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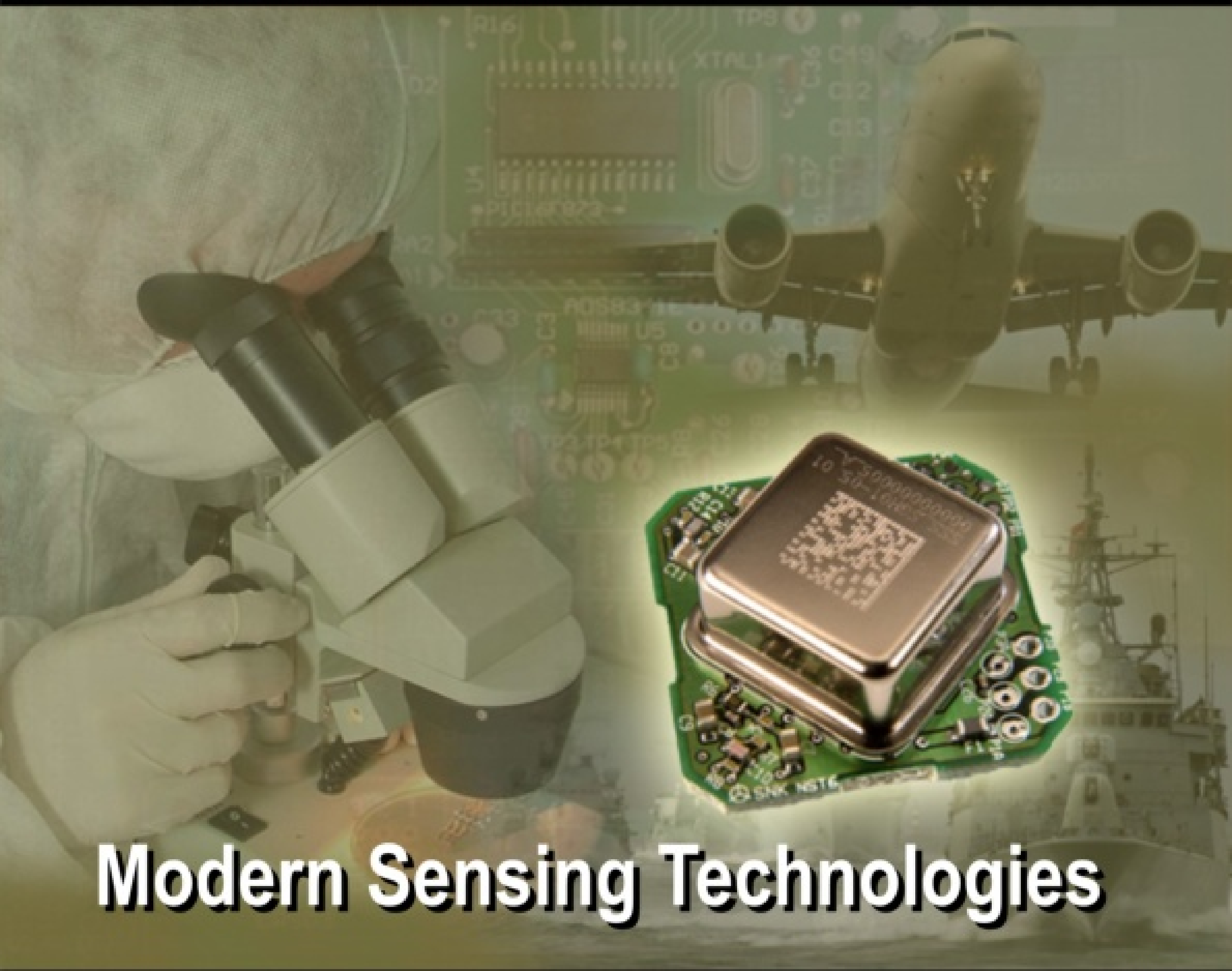

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A Micromachined Infrared Senor for an Infrared Focal Plane Array

