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Parylene based Uncooled Thermomechanical Array

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ABSTRACT

Novel thermo-mechanical detector arrays with integrated diffraction grating for optical readout were designed and fabricated. Parylene was used as the structural material due to its high thermal isolation and mismatch properties. Calculations reveal that the NETD performance of a thermo-mechanical array using Parylene can be significantly better than SiNx based designs and offer a theoretical NETD value <10mK assuming an optical readout with a high dynamic range detector array. Finite Element simulations were performed with length of the bimaterial leg as the optimization parameter. It was observed that only a few microns of isolation leg supported 30 fps applications, leaving rest of the leg to be bimaterial and providing large thermo-mechanical deflections.

Keywords: Thermo-mechanical detector, bimaterial, bimorph, optical readout, diffraction grating

1. INTRODUCTION

Optical microsystem based uncooled thermal imaging arrays were recently commercialized in small array formats and offer attractive performance and price [1,2]. Core advantages of the technology are the elimination of electrical interconnects and sensitivity of optical readout methods. Furthermore saturation or sun blindness can be handled with an interferometric readout that was proposed by the authors previously [3]

The performance level of uncooled thermo-mechanical detectors reveal that there is still further room for improving current performance. In this work, parylene based thermomechanical detector design is investigated and compared with nitride based thermomechanical arrays. With its low thermal conductivity, and high thermal expansion coefficient, parylene is among the most suitable choices. Titanium was chosen as a mismatch material to parylene and as a reflector for the readout.

2. MATERIAL CHOICE

Thermomechanical properties of commonly used MEMS and microelectronics materials are tabulated in table 1. Silicon nitride is not only a commonly used material in MEMS, but it is also a good Infrared (IR) absorber, which makes it a very suitable material for MEMS based IR imaging. Together with nitride, aluminum is a good thermal mismatch also provides high reflectance making it also suitable as an optical reflector.

Material	**CTE (10^{-6} K^{-1})**	**E (GPa)**	**k (W/K)**	**c (J/kg.K)**	**d (kg/m^3)**
Si	2.6	162	149	700	2420
Al	25	69	237	908	2700
Au	14.3	80	318	130	19400
SiN_x	0.8	180	18.5	691	2400
SiO_2	0.4	67	1.4	1000	2660
Ti	8.6	116	21.9	532	4506
Parylene	35	3.2	0.082	1000	1289
Polysilicon	9.4	160	125	753	2331

Table **1:** thermo-mechanical properties of selected MEMS and Microelectronics materials [4]

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Having high thermal mismatch and excellent insulation properties, parylene is one of the most suitable materials to serve as a structural layer. Parylene based detectors were designed and fabricated at microelectronics research center / Georgia Institute of Technology. Titanium was used as the bimaterial layer, which has relatively low CTE and fairly good optical reflection. Further fabrication details will be given in the fabrication chapter.

3. SIMULATIONS

3.1 Bimaterial Bending

In this section, the bending of SiN / Al and Parylene / Ti bimorph cantilevers are simulated. Nitride / Aluminum pair was investigated previously [5,6]. For different layer thickness, bending of a 50 um cantilever beam is simulated in figure 1.

