Thermal-mechanical Detector Array with Integrated Diffraction Grating

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***Abstract*-An uncooled thermal detector array with low NETD is designed and fabricated using MEMS bimaterial structures. A diffraction grating is embedded on the pixel membrane for sensing sub-nm mechanical deflections. The first order reflected light was focused on a CCD camera to monitor the entire array. Results show that it is possible to achieve <50mK NETD using a 12 bit CCD camera.**

I. INTRODUCTION

Design and fabrication of a novel uncooled opto - mechanical infrared detector array with optical readout is reported. Main difference from other thermal IR detectors is the use of integrated diffraction gratings at each pixel on the moving part of the pixel and the separation of the detection from the readout electronics. The calculated noise equivalent temperature difference (NETD) assuming f/1 optics, 30 fps and 12 bit CCD camera is below 50mK. This performance is comparable to that of the other IR detector arrays, which are more complicated and expensive. The fabricated pixels are tested with direct heating. Tests in a vacuum package with absorption of IR radiation from thermal sources are left as a future work.

II. DEVICE STRUCTURE AND OPERATION PRINCIPLE

The detector pixels are tiny membranes that are connected to bimaterial legs made of Silicon Nitride and Aluminum (SiN_x and Al), which are connected to a substrate through thermal isolation legs (SiN_x). The conversion of IR radiation into temperature difference causes deflection along bimaterial legs. The mechanical detection is detected optically with sub-nm accuracy [1] using the metallic diffraction gratings embedded onto the absorbing membrane as shown in Figure 1.

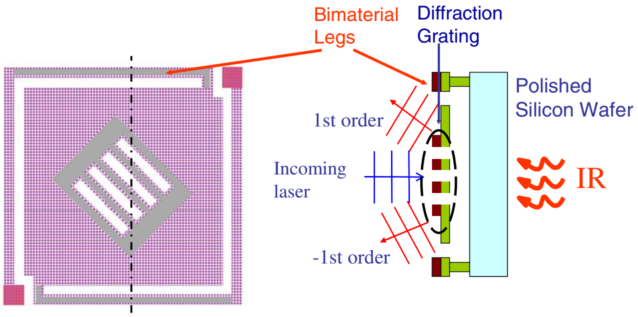

Fig. 1: One pixel operation illustrating optical readout. The carved part of the metal membrane and polished silicon underneath the pixel forms a diffraction grating. IR radiation is absorbed through the thin silicon wafer on a SiN layer.

III. DEVICE FABRICATION

The fabrication is simple with only 3 masks and 2um lithographic resolution. The fabrication starts with the deposition of 1.5 um thick sacrificial PECVD SiO_2. Than the anchors are defined with RIE ,using the first mask. Once the anchors are defined, LPCVD deposition of 300nm SiN_x and sputtering of 300 nm Aluminum takes place. Aluminum and Nitride are patterned with wet etch to form bimaterial and isolation legs. The patterned parts are protected against the sacrificial etch (buffered HF) with photoresist. Finally the array is released using Critical Point Dryer to avoid stiction. Figure 2 shows an SEM image of released devices. The design shown in the figure is a modification of a previous design [2], with embedded diffraction grating on top of pixel membrane.

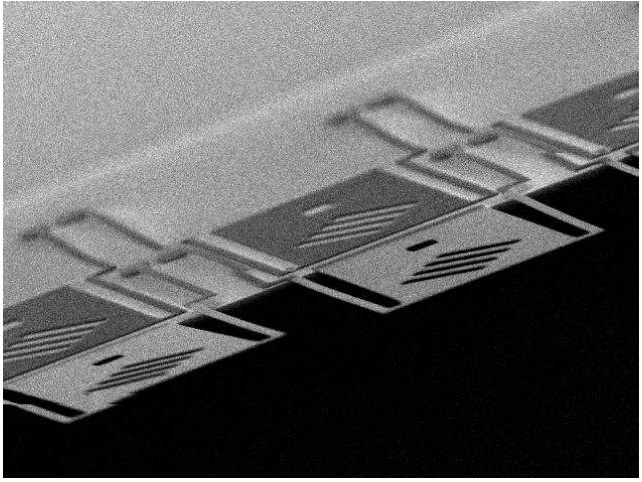

Fig. 2: SEM view of fabricated pixels. The image is taken at the edge of a die (manually scribed), where the edge pixels hang out.

IV. EXPERIMENTAL SETUP

An experimental setup was built to measure the deflection of the detectors per Kelvin by monitoring the first diffracted order from each detector. For this purpose, beam from a HeNe laser source (633 nm) was expanded to illuminate a group of detectors by a beam expander. A Thermoelectric cooler (TEC) was placed at the back of a test die and the die was illuminated with the laser beam. The reflected first diffraction orders from the die were separated using a pinhole and was imaged on to the CCD camera using a lens. A sample CCD image is shown in Figure 3.

