ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785
(ISRA), Journal Impact Factor: 2.114

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

TO ANALYSE CURRENT DENSITY EFFECT ON THERMAL ACTUATORS

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ABSTRACT

In this paper, MEMS sensor array is designed in different shapes using COMSOL Multi-physics. The current density variation with temperature is analysed for different shapes of sensor array using same material of copper alloy UNS C17500 with voltage applied at two boundaries of the array. The analysis is also done using interfacing of COMSOL with MATLAB.

KEYWORDS: Sensor Array, COMSOL Multi-physics, Different shapes, MATLAB, Thermal Expansion

INTRODUCTION

In today's world, the most exciting technology is pioneering in miniaturized form. These development have enabled the micro-systems to sense, perform and respond to become intelligent Micro-systems [13]. MEMS [Micro-Electro-Mechanical System] are the micro-components or micro- devices used to perform electrical and mechanical functions. MEMS devices are miniaturized structures to sense, control and actuate on the micro-scale using single micro-chip and function individually or in arrays to generate effects on macro-scale. MEMS based sensors are crucial components in automotive domain, medical tools, hard disks drives, computer peripherals, wireless devices and smart portable electronics such as cell phones and PDA's[11]. At small length scales, COMSOL Multi-physics is ideally suited for MEMS applications. Depending upon the capabilities of COMSOL Multi-physics, the MEMS module can be used to address any phenomenon related to mechanics electronics and optics at the micro-scale [12]. MEMS control the exceptional knowledge to design complex micro-systems and achieve best multi-sensing solution [14].

DESIGNING OF SENSOR ARRAY USING COMSOL

A geometry is drawn using copper beryllium alloy in different shapes to analyze current densities for different shapes. The geometry drawn using COMSOL Multi-physics include physics

1. Heat Transfer in solids.
2. Electric Current.

Heat Transfer describes the exchange of thermal energy, between physical systems because of the pressure and temperature applied, by dissipating heat. The fundamental modes of heat transfer are conduction, convection and radiation [15]. In an immobile solid, the temperature field verifies the following form of the heat equation .[16]

$$\rho\, C_p\ \Delta T/\Delta t - \Delta\,(k,\Delta t) = Q \qquad (1)$$

Cp = Heat Capacity at constant at constant pressure (J/Kg/K). K = Thermal Conductivity (W/m/K).
Q = Heat Source (W/m^3). T = Temperature (K).
ΔT = Temperature difference(K).
ρ = Density (Kg/m^3).

Normal Current Density: The normal current density node is applicable to exterior boundaries which represent either a source or a sink of current flowing due to electric potential applied. It provides a condition to specify the normal current density as an inward or outward current flow.[17]

$$-n.J = J_n \qquad (2)$$

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Or alternatively, as a current density J_0
$n.J = n.J_0$
The normal current density is positive when current flows inward in the domain[17].

Electric current density: *J* is simply the electric current *I* (SI unit: A) per unit area *A* (SI unit: m^2). [19]Its magnitude is given by:

$$J = \lim_{A \to 0} I(A)/A \quad (3)$$

A general estimate of the current density assumes the current is proportional to the electric field, as:

$$\mathbf{J} = \sigma.\mathbf{E} \quad (4)$$

Where E is the electric field and σ is the thermal conductivity[18].

At high frequencies, current density increases because the conducting region in a wire becomes confined near its surface, the so-called skin effect.

An electromigration is a phenomenon in which the material forming interconnection actually moves at high current densities[19]. Electromigration is the transfer of material caused by the gradual movement of the ions in a conductor due to transfer of momentum between conducting electrons and diffusing metal atoms. At high direct current densities this effect is essential in applications, such as in micro-electronics. As the structural size decrease in electronics circuits such as in integrated circuits (ICs), the practical significance of electromigration increases[20]. Most electrical conductors have a finite positive resistance, making them dissipate more power in the form of heat.

