Optical Readout of MEMS-Based Infrared Detectors

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Abstract:

In this project, we construct and characterize a simple optical readout system for a bimorph microelectromechanical system (MEMS)-based infrared detector array. In our project, a bimorph MEMS is a heat absorbing pixel attached to a bimorph beam consisting of two different materials, each with different coefficients of thermal expansion (CTE). The difference in CTE causes the beam to deform when exposed to IR radiation, and the angular deflection may be measured optically using a laser and a beam position detector.

Introduction:

The imager we are attempting to build consists of an array of bimorph MEMS beams with a heat absorbing pixel attached to each beam. The pixel absorbs incoming IR radiation, and the heat spreads to the beam, causing the beam to bend and hence the pixel to deflect. The angular deflection in the pixel is proportional to the change in temperature ΔT, and can be measured by reflecting a laser off the pixel's surface and into a detector. The laser can be made to scan across the array of pixels, giving a ΔT measurement for each pixel. The measurements can then be constructed into an image.

The specific focus of my internship on this project was to develop and analyze a rudimentary model of the optical readout system. In my model, illustrated in Figure 1, a collimated laser beam with $\lambda = 670$ nm is focused using a lens onto the MEMS array plane. The beam is then reflected into a second lens which focuses the beam into a differential detector.

Analysis of Differential Detector:

The differential detector is a quad photodiode which is configured to output a voltage proportional to the difference in current generated by the left and right halves, given by Eq.1, Eq.2, and Eq.3. *R* is the responsivity of the detector, *P* is the incident power, *d* is the horizontal distance from the beam center to the center of the differential detector, *w* is the radius of the beam incident on the detector, *G* is the length of the detector quad, and *g* is the width of the gap between the detector cells. If the focal length of the second lens is f_2, then *d* can easily be converted to Φ, the angular deflection of the reflecting surface, using Eq.4.

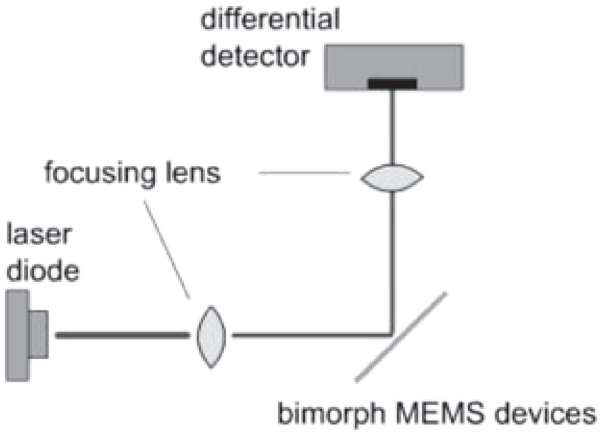

Figure 1: Optical readout system.

The integrals in Eq.2 and Eq.3 are difficult to solve analytically, but one notes that they are simply Gaussian distribution functions with mean $\mu = d$ and

$$V_{out} = (I_R - I_L)\cdot 10^4\, volts = \Delta I \cdot 10^4\, volts \qquad \text{Eq.1}$$

$$I_R = \Re P \frac{\int_{g/2}^{+G/2} \exp\left[-2\left(\frac{x-d}{w}\right)^2\right]dx}{\int_{-\infty}^{+\infty} \exp\left[-2\left(\frac{x-d}{w}\right)^2\right]dx} \qquad \text{Eq.2}$$

$$I_L = \Re P \frac{\int_{-G/2}^{-g/2} \exp\left[-2\left(\frac{x-d}{w}\right)^2\right]dx}{\int_{-\infty}^{+\infty} \exp\left[-2\left(\frac{x-d}{w}\right)^2\right]dx} \qquad \text{Eq.3}$$

$$d = 2 f_2 \phi \qquad \text{Eq.4}$$

$$i_{shot} = \sqrt{2e\Delta f\,(I_R + I_L)} \qquad \text{Eq.5}$$

standard deviation σ = *w*/2. Using values relevant to our setup, and varying between three different values for beam radius, we obtain the plot of voltage response to angular deflection given in Figure 2. In the region near zero, the voltage response is approximately linear. As the angle increases, the sensitivity of the detector decreases. It is important to note that after a particular angle, the detector is no longer sensitive to changes. This implies that in my particular readout system there is a maximum detectable angle, and hence, temperature change. If the incident beam radius is made smaller, the sensitivity near zero increases (higher $dV/d\Phi$) but the maximum detectable angle decreases as well.

