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ANALYSIS OF THERMOELECTRIC MATERIALS USED FOR COOLING OF SOLAR PV MODULE

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Abstract - *Solar energy represents a great potential of renewable energy source in the world. The solar irradiation and the ambient temperature affect the output power of photovoltaic (PV) system. The efficiency of solar panels decreases when the temperature of the solar panels increases. In order to control and maintain the operating temperature, cooling of PV module should be carried out. The thermoelectric effect is the effect in which the difference in temperature produces an electric potential. Thermoelectric devices are used to convert thermal energy into electrical energy by which it acts as both generator and cooler. Bismuth Telluride (Bi_2Te_3) is the frequently used thermoelectric material for the applications working at room temperature. In this project work, graphene as a thermoelectric material is analyzed and compared with bismuth telluride. The analysis of this project work eventuates that the graphene based TEG/TEC, gives larger current output and absorbed heat than Bismuth Telluride.*

Key Words: **PV module, Bismuth telluride, Thermoelectric, graphene, PV cooling**

1. INTRODUCTION

In this industrial era, main source is electricity and it is being obtained majorly from fossil fuels. This led to large consumption of fossil fuels. Therefore, it is inevitable to shift to renewable energy sources from fossil fuels. Among the renewable energy sources, solar energy is prominent and used worldwide. Almost for all the renewable energy the source is sun. The solar energy from the sun can be converted into electricity by means of photovoltaic cell.

The efficiency of the solar thermal conversion system is ranging from 40 to 60 % and that of photovoltaic cell is between10 and 20 % [1,2]. PV cells produce electricity when the wavelength ranges around 400 to 700 nm [3,4]. Usually the shorter wavelength has higher energy photons, but the high-energy photons will damage the photovoltaic cell. The generation of electricity from the PV cells is increased by decreasing the operating temperature [5–7]. Also, the life of PV gets increased, so that we get more electricity.

The solar panel gets affected by various environmental factors such as ambient and module surface temperature, shading, sunlight, wind speed, humidity, dust, etc. But the important factor here is solar irradiance and temperature. The material of solar PV cell also plays major part in the efficiency, various researches were carried out by comparing the materials such as MAPbI3, CdTe, and GaAs and resulted perovskite poly-crystalline do better than inorganics [8].When the PV cell gets heated up more than the operating temperature, the electricity generated is decreased. Since, energy from sun is enormous, only 5-20 % is converted to electricity [9,10]. Remaining of the energy is absorbed as heat which gives rise to the cell temperature up to 70°C. This affects the properties of solar cells and decreases their efficiency. Cooling of PV modules hence increase the annual performance of PV. Rather than cooling of PV module, the thermal waste can be used by affixing thermoelectric (TE) converters to the backside of PV modules. Due to the difference in temperature in the TE converter electricity can be generated.

TE technology has gone through stages of important research and growth. The See-beck, Peltier and Thomson effects were first identified between 1821 and 1851, and their applications to thermometry, power generation and refrigeration were recognized [11]. The thermoelectric technology has increased slowly up to the 1930's, the fast developments in major areas of TE happened and in the mid 1960's, thermoelectric devices are developed for applications in the cooling of aerospace and space-craft power. Development in improving efficiency was retarded and research has gone high in 1963, and again a narrow decline in TE research about three decades [12]. But in 1990 there was again interest in thermoelectric technology because of factors combination, also due to the environmental concerns regarding refrigerant fluids, alternative refrigeration and cooling of electronics [11]. Recently, the thermo electric materials research has been developed to a extent where flexible materials, conducting polymers are designed.[13]

In this project work, for cooling of solar panel, Thermo-electric cooling method is followed and graphene as a thermoelectric material is analyzed and compared with bismuth telluride.

2. MATERIALS AND METHODS

2.1 Thermo-Electric Material

The performance of Thermo electric generators and Thermo electric coolers depend on the dimensionless term ZT which is a thermoelectric property of material used in corresponding devices, also known as thermoelectric figure of merit.

$$ZT = S^2 \sigma T k \qquad (1)$$

where S is See-beck coefficient, σ is electric conductivity, k is thermal conductivity of material. It is now clear that for greater thermoelectric effect material selection is important. Z, See-beck coefficient is defined as the amount of voltage induced due to the temperature gradient across the material and it is described as S= V/ΔT. The temperature difference (ΔT) can be achieved between the room temperature and any waste source of heat such as exhaust in heat engine [14].