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Abstract: A micromachined infrared sensor for an infrared focal plane array has been designed and fabricated. Amorphous silicon was used as a sensing material, and silicon nitride was used as a membrane material. To get a good absorption in infrared range, the sensor structure was designed as a $\lambda/4$ cavity structure. A Ni-Cr film was selected as an electrode material and mixed etching scheme was applied in the patterning process of the Ni-Cr electrode. All the processes were made in 0.5 μm *i*MEMS fabricated in the Electronics and Telecommunication Research Institute (ETRI). The processed MEMS sensor had a small membrane deflection less than 0.15 μm. This small deflection can be attributed to the rigorous balancing of the stresses of individual layers. The efficiency of infrared absorption was more than 75% in the wavelength range of 8 ~ 14 μm. The processed infrared sensor showed high responsivity of ~230 kV/W at 1.0V bias and 2 Hz operation condition. The time constant of the sensor was 8.6 ms, which means that the sensor is suitable to be operated in 30 Hz frame rate. *Copyright © 2008 IFSA.*

Keywords: Infrared Sensor, MEMS, Focal Plane Array

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1. Introduction

The demands for infrared image sensors have been increased during last a few decades. Their application fields have been widened to civil applications beyond military interests. Recently developed civil application fields require uncooled type image sensors, which are much cheaper than cooled type sensors.

Pyroelectric type and bolometer type are two representative types in the uncooled infrared image sensors. For the case of the pyroelectric type sensors, the theoretical performances are the best among the uncooled type sensors but they need chopping operation of incident light. The use of chopper makes it difficult to minimize system size and power consumption. For these reasons, recent researches on the uncooled infrared image sensors are mainly focused on the bolometer type sensors.

Vanadium oxide has been the base sensing material in the bolometer type sensors for the past two decades [1]. It has relatively high thermal coefficient of resistance (TCR) and good noise properties. But, recently amorphous silicon (a-Si) has been tried as a sensing material, and it makes a competition with vanadium oxide based materials [2-4]. The amorphous silicon is weaker than vanadium oxide in the respect of noise performances, but its process is much easier and has merits in the respect of uniformity and reproducibility.

In the present study, a MEMS sensor structure for a bolometer type image sensor was designed and fabricated. Amorphous silicon was selected as a sensing material. A Ni-Cr film which has low thermal conductivity was selected as an electrode material to maximize the sensor responsivity and mixed etching scheme was applied in the patterning process of the Ni-Cr electrode. The stress values of each consititutional layers were analyzed and rigorously balanced to minimize the membrane deflection. Considering monolithic integration with read-out integrated circuit (ROIC), the structure and the processes were designed to be fully compatible with CMOS process.

The processed sensor showed good optical response properties. The responsivity of the sensor was ~50 kV/W at 0.5V bias and 30 Hz operation condition. The measured thermal time constant was ~8.6 ms.

2. Design of Sensor Structure

2.1. Vertical Structure

Fig. 1 is a schematic diagram showing the vertical structure of the unit pixel. Amorphous silicon was adapted as a sensor material. Silicon nitride was used as membrane layers. To get a good absorption in infrared range, the sensor was designed as a λ/4 cavity structure [5]. With λ/4 cavity structure, the absorption of light is interferometrically enhanced. Considering the wavelength range of operation, the height of the gap between the sensor membrane and the underlying reflector was designed as 2 μm, which was controlled by the thickness of the sacrificial layer. The reflector was made with sputtered Al film. A thin TiN film was used as an absorption layer. The thickness of TiN layer was controlled to have 377 Ω of sheet resistance, which corresponds to the optimum value to get perfect absorption in λ/4 cavity structure [5].

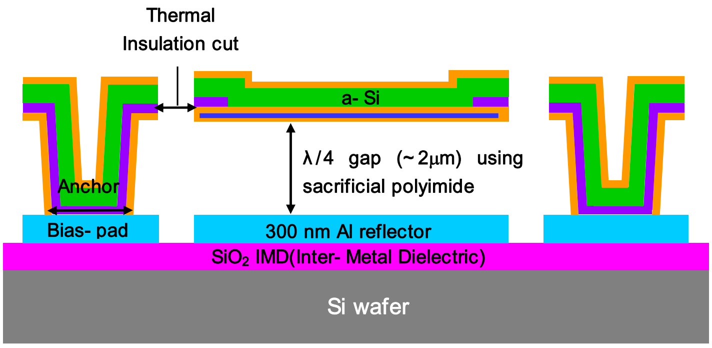


Fig. 1. Vertical structure of the designed sensor.

Considering the monolithic process with read-out integrated circuit (ROIC) by post CMOS micromachining processes, polyimide (PI2545, HD Microsystems Co., USA) was selected as a sacrificial layer, which can be processed in a low temperature, typically less than 400 ^{o}C. The pitch of the unit pixel was 50 μm, and filling factor was more than 77 %.