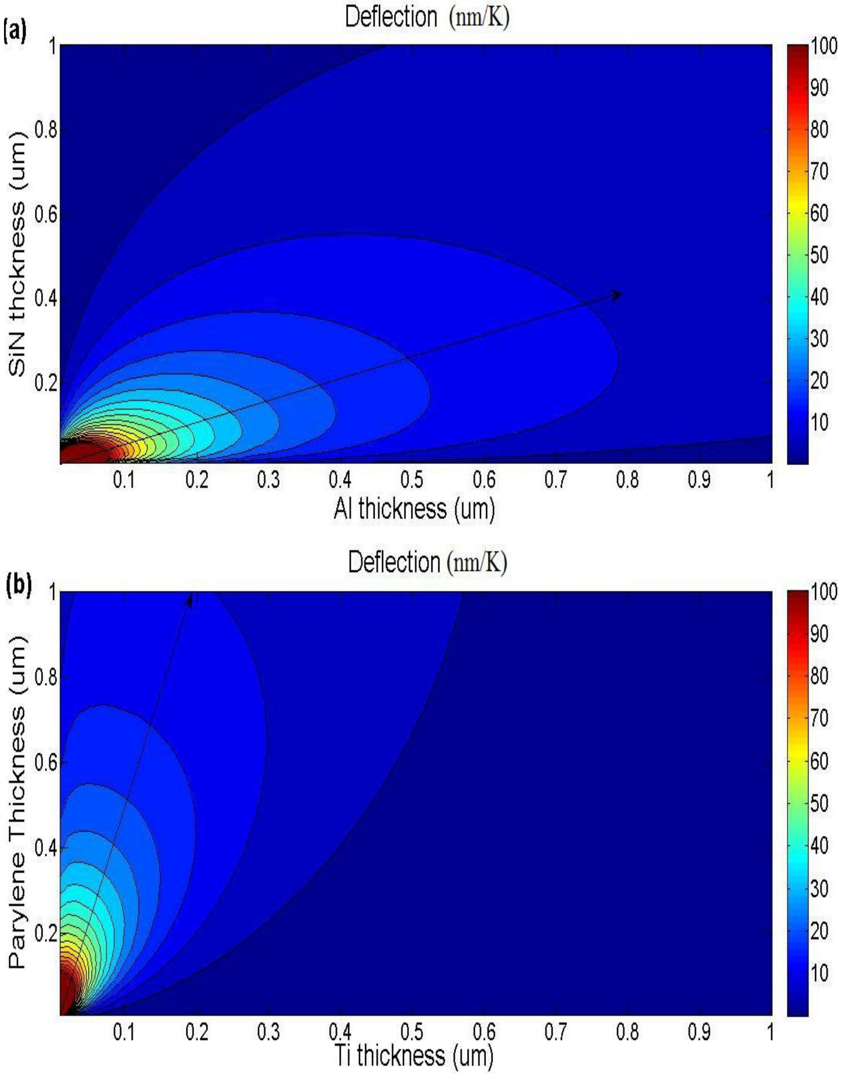

Fig. 1. Displacement contours of a 50 um long cantilever beam with respect to bimaterial pair thickness. a) SiN / Al b) Parylene / Ti

The arrows on figure 1 indicates a line that is perpendicular to displacement contours and therefore suggest a thickness ratio of 1:1.5 for SiN / Al beam whereas 5:1 for Parylene / Ti. For a given structural layer thickness, highest deflection is observed when complementary material thickness is adjusted to be on the arrow.

Other fabrication and optical readout based constraints require >100 nm metal for adequate optical reflection, and >200 nm structural layer thickness for structural rigidity. Based on all these constraints the following thickness': 200, 300, 500, 100 nm for nitride, aluminum, parylene and titanium will be used in the simulations of noise chapter.

4. NOISE

The major drawback of designing a thermo-mechanical detector architecture is between the isolation and bimaterial parts of the leg. For a cantilever type, one end fixed, detector, longer bimaterial legs indicate higher deflections and reduced thermal conductivity. This section deals with the optimization of the bimaterial leg length for a one end fixed and guided detector architectures.

Figure 2 illustrates a design tradeoff study for a 50x50um pixel with a leg of 100um similar to those used in Ref. [6]. The total leg length is divided into two sections, (i) bimaterial section and (ii) thermal isolation section. The figure shows NETD and time constant as a function of the biomaterial section assuming total leg length remains constant. The performance is simulated for a SiN / Al pair as well as a parylene / Ti device with previously mentioned thickness values.

