average NETD of these sensors is around 35mk with an aperture of F/1 and operating at 30Hz frame rates. The challenge facing existing and future un cooled IR imagers is to achieve NETD values of only a few mK i.e. performance equals the best cooled photonic devices, while reaching the resolution of high definition television.

Thermal detectors in general have three distinct parts: i) an IR absorber ii) a thermal isolator &iii) a transducer which converts temperature change to a change in the measurable electrical parameter. In this category the un cooled vanadium oxide (VOx) and amorphous silicon (a-Si) micro bolometer are the technologies of the choice for thermal imaging cameras. However, the performance of these devices has not improved significantly in recent years and studies indicate that these technologies may be reaching their performance limits (1, 2). Because of these sensitivity limitations & the still appreciable cost of microbolometers efforts are on to have a much cheaper & more sensitive un cooled IR detector for military & commercial applications.

Due to above said reasons, researcher's world over have come out with the most promising IR sensing methods to use thermally actuated micro electro- mechanical structures (MEMS). One of such devices is bimorph micro cantilevers that mechanically respond by undergoing bending when IR photons are absorbed. Earlier study have shown that micromechanical deformation can readily be determined by a number of means, including optical, capacititive, piezoresistive and electron tunneling with extremely high sensitivity. I will try to briefly describe the principle, fabrication and performance parameters of bimorph micro cantilever un cooled IR sensor and the summary of the progress made so far.

Why micro cantilevers: Apart from one of the attractive features of uncooled IR detectors viz the ability for monolithic integration and compatibility with CMOS technology, the following factors have added advantage in favour of micro cantilevers.

a) An order of magnitude improvement in NETD due to extremely high sensitivity and low noise.

b) low cost due to 100% silicon IC compatibility,

c) High image quality and increased yield due to its ability to do offset & sensitivity corrections on the imager, pixel by pixel;

d) No cryogenic cooler and no high vacuum processing

e) High dynamic range –a true 14 bit dynamic range (capable of >16 bit operation) with a linear response at small signals and gap changes and logarithmic response at large signals up to 2000K.

Basic Principles of Micro Cantilever IR Detectors: The micro cantilever sensor structure being described here is based on a capacitative bridge detection circuit. Four primary components make up the typical design of a micro cantilever based IR detector. One component is an IR absorber and sensing bi material plate. Bimetals were known as early as 18th century. The use of bi material elements in MEMS technology [2-5] was proposed by Halsor in 1975 but real progress seems to have taken place in last decade.The term bi material denotes a sandwich structure consisting of two firmly connected thin plates of different materials termed components. These components are chosen to have significantly different coefficient of thermal expansion. When heated each component expands differently in proportion to its coefficient of thermal expansion. Since solid bodies tend to keep their volume unchanged, internal stresses developed tend to bend the bi material device into an arc.

The bi material plate consists of a Si Nx layer on the top that absorbs IR radiation and converts it to heat and an aluminum/gold metal layer on the bottom that serves as a sensing component for capacitance read out. In this design an Al layer is used as a top electrode. The second component is a bottom electrode located underneath. These two electrodes together form a capacitor. The third component is the actuation legs that convert heat from the absorber to mechanical deformations. Finally the fourth component is thermal isolator that minimizes the amount of heat conducted to the substrates as shown in Fig.1. When the sensing bi material plate transfers IR radiation to heat or temperature change it deforms due to the mismatch of coefficient of thermal expansion. The capacitance between the bi material plate and the bottom electrode changes. The bi material actuation legs also bend, since the heat from the sensing plate is conducted to the legs.

Fabrication Process: The bi material (SiNx/Al) micro cantilever structure could be fabricated on a (100) silicon wafer. The wafer is cleaned with 40% HF to remove the native oxide layer.

The thermal isolation regions consists of SiNx only and are thinned & narrowed as compared to the rest of the legs in order to improve thermal isolation between the micro cantilever & the base.