2.2. Thermal Design

Thermal parameters are very important in designing of IR sensors, which influence responsivity and speed of sensor. Two important thermal parameters are thermal conductance (G) and thermal time constant (τ). Thermal conductance influences responsivity of sensor with following relation [6].

$$R = \frac{BIR\alpha\varepsilon}{G(1+4\pi^2 f^2 \tau^2)^{1/2}}, \tag{1}$$

where B is the bridging factor, I is the bias current, R is the detector resistance, α is the temperature coefficient of resistance, ε is the absorptivity, G is the thermal conductance, f is the operating frequency, and τ is the detector time constant, which is defined as follow:

$$\tau = C / G, \tag{2}$$

where C is the thermal capacity of the sensor membrane. The thermal time constant determines the speed of sensor response. Too small value of the time constant deteriorates signal amplitude and too large value make it impossible to be operated in a suitable frame rate. Therefore, there exists an optimum value in the thermal time constant. To be operated with 30 Hz frame rate, ~ 10 ms is the optimum value.

The thermal parameters were controlled by varying the width of the legs in structure design. The width of legs was variably designed from 1 μm to 2 μm. For the case of the sensor structure with the legs of 2 μm width, the designed thermal conductance was ~ 1.5 x 10^{-7} J/K. And corresponding thermal time constant was ~10 ms.

3. Process

3.1. Process Overview

Fig. 2 is a schematic diagram showing the process of the infrared sensor. An aluminium film with thickness of 3000Å, which acts as a reflector, was deposited and patterned by lithography process on an insulation oxide layer. Then, polyimide, which acts as a sacrificial layer, was spin-coated and cured. The coated polyimide layer was patterned to make anchor areas by lithographic process and dry etching. Then, the first nitride layer was deposited by plasma enhanced chemical vapor deposition process (PECVD) with thickness of 500Å. After deposition of the first nitride layer, TiN layer, which acts as an absorption layer, was deposited by sputtering process. The thickness of TiN layer was 100Å, which corresponds to the sheet resistance value of 377 Ω. The TiN absorption layer was patterned by lithography and dry etching process. Followed by patterning of the TiN layer, the second nitride layer was deposited by PECVD process. Then, contact holes for electrical connection were formed in the anchor areas. After formation of the contact holes, electrode metal was deposited and patterned. A Ni-Cr film with thickness of 500Å was used as an electrode material. Followed by patterning of the electrodes, a-Si film was deposited by PECVD process with thickness of 1500Å. Then, protection silicon nitride was deposited by PECVD process. After deposition of protection nitride, membrane was patterned and dry etched. Finally, Removal of the polyimide sacrificial layer was done with oxygen plasma.

Fig. 3 shows the SEM images of the processed sensor. As can be seen from the figure, the MEMS structure for an infrared sensor could be successfully fabricated. All the processes used in the fabrication were fully CMOS compatible. Therefore, these processes can be directly applied to the fabrication of monolithic type sensors.