2.2 Bismuth Telluride

Bismuth telluride is the widely used material for most of the Peltier devices and thermoelectric generators. This is because around room temperature Bi_2Te_3 (alloys with Sb_2Te_3 as p-type and Bi_2Se_3 as n-type material) has the highest thermoelectric figure of merit, *zT*, of any material. Bismuth Telluride (Bi_2Te_3) is the mostly used TE material for any application working at room temperature which has See-beck coefficient approximately -149 μv/°c. (maximum value -288μv/°c at 540°c at ambient temperature)

2.3 Graphene As Thermo-Electric Material

In recent years, we have seen a ample interest towards the electrical properties of graphene. Graphene has unique properties such as higher thermal conductivity, fast moving electrons and can be used in nano applications [15]. The figure of merit is directly proportional to the overall performance of TEG. Hence, graphene has a greater chance regarding TEG. Higher electrical conductivity and larger See-beck coefficient and low thermal conductivity is necessary for a material to attain thermoelectric figure of merit. Hence, figure of merit of the material's also depends on power factor, given in equation (2). In solids, conduction is happening by the vibration combinations and molecular collisions, phonons propagation and collisions, and of free electrons diffusion and collisions. Thus, the thermal conductivity of solids are as follows,

$$P = \sigma S^2 \qquad (2)$$

$$k_{tot} = k_e + k_{ph} \qquad (3)$$

where k_t

k_t is total thermal conductivity, k_e is electronic contribution to thermal conductivity and k_{ph} is thermal conductivity due to phonon conductance. Phonon is defined as "collective excitation in a periodic, elastic arrangement of atoms or molecules in condensed matter, like solids and some liquids, often designated a quasiparticle which represents an excited state in the quantum mechanical quantization of the modes of vibrations of elastic structures of interacting particle". Graphene has an advantage of transport properties as a possible thermoelectric material, but has a limitation due to high thermal conductivity. In graphene, the main factor limiting the TE conversion is the high thermal conductivity by phonon. So, graphene has a low figure of merit with high-power factor. The usual idea to enhance figure of merit is to place phonon scatterers to reduce the conductance of phonon while maintaining high electrical conductance and See-beck coefficient.

Table: 2.1 Thermo-electric properties of Bismuth telluride and Graphene

Materials /Properties	Bi_2Te_3		Bi_2Te_3 & Graphene	
	P junction Bi_2Te_3	N junction Bi_2Te_3	P junction Graphene	N junction Bi_2Te_3
S (μv/k)	140	-150	150	-150
P (Ωm)	0.6 * 10-5	4*10-5	1.67*10-7	4*10-5
K ($Wm^{-1}K^{-1}$)	1.3	0.21	50.4	0.21
ZT	0.8	0.8	0.8	0.8

2.4 Model Development

A model is designed to perform a comparative analysis between the thermo-electric materials Bismuth telluride and graphene. For simple design and analysis purpose, with standard dimensions, the thermo- electric cooler module is attached to copper alloy and total current density and temperature analysis is carried out.

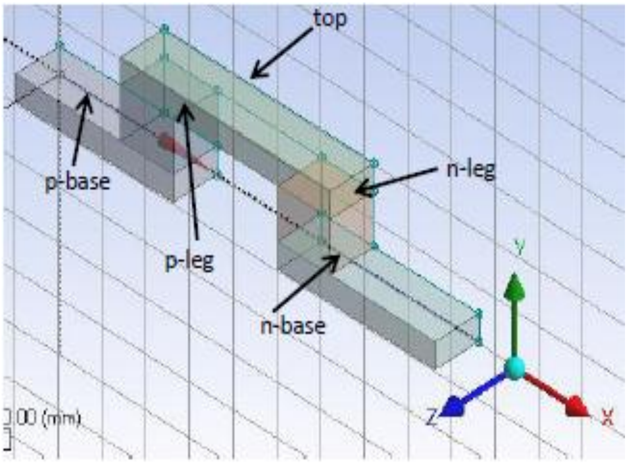

Fig:2.1 Parts of the Model

Table 2.2 Dimensions of the model

NAME	DIMENSION
Base length	36mm
Base height	5 mm
Copper alloy Length	54 mm
Copper alloy Height	5 mm
P and N type TEC Length	10 mm
P and N type TEC Height	10 mm
Width	10 mm

