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Multiphysics Modeling and Simulation of MEMS based Thermal Bimorph Sensor Array for Automated Solar Energy Storage Applications

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Abstract: The objective of this work is to develop a novel MEMS based Thermal Bimorph sensor array for storing solar energy to meet the growing needs of the industry.

Two bimorph array facing opposite to each other are designed and attached with metal micro plates. The micro solar thin film is placed on the top of each plate for receiving the energy and it can be used in Storage devices. With respect to the direction of sun light, one bimorph array will receive more energy in the form of heat than the other and deflect accordingly. The deflection of the bimorph array also depends on the material used for the configuration. Due to the varied temperature, position of each bimorph is changed and the films receive maximum energy. By increasing the number of array, sensitivity and efficiency can also be improved.

The thermal bimorphs and micro plates are designed using Thermal stress in Structural mechanics of COMSOL Multiphysics 4.1. The result of simulation shows the better displacement for the temperature ranges

Keywords: Thermal Bimorph, MEMS Thermal Actuator, Solar Energy, Co-efficient of Thermal Expansion (CTE)

1. Introduction

1.1 Solar Energy

Solar radiation accounts for the secondary solar-powered resources such as wind, hydroelectricity and biomass etc., and most of the available renewable energy on earth relies on solar power. Only a small fraction of the available solar energy is being used nowadays.

Solar powered electrical generation relies on heat engines and photovoltaics. The amount of solar energy reaching the earth's surface can be calculated by taking the mean of solar radiation intensity at the outer regions of the earth's atmosphere and the amount of radiation reaching the earth's surface [1, 2].

The atmosphere absorbs about 68 W/m^2 and reflects 77 W/m^2 solar energy. The solar energy reaching the earth surface every year is 3.2 million EJ, which equals 7000 times that of global energy consumption. Energy problems can be solved, if one portion of it have been harvested [1].In the year 2005 the global energy consumption was found as0.014% of solar energy reaching the earth surface. The projected global consumption in 2100 is 0.051%. We should therefore be able to harvest enough of solar energy to replace the harmful fossil fuels.

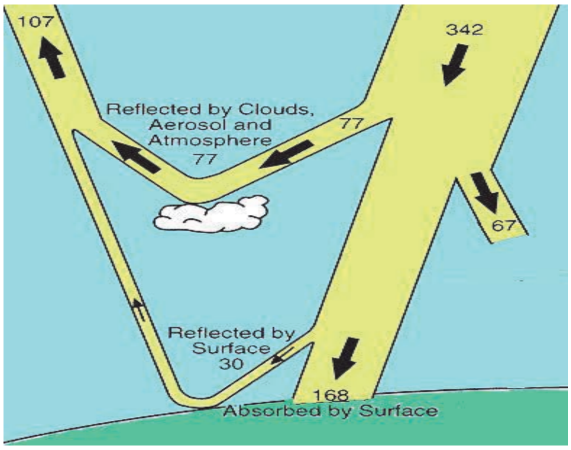

Figure 1. Solar radiation distribution. On average, each square metre of the upper regions of the atmosphere receives 342 watts of solar radiation [W/m^2]. and 30 W/m^2 is reflected back The total of the reflected radiation is 107 W/m^2, or 31% of the incoming radiation.

The intensity of the solar radiation reaching us is about 1369 watts per square meter [W/m^2]. This is called as solar constant.. The total solar radiation intercepted by the Earth is the Solar Constant multiplied by the cross sectional area of the Earth. When we divide the calculated number by the surface area of the Earth, we can find the amount of solar energy received, by a

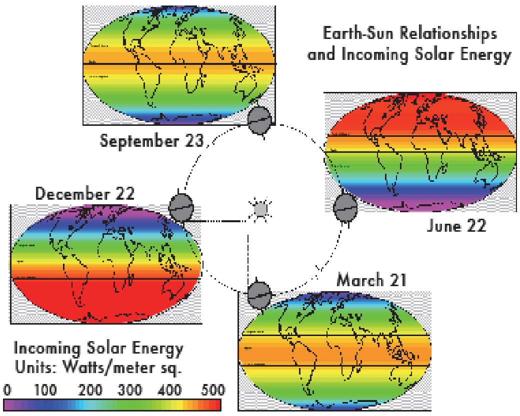

Figure 2. The intensity of solar radiation (solar power) in various parts of the world depending on the season, measured in watts per square meter [W/m^2].

square meter of the Earth's surface[1,2].Thus, the average solar radiation S per square meter of the Earth's surface is,

$$R = \frac{S\pi r^2}{4\pi r^2} = \frac{1369}{4} \approx 342\frac{W}{m^2}$$

where S is the Solar constant in W/m^2 and r is the Earth's radius.

