THE STUDY OF HEAT TRANSFER IN THERMOPILE THERMOMETER

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ABSTRACT

Thermopile thermometer can measure the temperature of an object without attaching the object. It measures the temperature by receiving the radiation energy from objects. The idea of this is from the law of Stefan-Boltzmann. In the past it was not used well because the size was big and the cost was too expensive. But, In these days it can be used many field because the size become smaller and advantage of cost by using micro machine technology. However, The accuracy of measuring is not better than electric type. So we want to improve the accuracy of sensor by analyzing the heat transfer of the thermopile. To analyze temperature distribution in the thermopile sensor, we use the FEM software which is named ANSYS. The conduction and radiation heat transfer is considered to simulate the temperature distribution and time response inside of the sensor.

1 INTRODUCTION

The temperature of an object is measured by using many methods, which developed until now. The methods can be divided into three types. The first type is the dynamic type. It measures the temperature by using the fact that dynamic characteristics like a volume or pressure are changed by temperature. In the dynamic type there are mercury, alcohol, metal and gas thermometer. The second type is the electric type which using that electric characteristics like a voltage or resistance are changed by temperature. The accuracy of measuring and time response of this type are better than dynamic type. In the electric type there are resistance, thermocouple thermometer. The first and second type are measuring the temperature by attaching the thermometer to the object directly. The third type is radiation thermometer. It measures the temperature not attaching the thermometer to the object. So it has the merit that it can measure temperature of the object, which we can't attach. It can be also applied the sensor of body temperature for warning, ear thermometer and measuring the temperature of foods in the oven and microwave and so on. So We are studying about thermopile thermometer, which is a kind of radiation thermometer. It measures the temperature by receiving the radiation energy from objects.

2 THE PRINCIPLE AND STRUCTURE

2.1 Subsection Headings

Figure.1 is the principle of measuring, figure.2 is the picture of shape of real sensor and figure.3 is the picture of inside. The thermopile is infrared rays temperature sensor that measure temperature by receiving the radiation energy from the object like figure. 1.

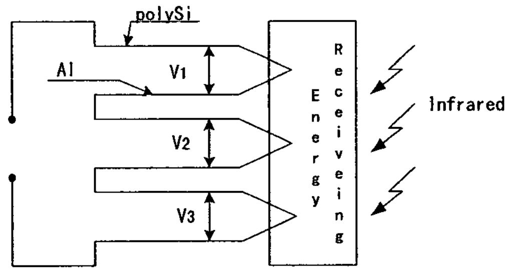

Figure. 1. The principle of measuring.

In the Figure. 3. the part that is square and black receive the radiation energy. and it called receiving energy part. This part is thin layer and the heat capacity is small. so, the temperature of this part is changed easily by little energy. The surrounding of black part is heat sink which is linked with black part on upper plate. The heat capacity of this is big, it is not easy to change the temperature.
Thermocouple is located between two parts, and the difference of temperature these two parts is detected by change of voltage.

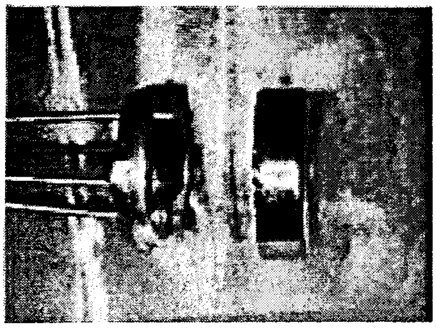

Figure. 2. The picture of shape.

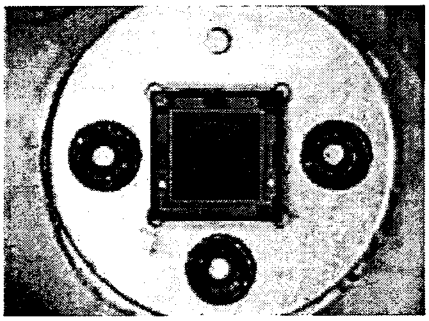

Figure. 3. The picture of inside.

Because the voltage of one thermocouple is very little, so many thermocouples is used to raise the voltage. It is used 80 thermocouples in that sensor. The unit output voltage is mV.

2.2 Structure Of Sensor

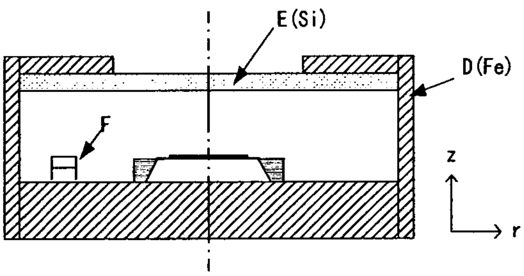

Figure. 4. The vertical section of sensor

Figure.4 is the vertical section of sensor and figure.5 is magnificent of Figure.4.