At high current densities, the conductor melt and thus causing the insulating material to fail, or changing the desired electrical properties. In superconductors a strong magnetic field is generated at high current densities to cause spontaneous loss of the superconductive property.

The current density is a significant parameter in Ampere’s circuital law (one of Maxwell's equations), relating current density to magnetic field.

Joule Heating is a common effect at the micro-scale, where current densities are very high. The analysis also estimates the influence of temperature on the total current as a function of voltage. All boundaries are electrically insulated except the left and right surfaces attached to the solid frame. Over these surfaces electric potential is applied and thus creating a current balance..

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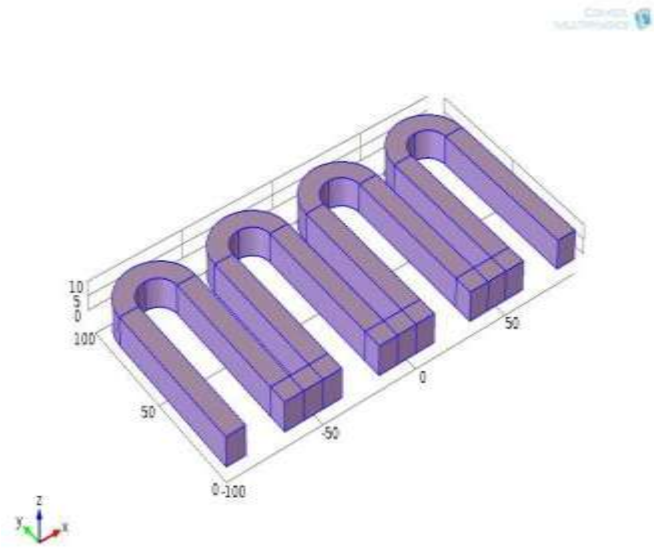

Fig. 1. U-shape model defining physics used

Different shapes of sensor array is designed using same material which is copper beryllium alloy i.e. UNS C17500. The sensor array designed using different shapes include u –
shape[2] as shown above in Fig.1.
The other shapes may include a triangular shape with rectangular cut[1] and triangular shape with triangular cut as shown below in Fig.2 and Fig.3 respectively. The figures obtained include the two physics applied to the sensor array i.e. Heat Transfer in Solids and Electric Current module.

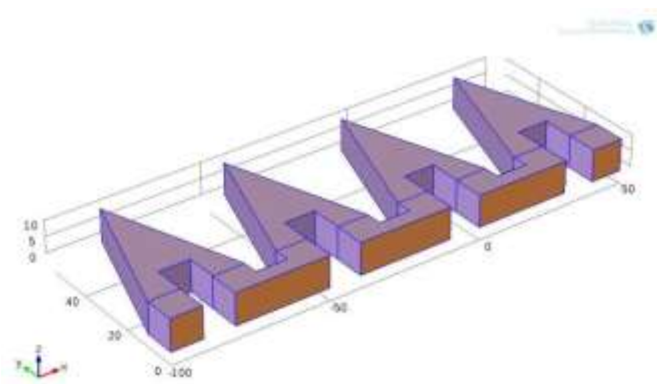

Fig. 2 Triangular shape with rectangular cut showing heat flux applied using heat transfer in solids module

An inward heat flux is applied at all the boundaries as shown in purple except at the fixed boundaries as shown in brown in Fig. 2.

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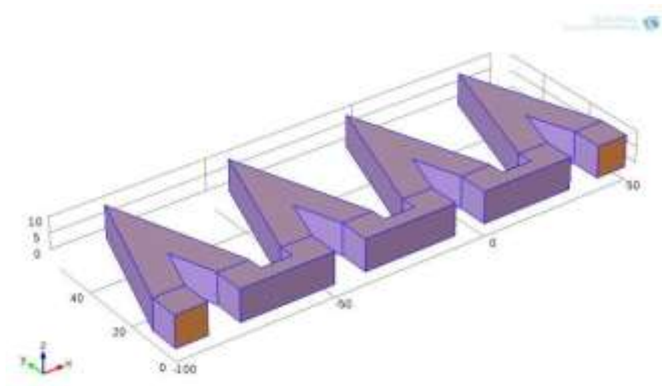

Fig. 3 Triangular shape with triangular cut showing electric potential applied using electric current module

An electric potential is applied at two of the boundaries and all other boundaries are insulated as shown in Fig. 3.And external temperature applied can be varied from 100K to
900K.