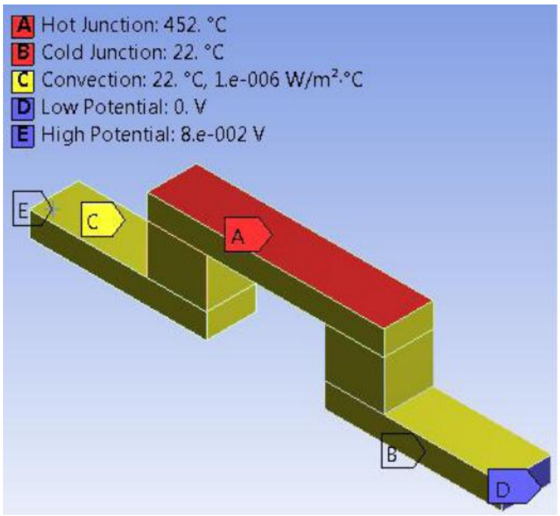

Fig. 2.2 Boundary Conditions

Table 2.3 Boundary Conditions

Name	Values
Hot Junction Temperature	452 c
Cold Junction Temperature	22 c
Convection Temperature	22 c
Low Potential voltage	0 v
High Potential Voltage	8.e-002 v

2.5 Boundary Conditions

To run a simulation of Thermo-electric Generator and Thermo-electric Cooler in Ansys, a fundamental model with a single cell was designed. This fundamental model was designed in following the regular model of Thermo-electric Cooler (TEC) with Bismuth Telluride (Bi_2Te_3) but in an amplified scale of a single cell. Two simulations are created, one with the regular Bi_2Te_3 and the other is graphene in speculation with Bi_2Te_3. The same geometry will be used in both simulations. The geometry was imported to design modeler of Ansys workbench. The boundary conditions at the hot junction and cold junction temperatures were also maintained same in both simulations. The boundary conditions for the designed model are given as per the table (2.3)

3. RESULTS AND DISCUSSIONS

The model of thermos-electric module attached with a copper alloy has been developed and analysis has been done using ANSYS Workbench18.0. The analysis has been performed for two different materials Bismuth telluride and graphene. Thermo-electric analysis has been performed for finding parameters like temperature difference, Total current density. In Ansys the simulation for thermal and electric fields can be simultaneously analyzed by Steady-State Thermal-Electric analysis. This analysis can check See-beck, Peltier, and Thomson effects for thermoelectricity. Bismuth telluride and graphene TEC materials are compared by the analysis of total current density and heat absorbed. Current density is defined as the total amount of current flowing through a unit value of an cross-sectional area.

3.1 Meshing

After importing the geometry into ANSYS Thermo-electric, the meshing is dividing the domain into various parts such as nodes and elements. The meshing accuracy is respective for user. Based on the computational power, shapes such as triangle, quadrilateral, tetrahedron can be used. Table (5.3) represents the meshing parameters followed for this model.

Table 3.1 Meshing Parameters

Properties	Values
Relevance Centre	Coarse
Size of element	Default
Quality of target	Default - 0.050
Smoothing	Medium
Node	8570
Element	1470

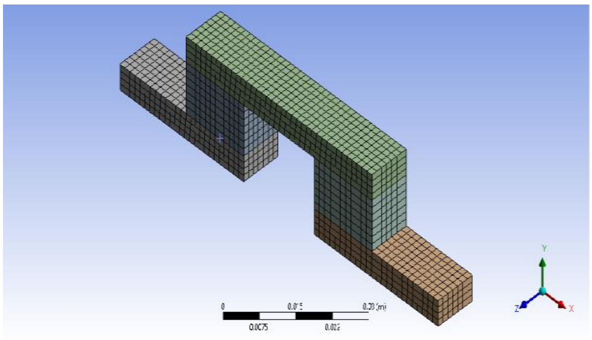

Fig: 3.1 Meshed Model

3.2 Modelling Of Thermo-Electric Generator/Thermo-Electric Cooler With Bi_2te_3

The figure 3.2 and 3.3 shows the contour of total current density and temperature difference of only Bi_2Te_3 respectively.