In the figure.5, (A) is the receiving energy part and hot junction of thermocouple is placed on it, and (C) is a heat sink which is consisted of silicon. Cold junction of the

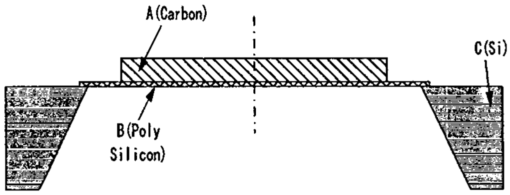

Figure. 5. magnificent of Figure.4.

thermocouple is placed on the top part of (C). (D) is consisted of metal and (F) is thermistor that measure surrounding temperature. Therefore the temperature of object is represented as a function of thermocouples voltage and thermistor voltage.

3 GOVERNING EQUATION

3.1 Radiation Energy From Object

The radiation energy from absolute temperature is calculated by Stefan-Boltmann law. so when the thermopile receive the radiation energy, the equation in receiving energy part is following equation.

$$W_0 = \frac{\sigma(\eta T^4 - T_0^4)A_0}{\pi L^2} \quad [W/cm^2] \tag{1}$$

T : Absolute temperature of object(K)
T_0 : Absolute temperature of surrounding(K)
η : Emissivity of object
σ : The number of Stefan-Boltmann
$5.673\times$ 10-12$[W/cm^2K^4]$
A_0: Aperture area of object $[cm^2]$
L: Length between object and sensor[cm]

3.2 Governing Equation And Boundary Condition

Thermopile sensor received radiation energy from the object. and the received energy is transferred by heat conduction to heat sink, by heat convection to air and by radiation to air. but in this study, it is supposed that the received radiation energy is only transferred by heat conduction to heat sink. The boundary equation of receiving energy part is the following equation (2).

$$W_{in} = k\frac{\partial T}{\partial z} \quad [W/cm^2] \tag{2}$$

k : Heat conductivity
W_{in} : The receiving energy of sensor.

The sensor is supposed that axis symmetric on Z axis. so, it can be analyzed 2-dimension. The heat conduction equation of 2-D cylindrical coordinate of part (A) is equation (3).

$$\frac{k_A}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + k_A\frac{\partial^2 T}{\partial y^2} = 0 \qquad (3)$$

k_A : Heat conductivity of material A

The heat conduction equation of other parts are the same with equation (3). but just k is different upon the material. Equation (4) is the boundary condition of difference materials. The boundary condition of contacting with air is adiabatic

$$W = k_1\frac{\partial T}{\partial z_1} = k_2\frac{\partial T}{\partial z_2} \qquad (4)$$

4 NUMERICAL ANALYSIS

The FEM(Finite Element Method) is used to analyze heat transfer function. The temperature distribution of element is defined like this.

$$T(r,z) = [N(r,z)]\{\phi\} \qquad (5)$$

$[N]$ is interpolation function of connecting the node temperature and element inside temperature. When the Galerkin method is applied to equation (3), the equation is like this.

$$k_A \iint_{s_{1e2e3e}} \left(\frac{\partial[N]^T}{\partial r}\frac{\partial[N]}{\partial r} + \frac{\partial[N]^T}{\partial z}\frac{\partial[N]}{\partial z}\right) r\,dr\,dy \cdot \{\phi\} = -\int_s q[N]^T r\,ds \qquad (6)$$

s_{1e2e3e} is the triangle area of element. s is the surroundings of element. and q is the heat flux. So, Finite element heat transfer function about element is obtained.

$$[k]\{\phi\} = \{f\} \qquad (7)$$

$[k]$ is the heat transfer matrix. and $\{f\}$ is heat flux vector of element. The global matrix is built up by jointing local element matrix. The temperature distribution is obtain by solving the global matrix.

In this study, ANSYS5.7. which is FEM software is used to analyze the temperature distribution.

5 THE RESULT OF NUMERICAL ANALYSIS

The thermal conductivity of each material is like this.

Carbon : 0.24 $(W/cm\cdot K)$
Poly-Silicon : 1.25 $(W/cm\cdot K)$
Silicon : 1.63 $(W/cm\cdot K)$
Iron : 0.80 $(W/cm\cdot K)$

Time step of calculation is 1.0×10^{-4}. The mesh of this analysis is shown Figure.6.