RESULTS OBTAINED USING MATLAB DESKTOP

Mesh generation is an essential part of the simulation process, and is very basic for obtaining the best results in the fastest manner. The finer the mesh, the more accurate the solution will be. The geometry has been meshed using an extremely fine element size as shown in Fig.4 using MATLAB desktop.

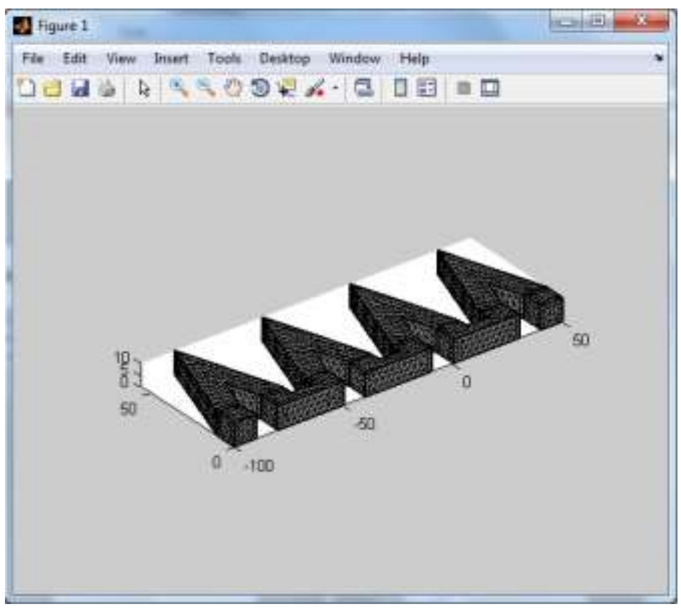

Fig.4 Meshed Geometry

The current density is also analysed to explore the physics by considering the nature of solids, including metals, semiconductors and insulators. To explain fundamental observation a highly structured theoretical formalism has been developed.

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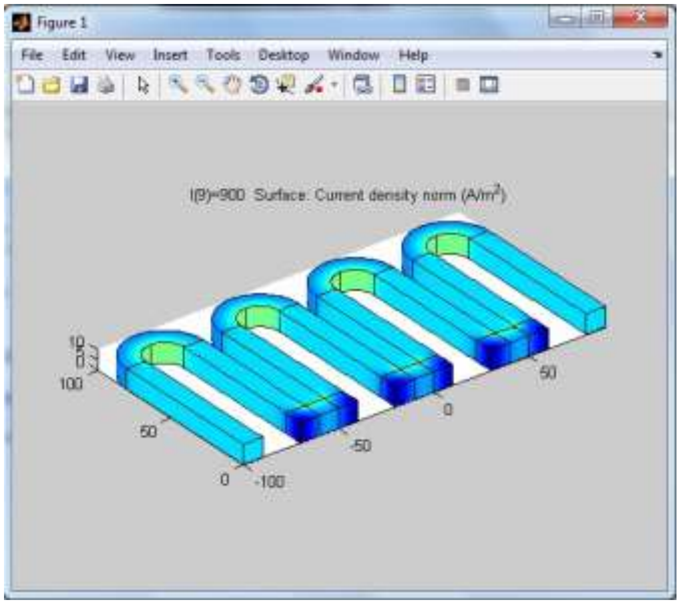

