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Investigations on the Temperature Field in Multilayer Pyroelectric Thin Film IR Sensors using 3D simulation

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***Abstract*— Multilayer pyroelectric thin film IR sensor uses the pyroelectric effect to transform temperature variation to corresponding electrical signal. Large temperature variation rate in pyroelectric film is very important for high response of the pyroelectric thin film IR sensor. In this paper, a 3D finite element modeling (FEM) using COMSOL MULTIPHYSICS is applied to simulate the temperature field of multilayer pyroelectric thin film IR sensor. Different thicknesses of the layers of the sensor were studied in order to optimize its geometry. Furthermore, different thermal characteristics of the pyroelectric layer were used to obtain the best response of the sensor in terms of magnitude frequency. Finally, all the obtained results were integrated to simulate the best response of the sensor**

***Keywords*—FEM; Multilayer Pyroelectric Thin Film Sensor; 3D Simulation; Temperature Field.**

I. Introduction

Multilayer pyroelectric thin film IR sensor is used in many applications as intruder alarm, sensor for pollution monitoring, gas analysis and hot image sensor [1],[2]. Multilayer pyroelectric thin film IR sensor has many advantages, such as lower system cost, room-temperature operation, fast and wide spectral response with high sensitivity. For some applications, the flexible film sensors can capture the image from biomedicine, artificial skin, and wearable electronics [3]-[7].

In literature concerning the subject, Li L. et al. used a 2D finite element method to simulate the temperature field of multilayer pyroelectric thin film sensor with application to PZT pyroelectric material [8]. The simulation results proved that the porous silica film reduces the heat loss due to the conduction of heat from the pyroelectric film to the silica substrate.

In this work, a 3D finite element method using COMSOL MULTIPHYSICS was performed in order to simulate the temperature field of multilayer pyroelectric thin film IR sensor. Simulation was performed by varying the thickness of the porous silica layer, the thickness of the pyroelectric layer and the thermal characteristics of the pyroelectric layer; the objective of this study is to optimize the design of the multilayer pyroelectric IR sensor for the best magnitude and frequency response.

II. Multilayer Pyroelectric Thin Film IF Detector

The principle dynamic current pyroelectric response of multilayer pyroelectric thin film IR sensor can be expressed as:

$$i_p = \eta RA(dT/dt) \qquad (1)$$

where η is the absorption coefficient of radiation, R, the pyroelectric coefficient of the pyroelectric thin film, A, the sensor area and dT/dt the temperature variation rate of the pyroelectric film. From expression (1), we can see that the current response of multilayer pyroelectric thin film IR sensors is proportional to the temperature variation rate of the pyroelectric film. That is, higher the temperature variation rate in pyroelectric film, higher the current response of multilayer pyroelectric thin film IR sensor.

The most used multilayer pyroelectric thin film IR sensor was composed of some functional films integrated on Silica substrate [9]. The schematic structural and cross-sectional diagram of multilayer pyroelectric thin film IR sensor is shown in Fig. 1.

III. Modeling and Simulation

According to Fig. 1, we consider the 3D finite element model of one unit cell sensor. The model is generated by COMSOL MULTIPHYSICS. The thickness of the geometry model of the unit cell is defined in Table 1. The length is 100 µm and the width is 100 µm. The parameters of various thermal properties of the films given in Table 1 were assigned to the corresponding layers. An IR radiation from a laser source with a wavelength of 10 µm is simulated. The incident radiation power, P, received by the sensor is 1.3 W/m^2. The surface of the incident radiation was considered as plane in the top of the sensor. For modeling, it was assumed that the film properties were isotropic [8]. The geometry model was meshed appropriately. The results obtained using the three-

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dimensional finite element simulation of the temperature field in the sensor is shown in Fig. 2 and Fig. 3 respectively.