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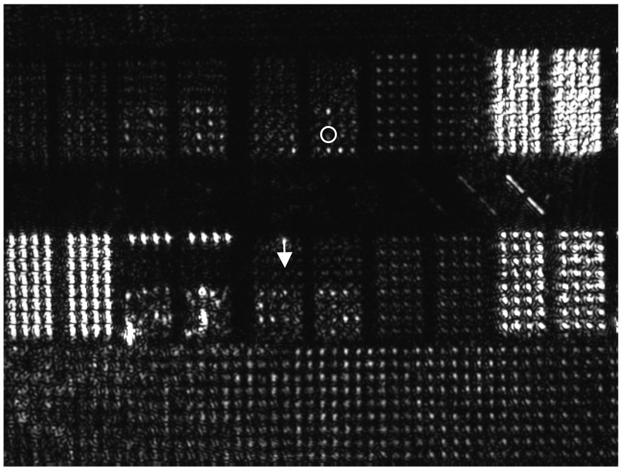

Fig. 3: A snapshot of imaged first diffraction orders taken by CCD camera, arrow shows an examplary pixel of design type illustrated in Fig. 1. The test die is composed of different designs with groups of 8 x 4 and also includes an array of 10 x 80 pixels. The first order reflected light from each group shows different intensities.

Temperature of the detectors were varied using TEC, and resulting amplitude modulation of first diffraction orders from detectors was recorded as a video file. TEC was first set to increase die temperature by 6 ˚C. First diffraction order intensity of the selected detector was extracted from the video of transient temperature increase. The intensity change is plotted in Figure 4.

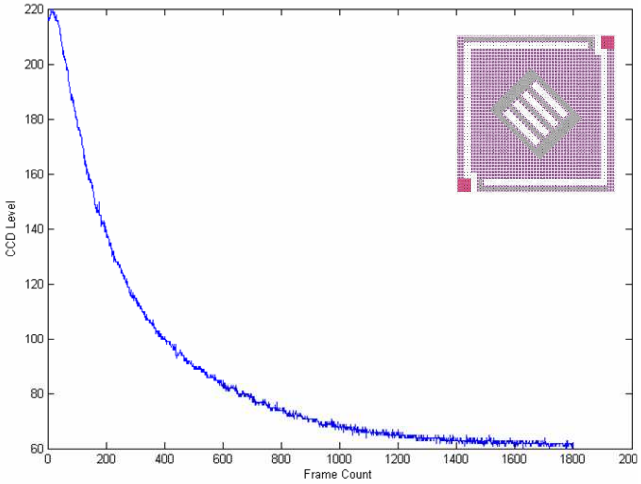

Fig. 3: Intensity modulation curve for a detector experiencing a temperature increase of 6 ˚C (8 bit CCD ,15 fps video)

The data belongs to a crab-leg design, that is also shown in Figure 1. As the gap between the grating and the reflective substrate changes linearly, a sinusoidal intensity pattern is expected at the returning orders. Due to the exponential nature of the heating characteristics, the curve does not exactly show a sinusoidal behaviour. For the mentioned design finite element simulations show that a 26.5 nm / ˚K deflection is expected. A total deflection of 159 nm is expected for 6 ˚K temperature increase. Since the first order intensity makes a period at every half wavelength, this displacement corresponds to a quarter cycle for the laser source. The intensity data shown in Figure 4 matches with the FEM results. Another data was captured with a 25 ˚C increase in die temperature. The intensity change of the first order is plotted in Figure 5.

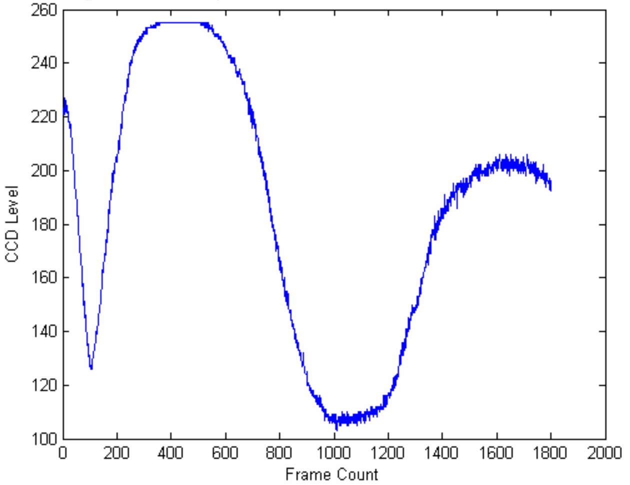

Fig. 5: Intensity modulation curve for a detector (shown with an arrow in Fig. 3 , pixel design shown in Fig. 4) for a temperature increase of 25 ˚C.

It is expected to observe 660 nm deflection for 25 ˚C temperature increase. Two periods of intensity modulation is observed which corresponds to a deflection of 650 nm therefore matches the expectation within experimental error. The variation in the peak intensity levels shown in Figure 5 can be accounted for the grating size. It was shown that , when the grating size becomes comparable to the wavelength, the scalar diffraction theory starts to fail, and the intensity vs. displacement curve deviates from a sinusoid [3].

V. DISCUSSION AND CONCLUSION

Every pixel in the die corresponds to a group of pixels on the CCD camera. The noise level in the intensity curve can be brought down to 1-bit by averaging a window of intensity levels that corresponds to a single detector in the die. Assuming 1-bit noise, calculations show that the Noise Equivalent Temperature Difference (NETD) is below 50mK using a 12-bit CCD camera and including all the thermal, optical, and mechanical noise sources. Future work involves experimental determination of the NETD in vacuum using absorption of IR radiation by the SiN membrane.

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REFERENCES

[1] W. Lee, N.A. Hall and F.L. Degertekin, Appl .Phys. Lett. 3032 ,2004.
[2] D. Grbovic et al. Appl. Phys. Lett. 89, 3118 (2006).
[3] W. Lee, F. L. Degertekin, “Rigorous Coupled-Wave Analysis of Multilayered Grating Structures”, J. Light. Tech, 22, 2359 (2004).