1.2 Thermal Actuator

Thermal micro actuators form potential applications for large and linear displacement, low power MEMS actuators. A thermal bimorph consists of two material layers with different coefficient of thermal expansion (CTE). Typically, the layers consist of one material with a high CTE, such as a metal like Al, and another material with a low CTE, such as polyimide. When the bimorph temperature decreases or increases, the high-CTE material will contract or expand, respectively, more than the low-CTE material, resulting in the bending movement in the bimorph curvature [4].

Thermal actuation is a well known mechanism that can be implemented at micro scale without any fabrication problems or the need for sophisticated material integration technology. In addition to that, thermal actuators have great properties such as large actuation force, and simplicity of design and integration..Furthermore, thermal actuators are usually considered and referred to as low actuators only suitable for DC or very low frequency applications.

The thermal bimorph actuators have been used in various applications like RF switches, nanoprobes, read-write cantilevers, micro legs, micro positioning applications, liquid drop ejectors and so on. Thermal bimorphs can achieve large mechanical displacements because of the large strain difference that is created when using materials with different coefficients of thermal expansion (CTE) [3].

In this paper, the solar energy is utilized to actuate the bimorph array and it actuates the micro plate without any influence of electrical source.

2. Design of Bimorph array

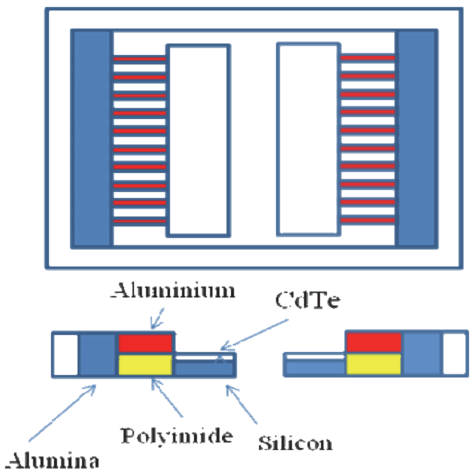

Figure 3. Schematic Diagram of Thermal Bimorph Array

The schematic drawing of the MEMS bimorph structure is illustrated in fig 3. A silicon micro plate is attached to the bottom of the bimorph array. The top of this array is made of Aluminum and the bottom of this array is made of Polyimide material. This array is connected to the thermal insulator made up of Alumina which has 10 bimorph elements. This array model is placed on both sides. Cadmium Telluride (CdTe) solar thin film is placed on the top of the silicon micro plate. The geometry design parameters and the properties of the material used in the analytical model were found and tabulated in Table 1 and 2[4,5].

Mechanical properties

Property	Al	Polyimide	Alumina
Young's Modulus	70GPa	3.1 GPa	400GPa
Poisson's ratio	0.35	0.34	0.22

Thermal properties

Property	Al	Polyimide
Thermal conductivity	237[W/m*K]	0.15[W/m*K]
Heat Capacity	904[J/kg*K]	1100[J/kg*K]
Coefficient of thermal expansion	230e-6[1/K]	5.5e-5[1/K]
Density	2700[Kg/m^3]	1300[Kg/m^3]

Table 1. Properties of materials used in simulation.

Parameters	Value
Total frame length	1.3mm
Thermal insulation length	1.15mm
Bimorph actuator length	200µm
Micro Plate length	1.05mm
Width of the microplate	200 µm
Width of the total frame	10µm
Width of the thermal insulation	100µm
Thickness of thermal insulation	10µm
Thickness of high CTE material	5µm
Thickness of low CTE material	5µm
Thickness of microplate	3µm
Thickness of thinfilm	2µm