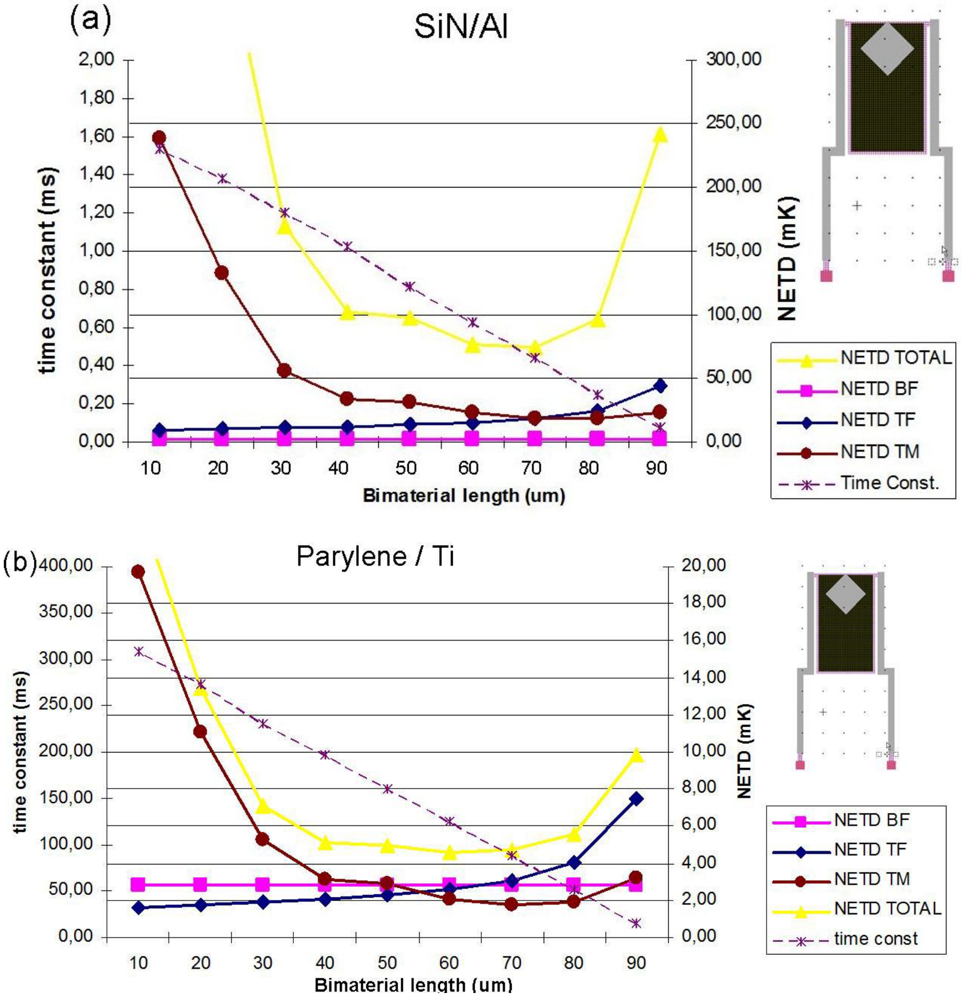

Fig 2: NETD and time constant vs. bimaterial length for a cantilever type detector. a) SiN / Al b) Parylene / Ti

For a thermomechanical detector array NETD is composed of four noise sources [6], namely, thermal fluctuation noise (NETD TF), Background fluctuation noise (NETD BF), Thermo-mechanical noise (NETD TM) and readout noise. Readout noise is calculated assuming an 12 bit digitization and 4x4 binning of CCD pixels per detector. Total NETD is the square sum of all components.

Simulations reveal that, for both materials there exists an NETD minima around 50-60 um of bimaterial length. For parylene / Ti pair, the restriction comes from the time constant value, which rises drastically after several micrometers of insulation layer due to high thermal isolation of parylene. For a 30 fps application, which requires <15 ms time constant, parylene / Ti device exhibits 6 mK total NETD at 90um bimaterial length. On the other hand, for the illustrated design SiN / Al pair device never reaches 15 ms time constant, and exhibits 70 mK total NETD at 70um bimaterial length.

Figure 3 illustrates NETD and time constant tradeoff for a different type of leg design (guided leg design) with the same leg and pixel dimensions as before.