Fig.5 Current Density Distribution in U – shape model

A high current density can be obsereved at the inner surfaces of U-shape bent, because the current takes a shorter path through the device as shown in Fig5.
Current Density is largest in the device's inner sharp corners.
A possible improvement of the model would be round these corners to their true physical curvature. So, distribution of current densities in another shape of triangle with rectangle cut is shown in Fig. 6 below.
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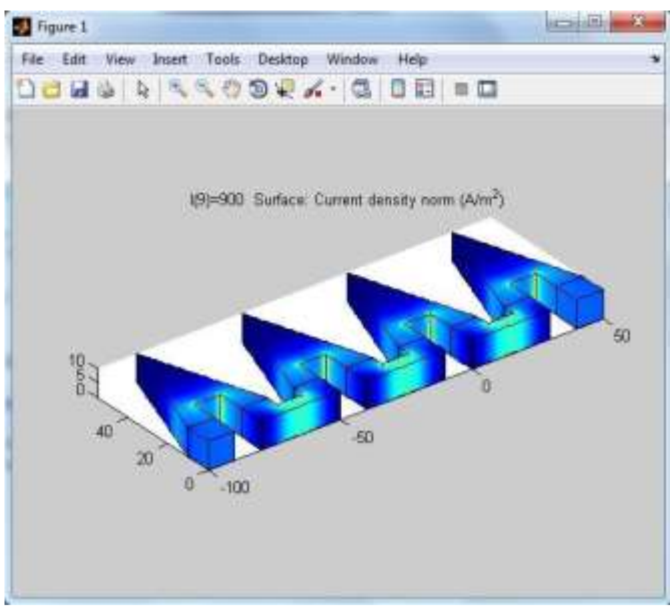

Fig.6 Current Density Distribution in Triangle with rectangle cut model

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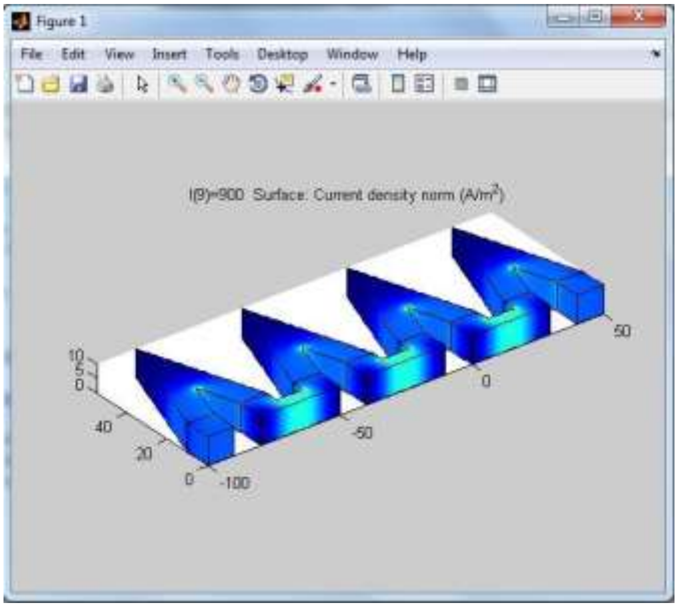

Fig.7 Current Density Distribution in Triangle with triangle cut model

As shown in Fig.7 above, current density distribution in a new shape of triangle with triangle cut can be observed.

THERMAL CONDUCTIVITY OF DIFFERENT SHAPES WITH RESPECT TO TEMPERATURE

With increase in temperature, thermal conductivity of alloys increases. This is because of contribution of electrons, as the temperature of alloy increases the movement of electrons increases, which result in an increase in thermal conductivity.