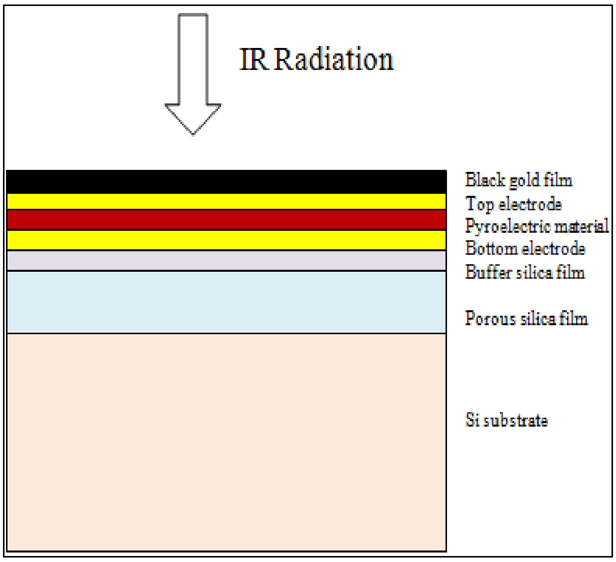

Fig. 1 The schematic structural and cross-sectional diagram of multilayer pyroelectric thin film IR sensor.

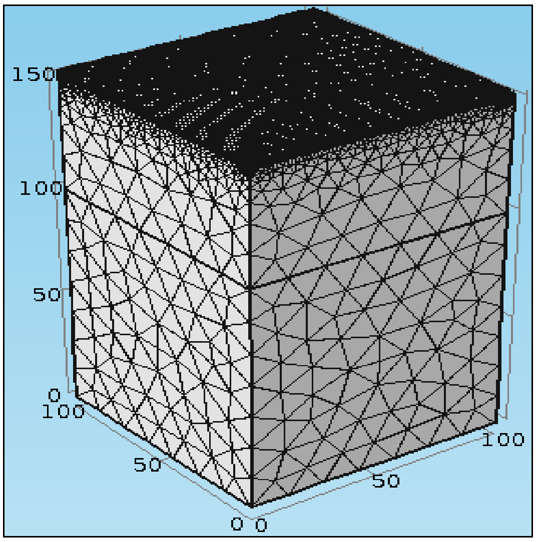

Fig. 2 The 3D finite element mesh of multilayer pyroelectric thin film IR sensor.

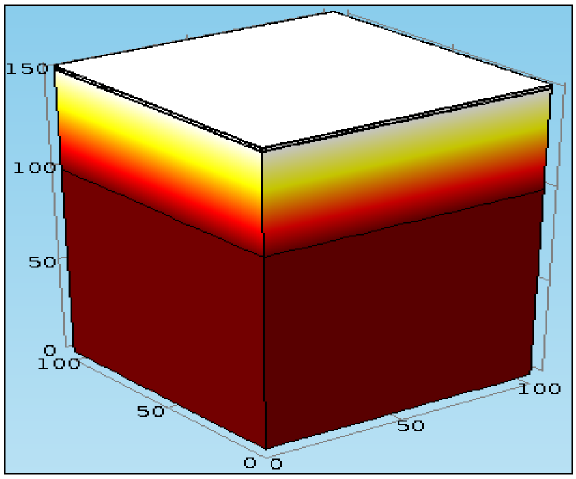

Fig. 3 3D temperature solution.

TABLE I
PARAMETERS USED FOR SIMULATION

Material	**Thermal Conductivity (W/mK)**	**Specific Heat (J/KgK)**	**Density (Kg/m^3)**	**Thickness (µm)**
Si substrate	145	708	2330	100
Porous silica film	0.02	780	1320	10-50
Buffer silica film	1.4	700	2250	0.5
Pyroelectric material	71.4	133	21450	0.15
Top electrode	0.1E-03	300 - 600	2000 - 8000	0.5-2
Bottom electrode	31.5	127	19300	0.1
Black gold film	2	130	345	0.5

IV. Results and Discussion

The transient temperature field in multilayer pyroelectric thin film IR sensor upon exposure to 0.02 s IR irradiations was simulated. Fig. 4 shows the temperature variation rate (dT/dt) in pyroelectric film with different thickness of porous silica film. As it can be seen, the value of dT/dt in pyroelectric film varies from 0 to 0.02 s. After the maximum peak, the value of dT/dt in pyroelectric film begins to decrease. Figure 4 shows that this decrease is depending on the thickness film. Frequency response has the best speed of decrease for 10 µm thickness. Furthermore, the magnitude remains the same for all thicknesses.