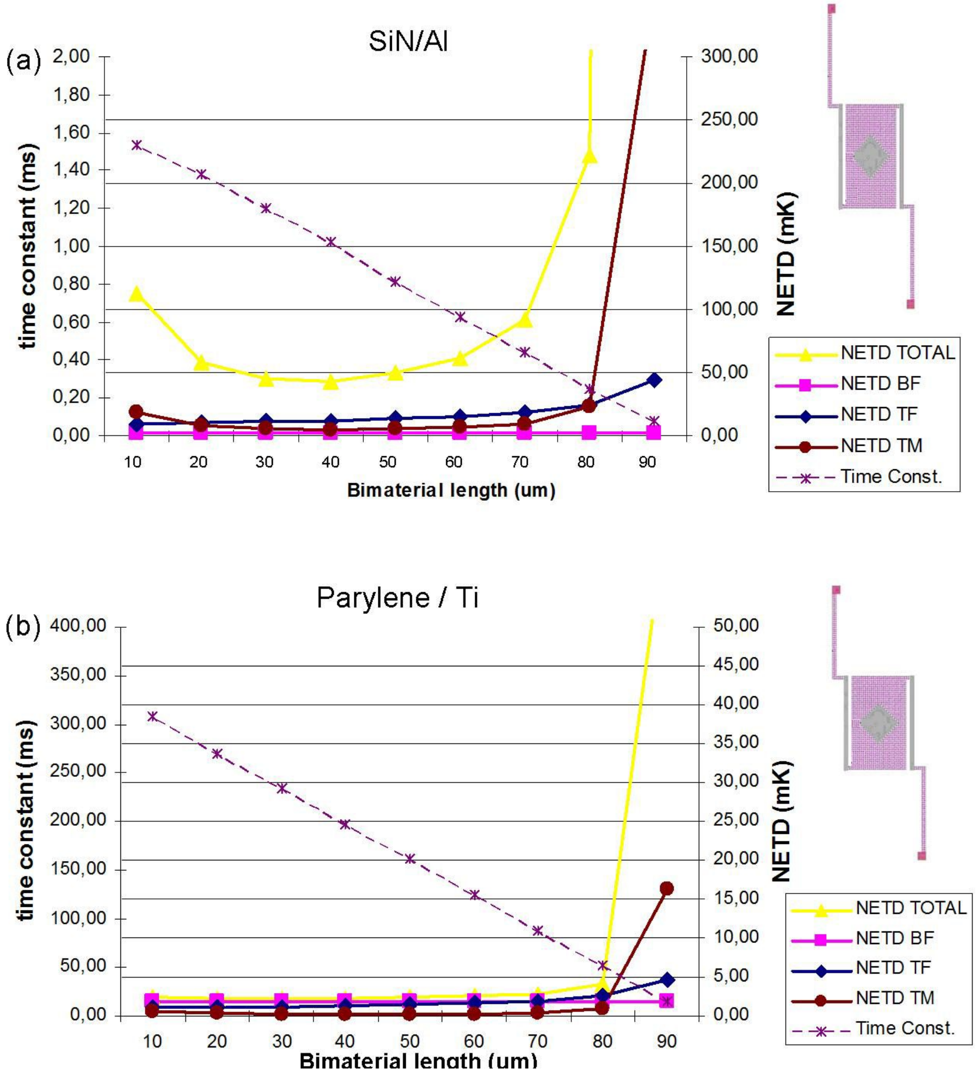

Fig 3: NETD and time constant vs. bimaterial length for a guided detector. a) SiN / Al b) Parylene / Ti

As opposed to the cantilever type detector, the highest deflection is observed when bimaterial length is around half of total legs size. Therefore at reasonable time constants, parylene / Ti device does not give < 50 mK NETD whereas SiN / Al device performs as well as 40 mK.

5. FABRICATION

Parylene / Ti devices were fabricated at the Microelectronics Research Center at Georgia Institute of Technology. Quartz wafers were used to serve as a transparent medium for the optical readout. Cr + Au gratings were evaporated and patterned on quartz wafer. Photoresist was spinned as a sacrificial layer. Parylene was evaporated on top of the sacrificial layer as a structural material. Titanium was sputtered and patterned to serve as the secondary bimaterial pair. A thin layer of titanium was sputtered on top of the devices for IR absorption. Detailed steps are given in Figure 4. A microscope image of the fabricated array is illustrated in Figure 5.