Table 2. Geometric values of the Parameters

3. Use of COMSOL Multiphysics

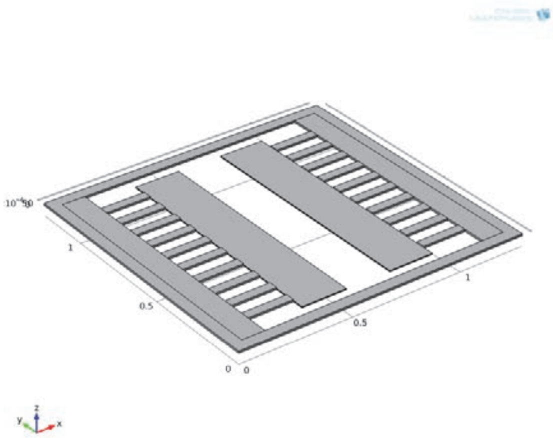

Figure 4 Geometry Model of Bimorph Array

Figure 4 shows the designed model of the Thermal Bimorph array (200µm×40µm ×5µm) for this application. The design is implemented and simulated using COMSOL Multiphysics 4.1 software. MEMS module is used to design the sensor and the physics applied here is the thermal stress in order to simulate the results with the input parameters.

4. Results and Discussion

Heat source is provided uniformly on the top of thermal bimorph elements. Owing to the change in coefficient of thermal expansion, the bimorph elements deflects accordingly.

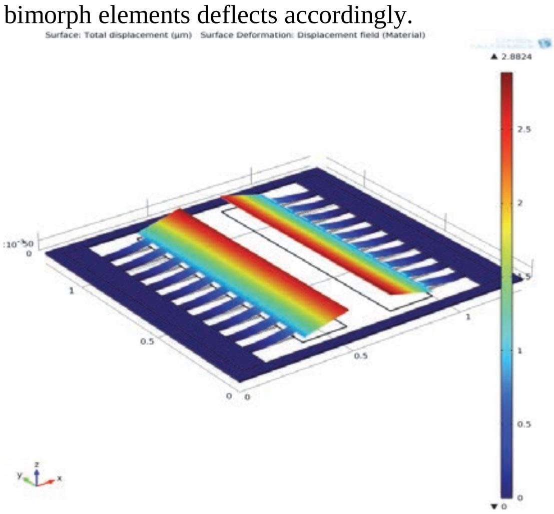

Figure 5. Total Displacement of micro plate at both ends

Figure 5 illustrates the deformation results of the microplate, when the temperature is at 299K. For the applied heat source and the material properties of both aluminium and polyimide in the array design, the maximum displacement has been obtained.

T_{EXT} [K]	Total displacement [µm]
294	0.0775
295	0.1475
296	0.2578
297	0.3778
298	0.5098
299	0.6435
300	0.7852
301	0.9257
302	1.0732
303	1.2162
304	1.3674
305	1.5079
306	1.6603
307	1.7884
308	1.9408
309	1.9665
310	2.1499
311	2.4124
312	2.4381
313	2.5923
314	2.621
315	2.8824

Table 3. Displacement values for the various temperatures

Fig 6 illustrates the relation between displacement of the microplate and the change in Temperature. The Temperature is varied from 294K to 315K and the maximum displacement of 2.88 µm has been obtained, when the temperature is at 315K. This also clearly indicates that the selected material exhibits better response for this application.

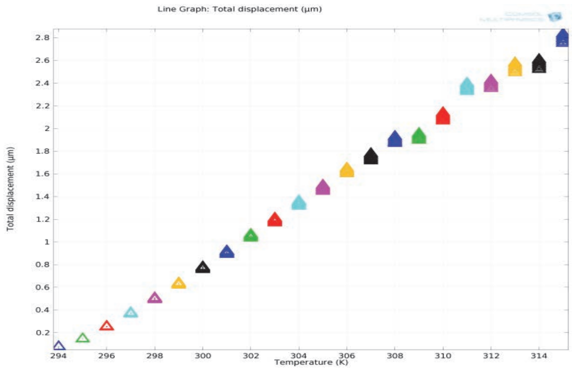

Figure 7. External Temperature (K) vs. Total Displacement (µm)

5. Conclusion:

MEMS based thermal bimorph sensor with novel thermal actuation mechanism is successfully designed using COMSOL Multiphysics 4.1.The design uses a complementary configuration of bimorph array to receive maximum energy from the sun. This can be further extended to store the energy in storage devices. A maximum displacement of 2.88µm has been achieved with a micro device of dimension 200µm×40µm ×5µm in size. The changes owing to temperature and displacement are studied and plotted. Deformation is observed on both side of the bimorph array. By varying the number of bimorph array, the length of the solar thin film also can be increased which in turn improves the performance of the bimorph sensor. The displacement obtained itself conforms that it can be used as a thermal source without any influence of external electrical source.

6. Future Work

The discussed simulated results could be implemented for practical studies and analyses in future for real time applications.

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