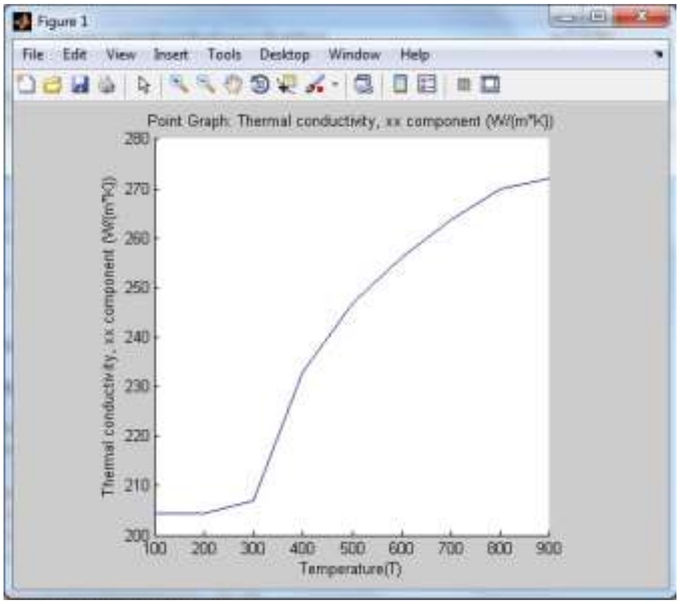

Fig.8 Thermal Conductivity of U – shape model.

As shown in Fig.8 thermal conductivity is nearly constant with increase in temperature upto 273K and then increases with increase in temperature due to movement of electrons.

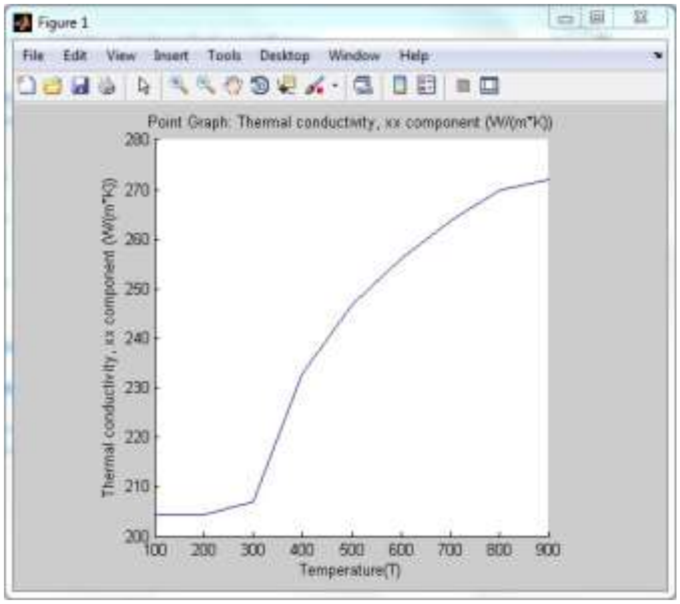

Fig.9 Thermal Conductivity of Triangle with rectangle cut model

As shown in Fig.9 and Fig.10 that thermal conductivity of all the three different shapes remain same. This is due to the reason that thermal conductivity graph of same material i.e. UNS C17500 is almost identical for all three geometries and do not depend upon the shape of the material.

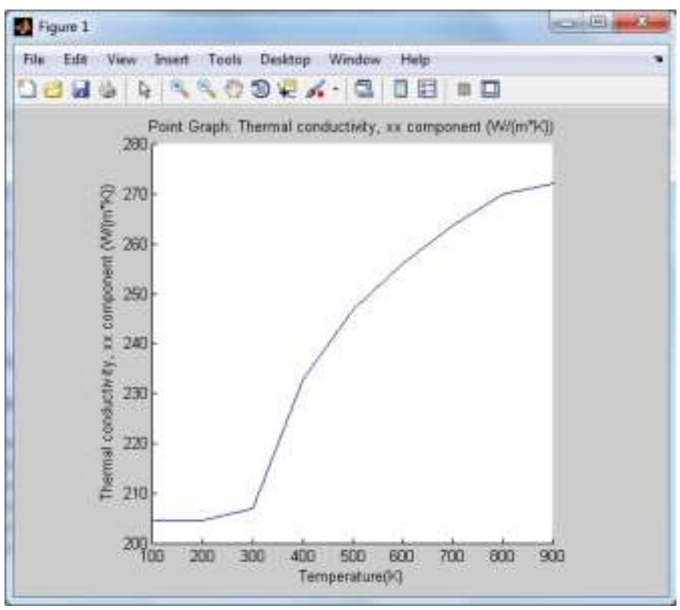

Fig.11 Thermal Conductivity of Triangle with triangle cut model

ANALYSIS OF CURRENT DENSITY DISTRIBUTION WITH TEMPERATURE

The current level defines the circuit performance and the dimensions of the conducting elements is determines the current density on the surface of the device. For example, when we reduce the size of integrated circuit, the smaller device demand lower current, so as to achieve higher current densities even on smaller chip areas.