Schematic diagram of bi metallic micro cantilever infrared detector operating principle is shown in fig.1. The IR radiation absorbing area, which is formed from a tuned transmission line that converts the infrared radiation in to heat, also forms the top plate of a variable plate capacitor. The bi material element converts the heat into mechanical movement similar to a thermostat. The two materials (the cantilever substrate & bimetal layer) are selected to have maximum difference in their coefficient of thermal expansion (CTE). To prevent the heat generated from the conversion of the IR radiation from being shunted to the substrate a thermal isolation support is provided.

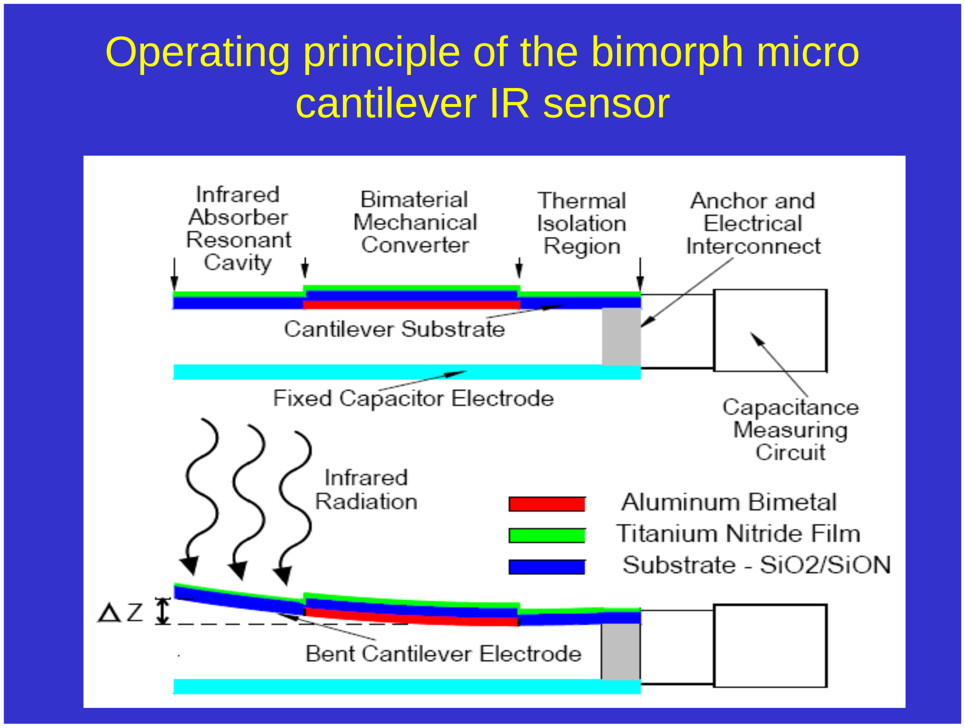

Fig 1 Schematic diagram of bi metallic micro cantilever infrared detector operating principle

Fig 2 shows the schematic diagram of the thermally compensated IR sensor structure. Silicon nitride micro cantilever with a thin gold/aluminum film on one side undergo a measurable bending in response to minute temperature changes. In such a case, the differential stress in the cantilever is created due to dissimilar coefficient of thermal expansion of silicon nitride substrate & the gold/Al coating. Temperatures of 10^{-4} to 10^{-5} K could be measured. The deflection of the micro cantilever tipwhen sensor temperature increases