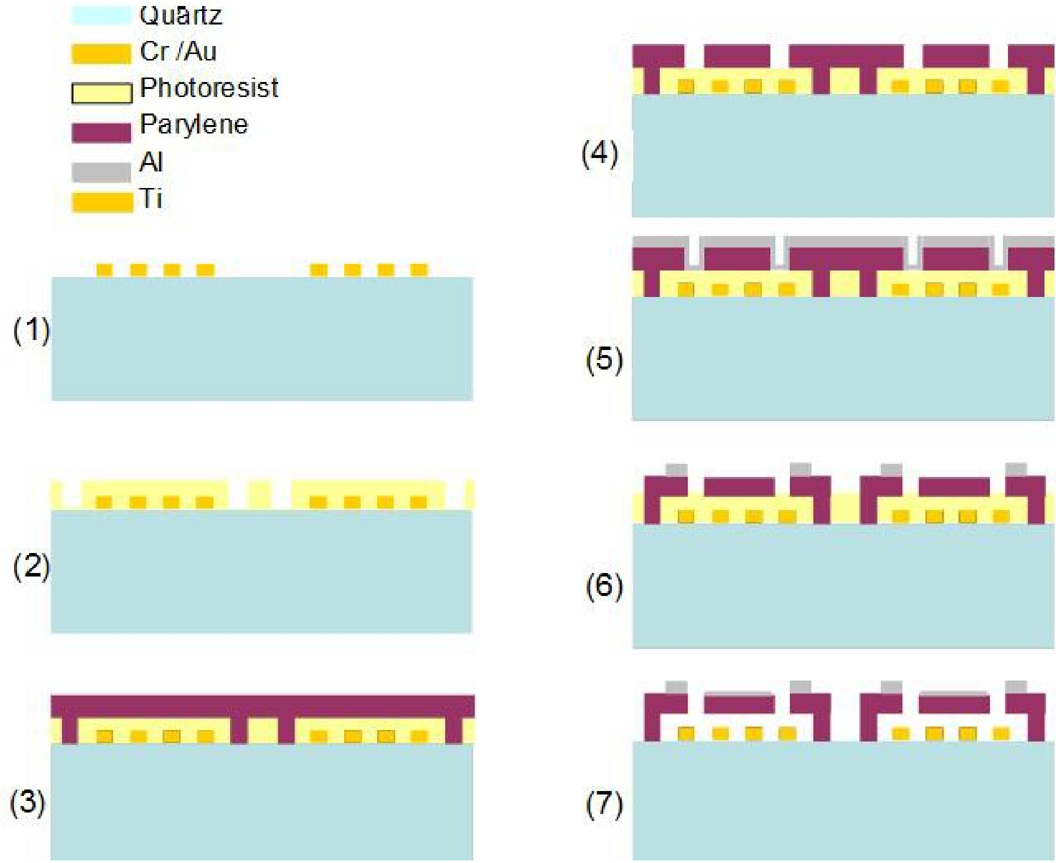

Fig. 4. Fabrication Steps**:**

1) Cr (10nm) and Au(100nm) evaporation and patterning with lift off.
2) 1.5 um PR spinning and patterning with anchor mask
3) 0.5 um parylene deposition 4) parylene patterning with RIE
5) Sputter 100nm Ti 6) Pattern Ti with diluted HF 7) Deposit 5 nm Ti