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An exciting issue is the influence of temperature on the linearity of the current density as a function of the total potential difference across the device.

From equation (4), current density is directly proportional to thermal conductivity and electric field across the device. At low temperatures increase in current density is in direct proportion with temperature from 100K to 300K (-173°C to27°C) because of the voltage applied at the boundaries and then after 300K it increases with respect to increase in thermal conductivity of material with respect to temperature

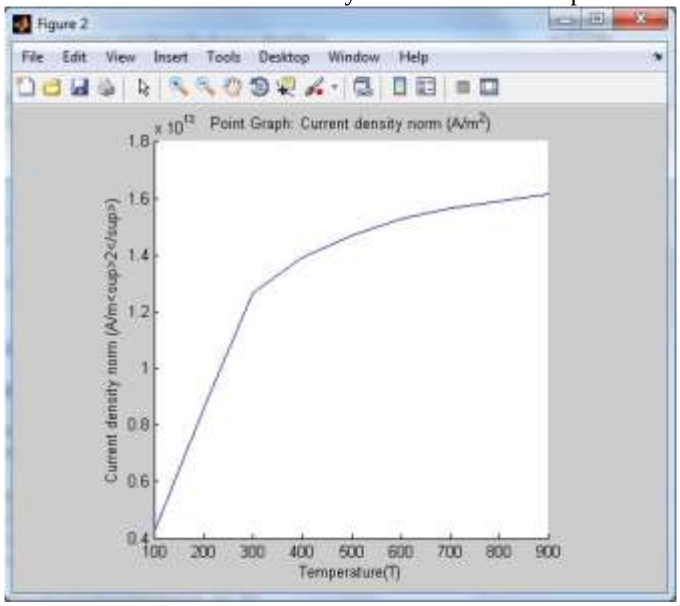

Fig. 12 Current Density norm of U – shape model.

Fig.13 shows the current density norm of model with different shape i.e. triangle with rectangular cut. In this the current density norm is increased with respect to u-shape model.

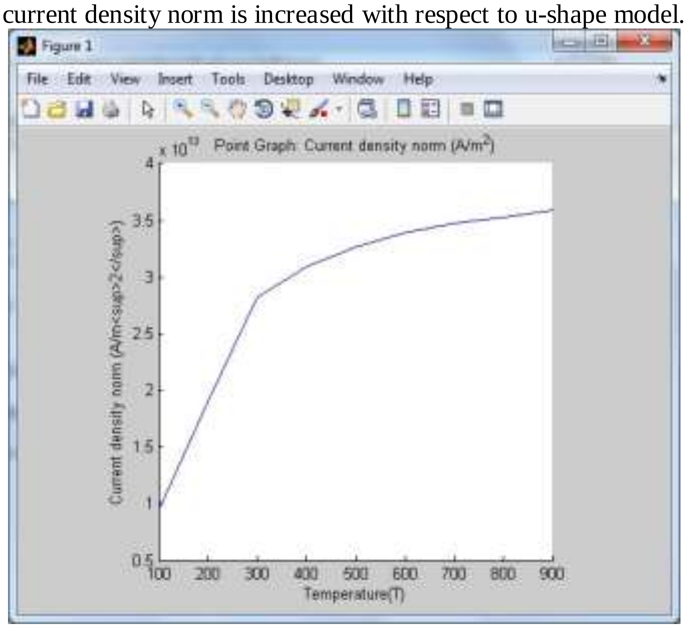

Fig.13 Current Density of Triangle with rectangle cut model

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As shown in Fig.14 the current density norm with respect to temperature has increased with greater difference between the lower and higher temperatures