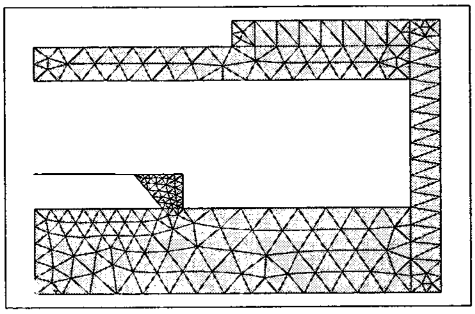

Figure. 6. Mesh of the numerical analysis

The temperature of black body is 473(K). The temperature of sensor is 298(K). The emissivity of black body is 1. Stefan-Boltzmann number is $5.673\times$ 10-12(W/cm^2K^4). the area of black body aperture 12.57(cm^2). the distance between black body and sensor is 3(cm). The receive energy is about 0.1076(W/cm^2) by equation (1).

The boundary condition to the air is adiabatic. The 2-dimension temperature distribution of hot junction at 0.2 second is fig.7. The Changing of temperature of hot junction to the z direction is too small. And the temperature distribution of hot junction and cold junction is fig.8. The Changing of temperature of cold junction is very small. The temperature distribution of hot junction is parabolic type and the hottest point is the center of hot junction.

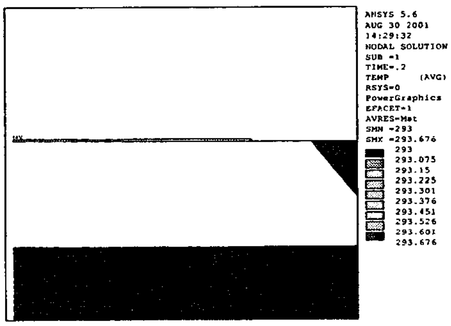

Figure. 7. the result of the numerical analysis at 0.2 second

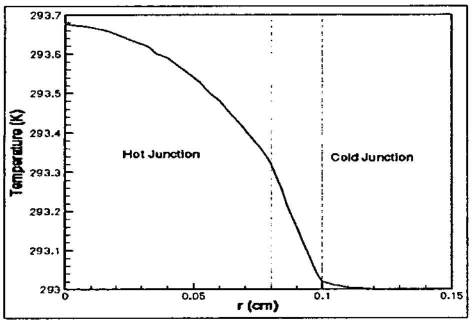

Figure. 8 Temperature distribution of hot junction and cold junction .

The raising time (10% ~90%) is about 0.04 second by fig.9. When the object temperature is changed, the raising time is not changed but hot junction temperature is varied. Fig.10 is hot junction temperature for various surrounding Temperature. Even if the object temperature is constant, the hot junction temperature is varied according to surrounding temperature. We can know that the object temperature is the function of surrounding and hot junction temperature.

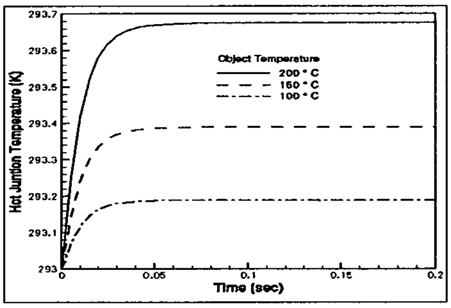

Figure. 9 Temperature of the hot junction (r=0) until time is 0.2sec with object temperature 100 °C , 150 °C , 200 °C .

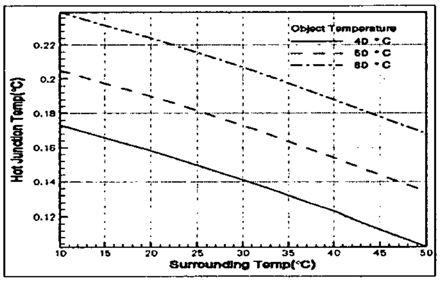

Figure. 10. Hot junction temperature for various surrounding Temperature with object Temperature 40 °c , 50 °c , 60 °c .

6 COLCULSION

We analyzed temperature distribution and response of thermopile sensor by using ANSYS software (FEM method). The thermopile sensor is made by micro machine technology.

1) The rising time of hot junction temperature is about 40ms.
2) The temperature of cold junction is not changed at 0.2sec.
3) The temperature of hot junction is changed when the surrounding temperature is changed, Even if the temperature of object is same.

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