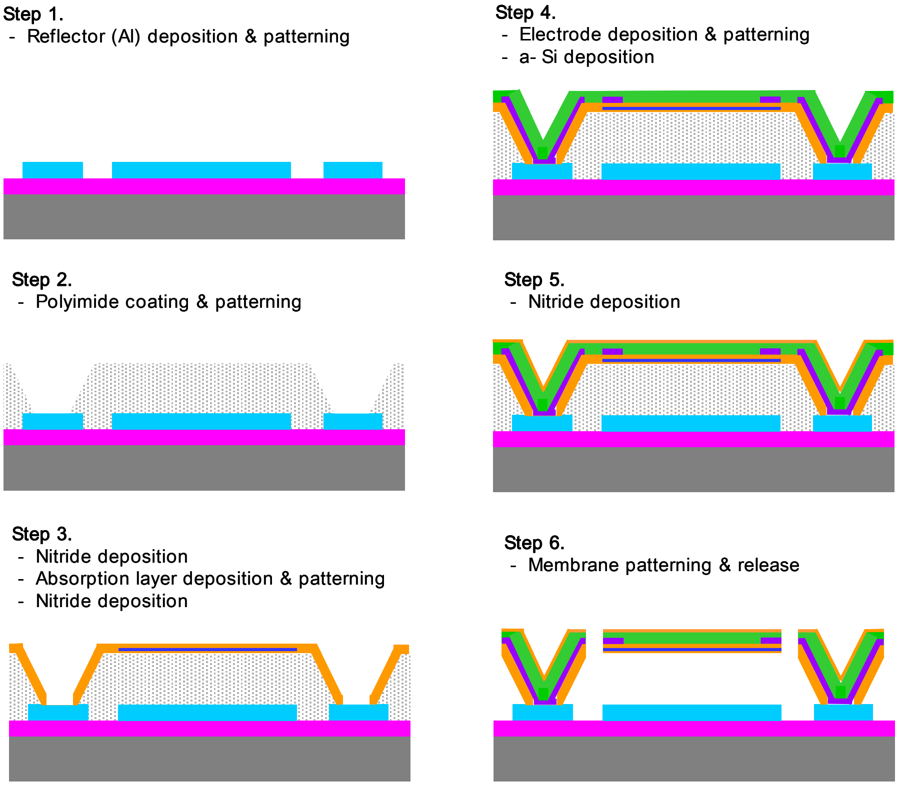
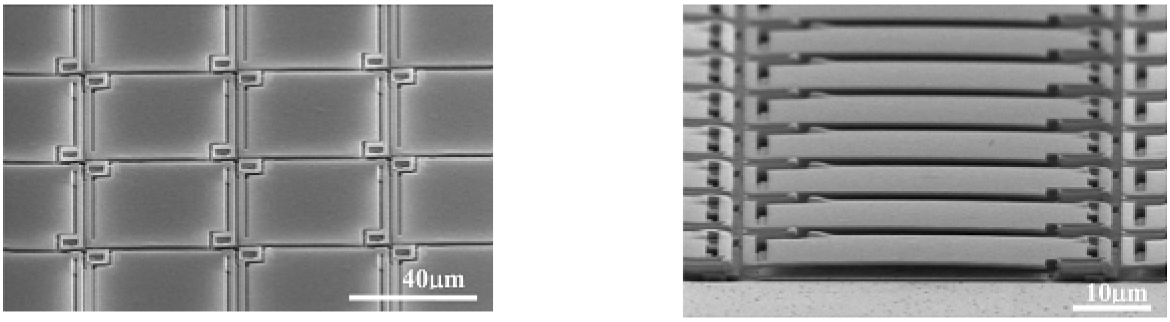


Fig. 2. Schematic diagram showing the processes of the sensor structure.



(a) (b)

Fig. 3. SEM micrographs of the processed pixel array ; (a) 45° tilt view, (b) 80° tilt view. The pixel pitch is 50 μm, and the width of the isolation leg is 2 μm.

3.2. Sensing Material

An amorphous silicon film was used as a sensing material. The a-Si film was deposited by PECVD process with source gases of SiH_4, H_2, and PH_3. PH_3 gas was added as a dopant to control the resistance of the film. Deposition temperature was 400 °C, and working pressure was 1.2 Torr. The measured TCR value of the a-Si film was around -2.3 %/K and the resistivity was 150 Ω·cm.

3.3. Electrode Patterning

A Ni-Cr film with thickness of 500Å was used as an electrode material. Dry etching of the Ni-Cr film is a very difficult process because of its poor selectivity with underlying nitride layer. Therefore, mixed etching scheme was applied to etch the Ni-Cr film. 70 % of the Ni-Cr film was dry etched with high density plasma etcher and the remained part of the film was etched with wet etching method. Chlorine based gases were used in dry etching and diluted TFN (Transene Co., USA) was used as an etchant in wet etching. The mixed etching scheme utilize both merits of dry etching and wet chemical etching, anisotropic character of dry etching and high selectivity of wet chemical etching. With the mixed etching scheme, wide process margin and process stability can be achieved.

3.4. Stress Balancing

A stress balancing can affect membrane deformation. If it is unsuitably designed, the membrane can be seriously deformed and a thermal short can be occurred. In the respect of the stress balancing, two parameters should be considered. These parameters are overall stress value and stress gradient along thickness direction. To minimize the overall stress value, each constituent film should be controlled to have low stress value. Among the constituent films, the a-Si film and the silicon nitride film are the most important. The stresses of these layers were evaluated and optimized as functions of flow rates of source gases, temperature, working pressure in PECVD process. Finally tuned stress of the a-Si film was 42 MPa in tensile and that of the silicon nitride film was 153 MPa in tensile. To minimize the stress gradient along the thickness direction, layer stacking should be symmetric. Fig. 4 is a schematic diagram showing the stress status of stacked layers.