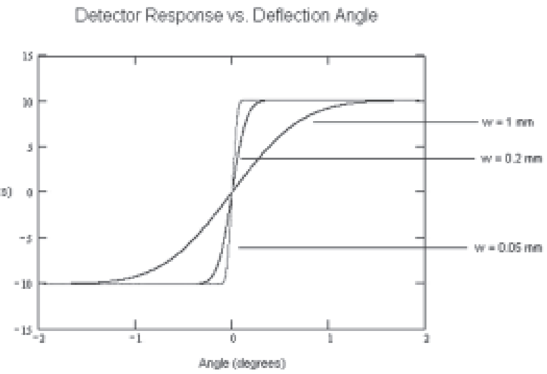

Figure 2: Differential detector response.

Noise Limited Sensitivity:

The output current ΔI and the shot noise i_{shot} in the differential detector are both functions of the angular deflection Φ in the bimorph devices, which is in turn a function of the temperature change of the device ΔT. The exact relation is beyond the scope of this paper; for these purposes, it is sufficient to know that the relation is linear. The minimum detectable temperature change, ΔT_{min}, is the change in temperature for which the output current equals the shot noise. The shot noise is given by Eq.5 where *e* is the charge of an electron and Δf is the bandwidth of the detector, here assumed to be 30 Hz. ΔI and i_{shot} are plotted for various beam radii on Figure 3. The points of intersection are ΔT_{min}.

As expected, a smaller beam radius yields a higher sensitivity (lower ΔT_{min}). It is apparent, however, that regardless of the beam radius, ΔT_{min} is very small, on the order of μK, well within our sensitivity requirements. This analysis on ΔT_{min} is valid only when shot noise is dominant over all other noise effects. At the time of writing, such was not the case. We detect noise levels of about 1 mK due to unknown causes.

Conclusion and Future Work:

The analysis above shows how the system we constructed behaves according to the angular deflections on the MEMS plane. We have also showed that there are limits to the range of detectable temperature changes, based on the radius of the beam incident on the differential detector. Future work on this project will focus primarily on reducing noise. Possible sources for noise include vibrations in the ground, pressure waves in the air, and thermal leakage from the devices. As of yet we have not fabricated a detectably working MEMS device. When we have done so, we can characterize its response to heat and answer certain important questions as: how fast does the beam bend in response to heat, and how does the source temperature correspond to change in device temperature? When we have a full model for the behavior of a particular system we may begin working on automating the readout system for a full implementation of the imager.

Acknowledgements:

I would like to thank my mentor Raja Jindal and my principal investigator Dr. John Bowers for their patience and support for this project. I would also especially like to thank all the members of Dr. Bowers' research group for making me feel welcome and for helping me with all the questions I've had.

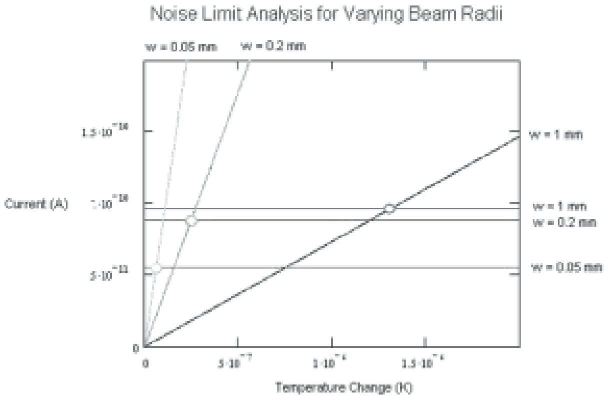

Figure 3: Noise limit sensitivity analysis.