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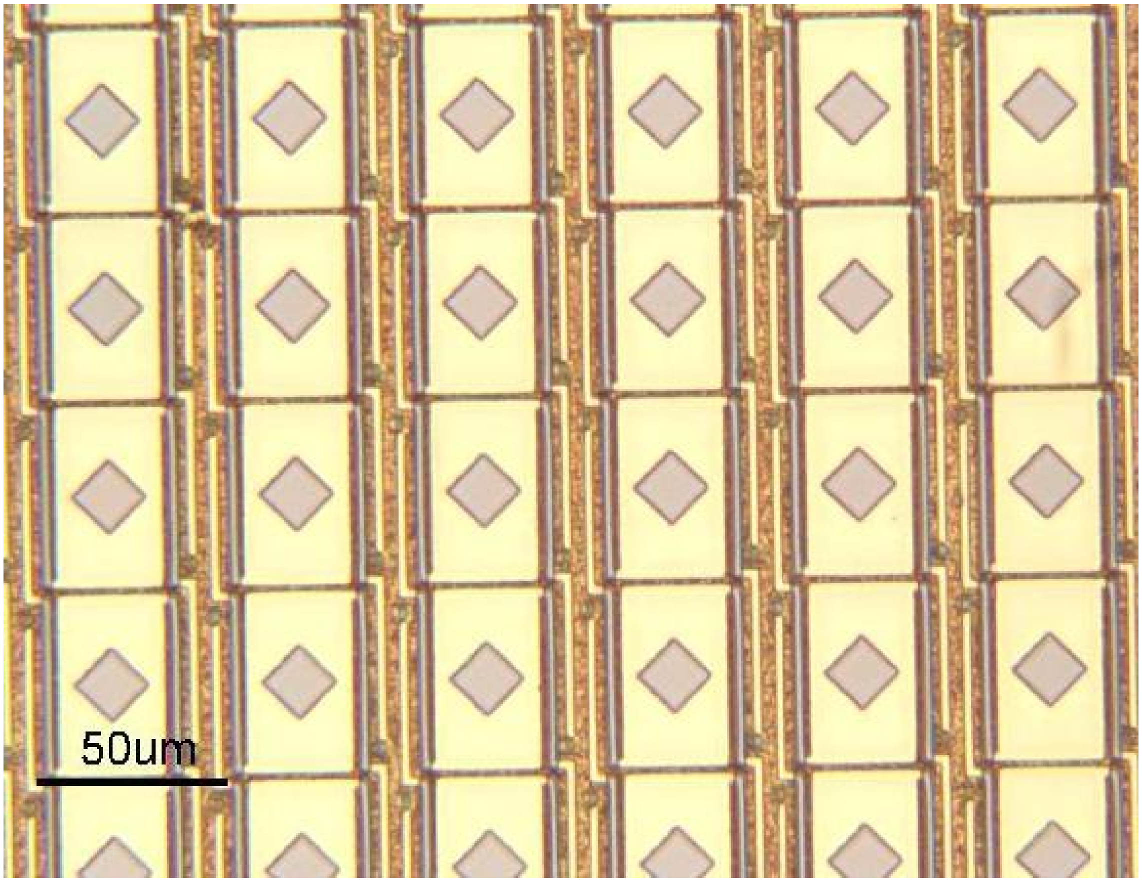

Fig. 5. Microscope image of the fabricated array

6. EXPERIMENTAL SETUP & RESULTS

The Detector array was illuminated with a laser and the diffracted 1st order light was imaged onto a CCD camera (Figure 6). The temperature of the dewar was increased to monitor change in 1st order intensity. Figure 7 illustrates the thermo-mechanical response of a selected pixel.

4x4 binning on the CCD camera was performed for the given pixel to suppress camera noise. A clear change in the intensity (300 CCD levels) was observed.