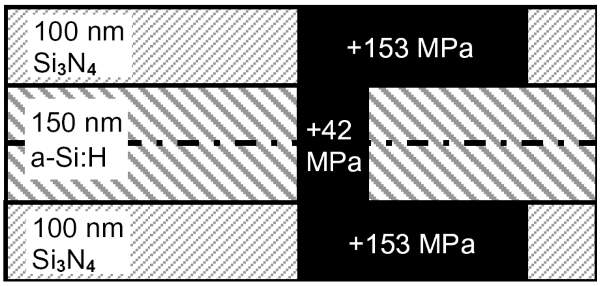


Fig. 4. Schematic diagram showing the stress status of stacked layers.

Fig. 5 shows the membrane deflection of processed sensor measured by surface profiler (SIS1200, SNU precision co., Korea). As can be seen in the figure, the membrane of the processed sensor was very flat. Maximum deflection is less than 0.15 μm. This small deflection can be attributed to the rigorous balancing of the stresses of individual layers.

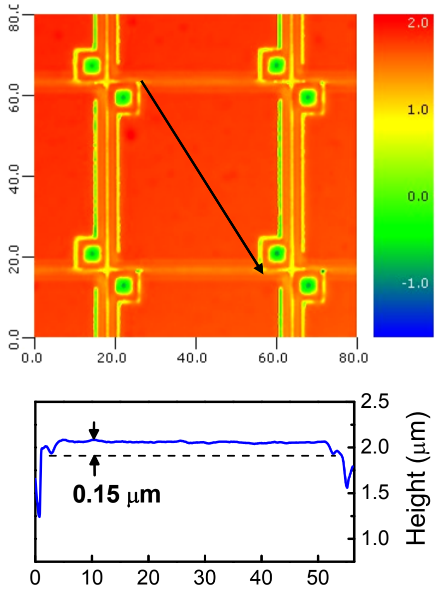


Fig. 5. Membrane deflection of the processed sensor measured by surface profiler.

4. Characterization

4.1. Absorbance in Infrared Range

Fig. 6 shows the infrared absorption properties of the processed sensor. The absorption property was measured with IR spectrometer (ISS66, Bruker Co., USA) with incident angle of 85^o. The infrared absorption efficiency of the processed sensor was more than 75 % in the wavelength range 8-14 µm. The absorption efficiency of 8-9 µm range is relatively lower than that of 10-14 µm range. This is because there are phonon bands of nitride around the wavelength of 10 µm. The nitride films, which were used as membrane layers, have anomalously high refractive index and high attenuation coefficient in that wavelength range [7].

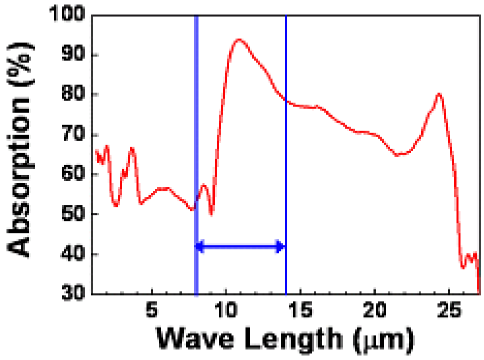


Fig. 6. Infrared absorption property of the processed sensor.

4.2. Infrared Responses

Fig. 7 shows the measurement system used for infrared response. The processed sensor was vacuum packaged and a simple linear amplifier with unit gain was used as a transducer circuit. A blackbody was used as an infrared source. Fig. 8 shows the measured infrared response of the processed sensor. The blue lines are chopper signals and the red lines are output signals of the sensor. The responsivity of the sensor can be calculated from these results. The calculated responsivity was ~230 kV/W at 1.0V bias (V_b) and 2 Hz operation condition. Fig. 9 shows the normalized responsivity as a function of chopper frequency. The normalized responsivity decreases as chopper frequency increases. Thermal time constant can be deduced from curve fitting of Fig. 9. The dotted line in the Fig. 9 is the fitting result. The thermal time constant of the sensor was ~8.6 ms, which well coincides with the designed value of 10 ms. This result means that the processed sensor is suitable to be operated at 30 Hz frame rate. The thermal conductance of the sensor can be calculated from the thermal time constant and thermal capacity of the sensor membrane. The calculated thermal conductance value was ~ 2.4×10^{-7} J/K.