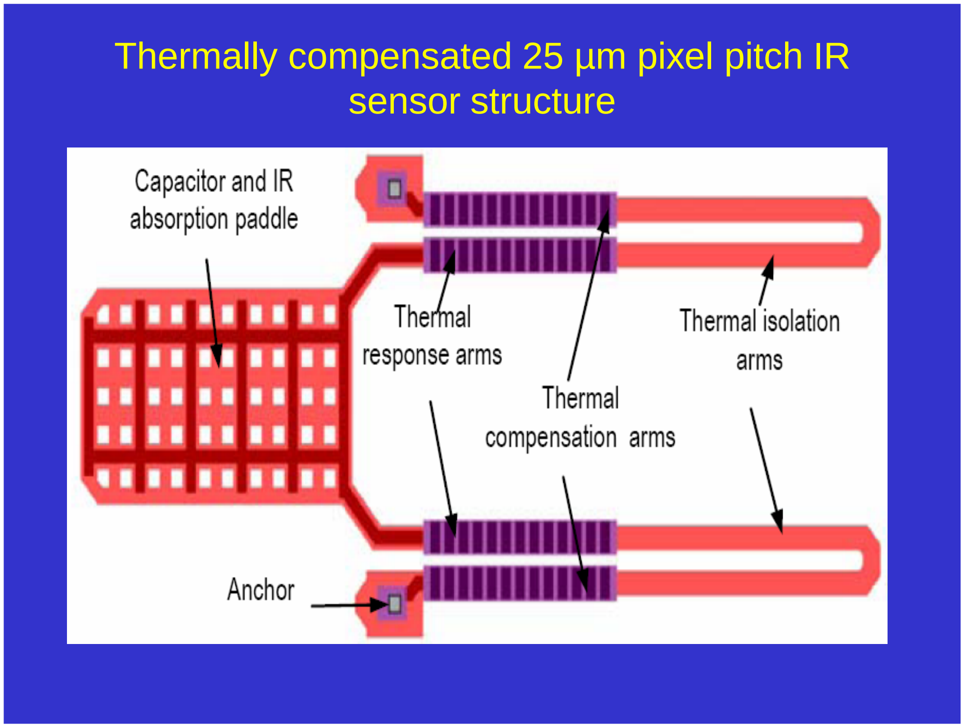

Fig 2Thermally compensated IR sensor structure.

from T_0 to T due to the absorption of the IR radiation is given by following equation in Fig3.

$$\Delta Z = (3L_P{}^2/8t_{bi})(\alpha_{bi} - \alpha_{subs})(T - T_o)K_o$$

Where

ΔZ = The deflection of the microcantilever tip

Lp = Length of the bimaterial section of the sensor

t_{bi} = Thickness of the bimaterial layer

α_{bi} = Thermal Coeff. of exp of the bimetal

α_{subs} = Thermal Coeff. of exp of the Substrate

$T-T_o$ =Differential absolute temperature

K_o = Constant

Fig 3- deflection delta Z of the tip of micro cantilever.