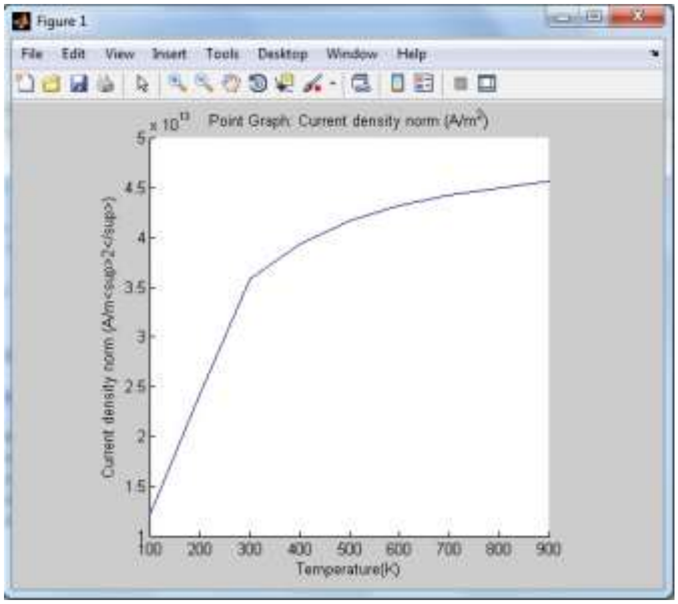

Fig.14 Current Density of Triangle with triangle cut model

The difference between current density of different shapes is due to difference in the area of cross section as current density is inversely related to area of cross section from equation (3). So from Fig.15 current density of triangle with triangle cut is highest and that of u-shape is lowest.

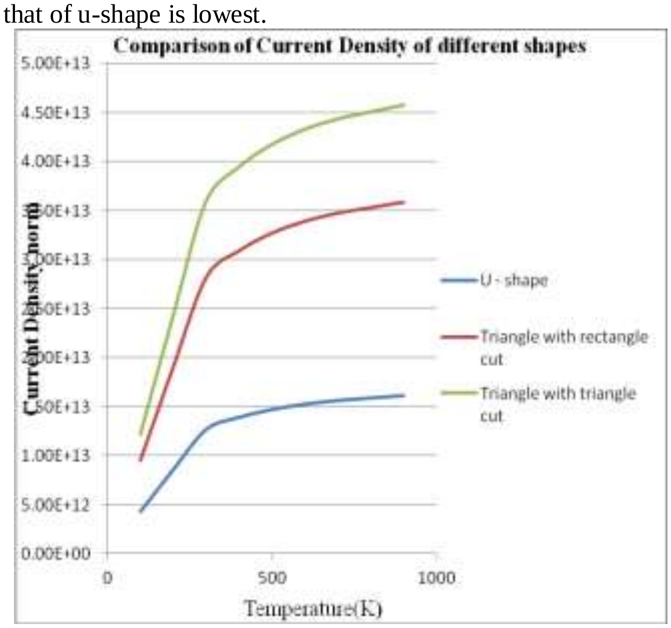

Fig.15 Comparison between current densities of different shapes with increasing temperature

CONCLUSION

A sensor array is designed using copper beryllium alloy UNS C17500 in different shapes. The current density norm is confined to sharp corners of the model. The current density is higher at the corners because the current takes a shorter path at edges. The thermal conductivity of all the three shapes remain the same. The current density of triangular shape with triangle cut is highest of all the shapes because of the area of cross section. Also at temperature above 300K current density increases with respect to increase in thermal conductivity with temperature.

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ACKNOWLEDGEMENT

The authors are grateful to HOD of ECE Department Mrs. Poonam Beniwal and all the faculty members of ECE Department. for providing Institutional support.

FUTURE WORK

Future work may involve study ofcurrent density of different models at higher temperatures.

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