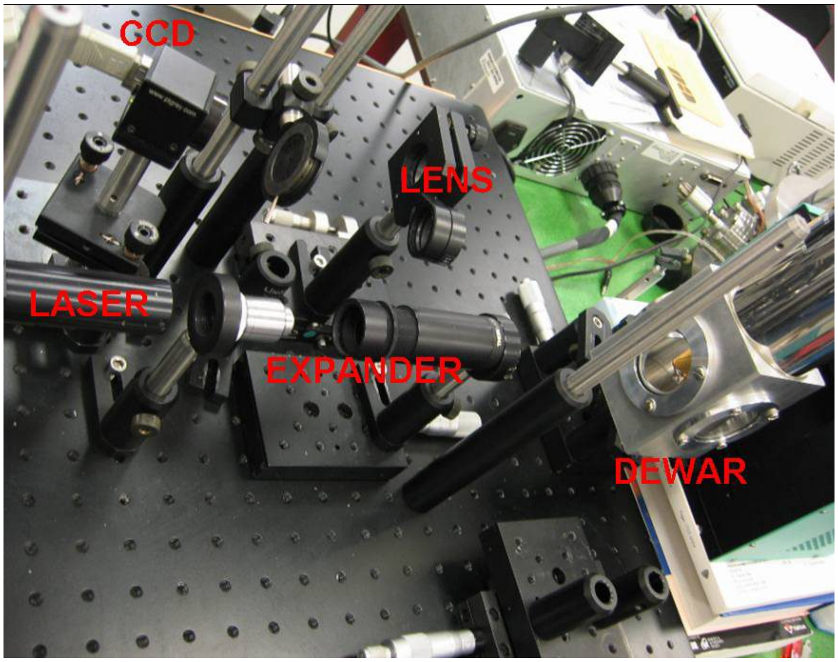

Fig. 6. Experimental setup

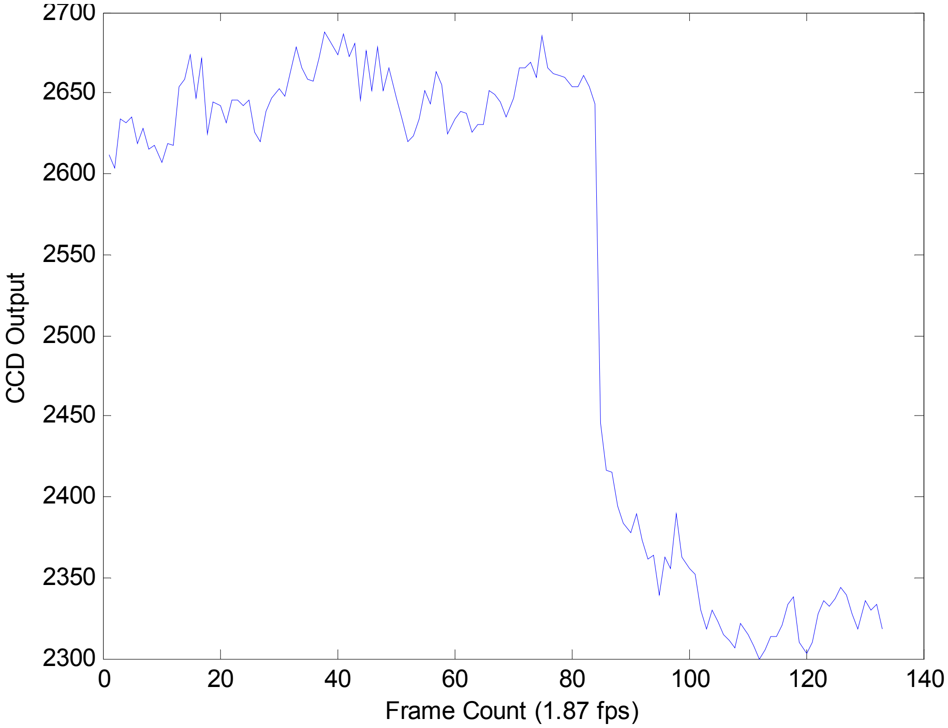

Fig. 7. 1st order light intensity of a selected pixel during heating.

7. CONCLUSION & FUTURE WORK

Parylene based thermal imaging array was designed and fabricated. Simulations were performed to compare theoretical performance of SiN / Al thermomechanical detectors with proposed parylene / Ti detectors. Theory suggests that there is room for an order of performance improvement by using Parylene as the structural layer of the thermomechanical detector.

Initial tests on parylene based IR detector demonstrate modulation of the diffracted light intensity with respect to temperature changes. Measurement of thermomechanical response to IR target, time constant measurements and image acquisition is left as a future work.

8. ACKNOWLEDGMENTS

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