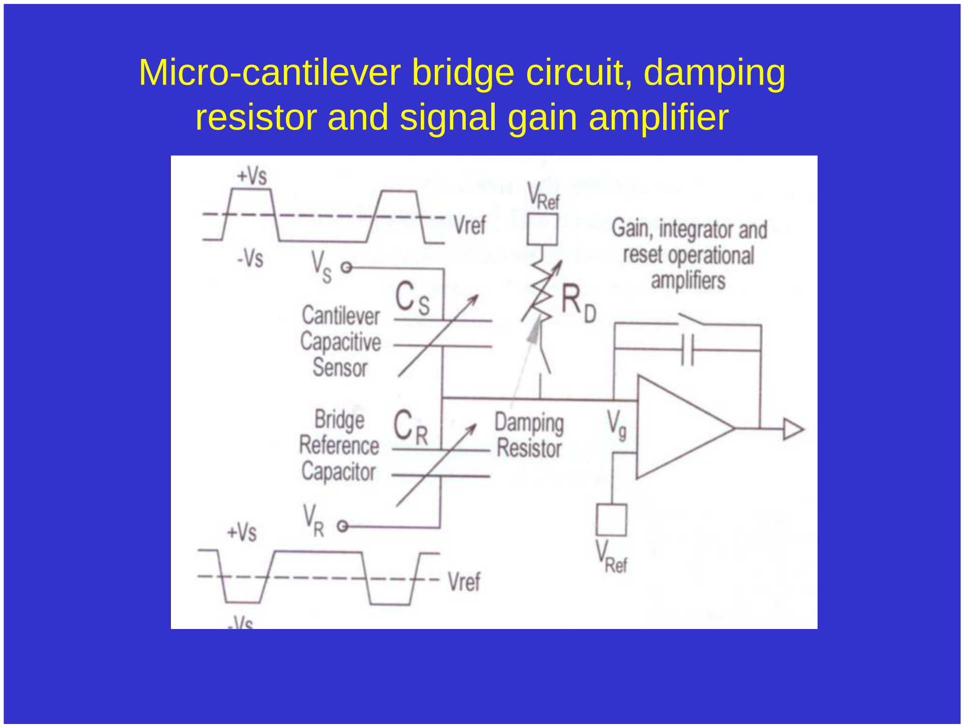

Fig.4. Micro cantilever bridge measuring circuit

IR radiation sensing technique: As can be seen in Fig4.the micro cantilever sensor operation forms part of the two capacitor bridge circuit. The sensor is energized by applying symmetric, oppositely phased voltage pulses+- Vs to the cantilever & bridge reference capacitors Cs and Cg respectively around a reference voltage .If the cantilever and bridge capacitances are the same size and Vs & Vg are of opposite sign then the voltage appearing at the common node between the capacitors are zero. The damping resistor circuit is used to dampen any mechanical motion in the sensor. During operation when the micro cantilever sensor is exposed to the IR radiation, the paddle moves up, increasing the capacitor gap, thereby decreasing the sensor capacitance and generating an offset voltage Vg at the common node and at the input to the gain and integrator circuit.

Performance Parameters: An ideal un cooled IR imager should usually perform at a frame rate of 30, thermal time constant 10ms, IR spectral band1-100um, fill factor 100% F/no 1, pixel area say 2500um^2, having absorber top side emissivity1 and bottom side emissivity 0.However, the ultimate performance will be dictated by actual fill factor, emissivity and their spectral band sensitivity, on the level of thermal isolation, and sensitivity of the thermal sensing mechanism. Thus the most important parameter NETD can be improved in two ways: 1) reduce optical thermal transfer coefficient by increasing thermal isolation and IR absorption and 2) increase sensitivity dV/dT.

The predominant noise source is the thermal and trapping noise associated with the pixel source follower transistor in the thermal circuit. The thermal noise generated in the transistor switches is negligible. The kTC noise generated by resetting the sense node capacitance as well as the 1/f noise in the pixel source follower can be suppressed by correlated double sampling.

Thermal sensors are inherently slow in responding to rapidly changing scene temperatures and image conditions when compared with quantum based optical sensors for video imaging applications with frame rates 30/60, the thermal response time of the detector should be less than 15msec and preferably 10msec.In fact there is usually a tradeoff between the sensor sensitivity and thermal response time- the faster the response time, the lower the sensitivity of the sensor.

Conclusion: Thermal imaging technology for the defense and commercial applications are impinging on the development of capacitive sensed micro cantilever based IR detectors that promises to outperform the current generation of micro bolometer devices on the market today.

Details about a few of the complete MEMS micro cantilever sensor structures have been described. Performance of such sensors parameters are briefly discussed.

Reference:

1. Flight simulator with IR and MMW radar image generation capabilities art. no. 62260A, June 2006, Proceedings of SPIE - The International Society for Optical Engineering 6226, DOI:10.1117/12.674533.
2. N.-T. Nguyen, S. A. M. Shaegh, N. Kashaninejad, and D.-T. Phan, "Design, fabrication and characterization of drug delivery systems based on lab-on-a-chip technology," Advanced drug delivery reviews (2013).
3. M. Bourne, A Consumer's Guide to MEMS & Nanotechnology, Bourne Research LLC, 1st edition, 2007.
4. BioMEMS 2013: Microsystem Device Market for Healthcare Applications, Yole Developpment, France, Feb. 2013.
5. C.D. Chin, V. Linder, and S. K. Sia. "Commercialization of microfluidic point-of-care diagnostic devices," Lab on a Chip 12.12 (2012): 2118-2134.