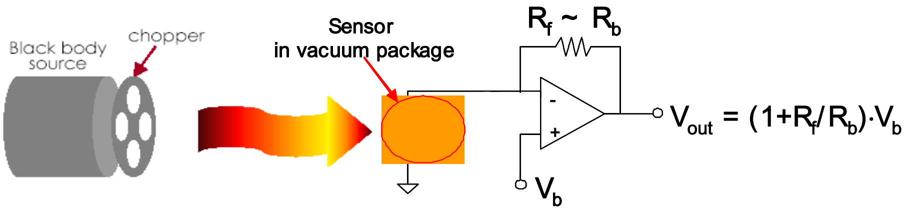
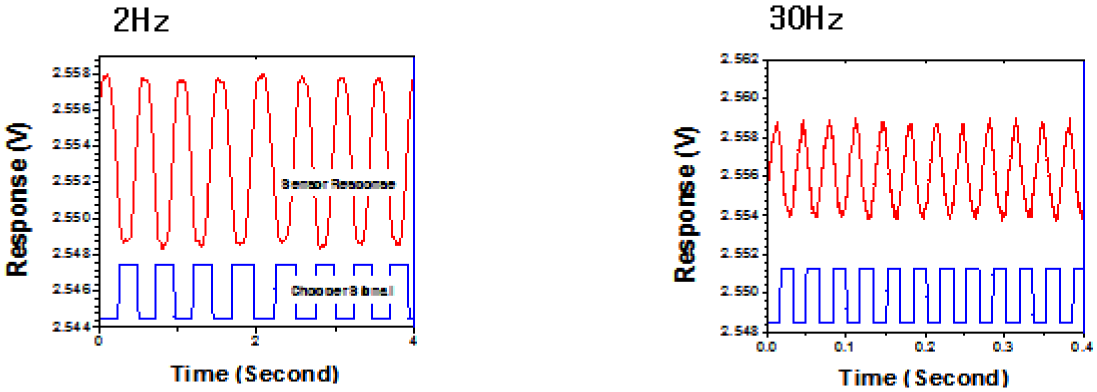


Fig. 7. Schematic diagram showing the measurement system for infrared response.



(a)

(b)

Fig. 8. Measured optical responses of the processed sensor; (a) the result from 2 Hz operation condition and (b) that of 30 Hz operation condition.

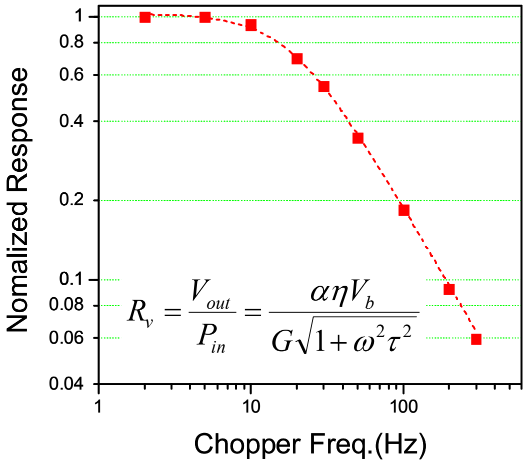


Fig. 9. The measured responsivity as a function of chopper frequency. The thermal time constant of the sensor can be obtained by fitting the curve.

5. Conclusions

A micromachined sensor part for an uncooled type infrared image sensor based on a-Si sensing material has been designed and fabricated. The MEMS sensor part was successfully fabricated with polyimide sacrificial layer. A Ni-Cr film with low thermal conductivity was adapted as an electrode material and mixed etching scheme was applied in the patterning process of the Ni-Cr electrode. All the processes used in the fabrication were fully CMOS compatible. Therefore, these processes can be directly applied to the fabrication of monolithic type sensors.

The processed MEMS sensor had a small membrane deflection less than 0.15 μm. This small deflection can be attributed to the rigorous balancing of the stresses of individual layers. The efficiency of infrared absorption was more than 75 % in the wavelength range 8 ~ 14 μm. The responsivity of the sensor was ~230 kV/W at 1.0 V bias and 2 Hz operation condition. The time constant of the sensor was ~8.6 ms, which means that the sensor is suitable to be operated in 30 Hz frame rate.

Acknowledgements

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