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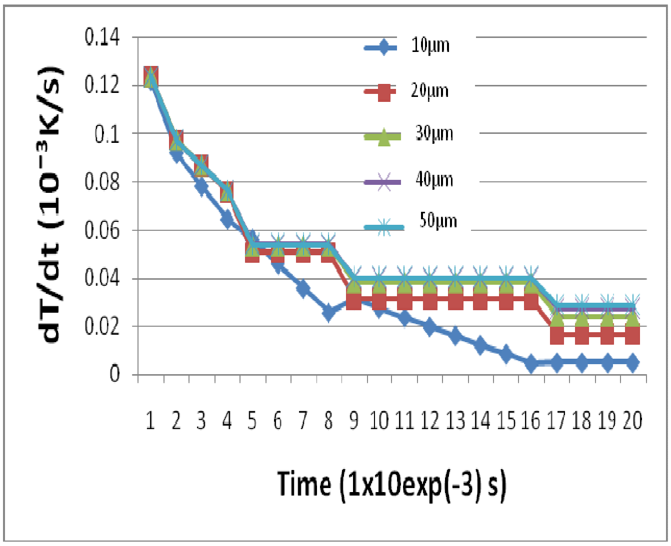

Fig. 4 Temperature variation rate in pyroelectric film as function of time with different thicknesses of porous silica film.

Fig. 5 shows the value of dT/dt with different thickness of pyroelectric materials when porous silica film thickness is 10 µm. We remark a same frequency response for all considered thickness but a higher amplitude response for 0.5 µm. In Figure 6 we treat the structure 10 µm of porous silica film and 0.5 µm thickness of pyroelectric and used different pyroelectric materials by varying thermal proprieties.

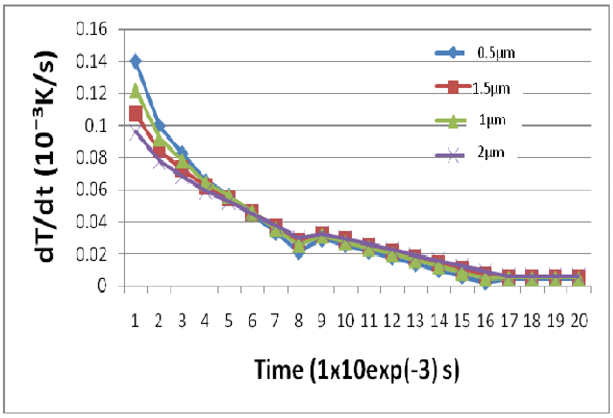

Fig. 5 Value of dT/dt with a different thickness of pyroelectric materials.

Fig. 6 shows that the best response is with the pyroelectric material which has a low thermal conductivity and a low density. Many pyroelectric materials present these thermal proprieties but the absorption coefficient is different. This affects the amplitude of the delivered current. Disregarding this notice the best response in frequency and amplitude with this kind of the multilayer pyroelectric IR sensor can be obtained for a thickness of porous silica film 10 µm, a thickness of the pyroelectric film is 0.5 µm, the density and the thermal conductivity of the pyroelectric film respectively 3000 kg/m^3 and 0.1 W/mK.

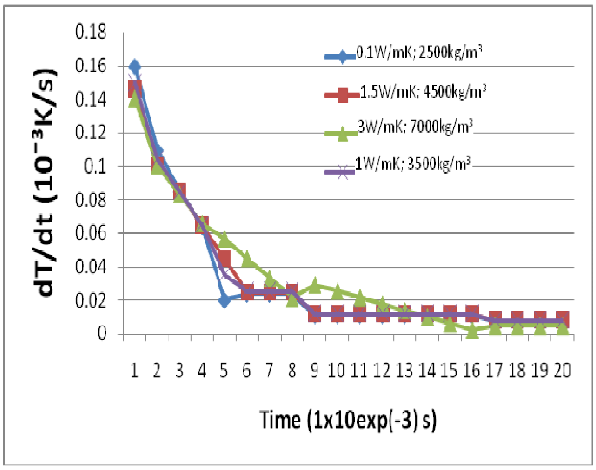

Fig. 6 Variation of the thermal properties of the pyroelectric layer of the sensor.

V. CONCLUSIONS

In this paper, a three dimensional model of a multilayer pyroelectric IR sensor is presented. A simulation solution was presented using COMSOL MULTYPHISICS. The study was performed to optimize the best response of the sensor in terms of frequency and magnitude. We have used different thicknesses of porous silica film, different thicknesses of pyroelectric material film and different thermal characteristics of pyroelectric material for simulations. We were interested in the magnitude and the frequency response of the sensor. The results obtained show that with a low thickness of the porous silica combined with low values of thermal conductivity and density of the pyroelectric material, the best frequency and magnitude response can be obtained

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