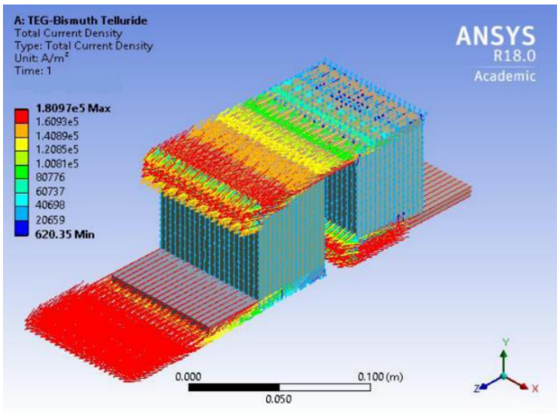

Fig 3.2 Total Current Density of only Bi_2Te_3

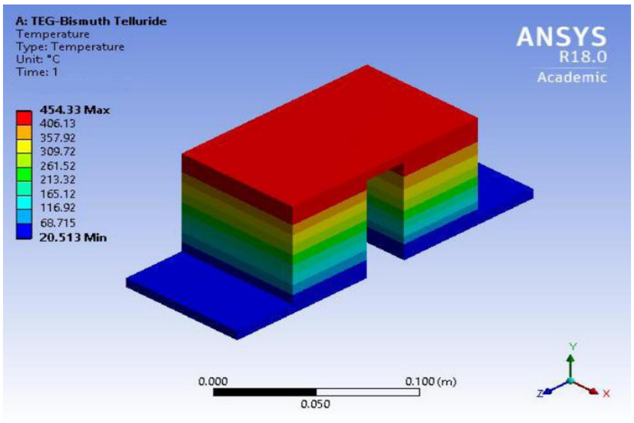

Fig 3.3 Temperature of Bi_2Te_3

3.3 Modelling Of Thermo-Electric Generator/Thermo-Electric Cooler With Graphene And Bi_2te_3

The figure 3.4 and 3.5 represents the total current density and temperature difference of graphene incorporated Bi_2Te_3.

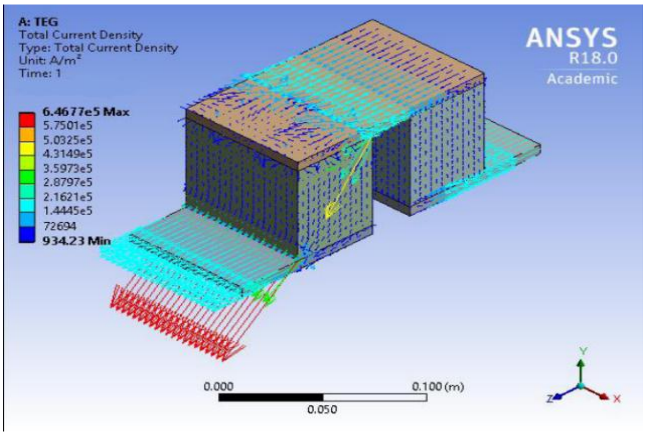

Fig: 3.4 Total Current Density of Graphene and Bi_2Te_3

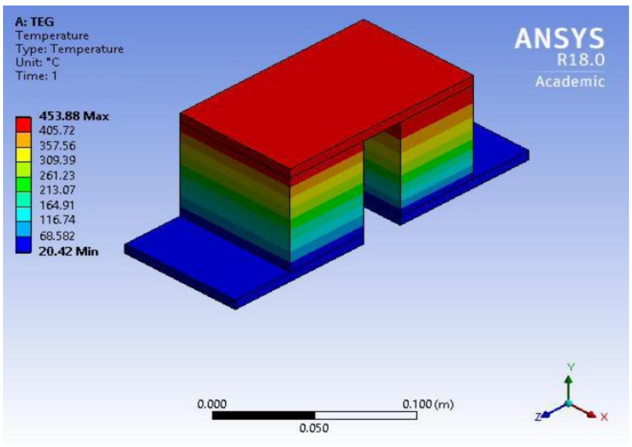

Fig: 3.5 Temperature of Graphene and Bi_2Te_3

- Heat absorbed = $mC_p\Delta T$

Where, m = mass flow rate
(Bi_2Te_3= 0.0007624 Kg/s,
Graphene = 0.1439 kg/s)
c_p = specific heat
(Bi_2Te_3=165 J $kg^{-1} K^{-1}$,
Graphene = 21 J $kg^{-1} K^{-1}$)
ΔT = temperature difference

- Generated Current = Current density * Area

Where, Area= 0.0004669 m^2

The results are given in table 3.2. It is obvious that the Thermo-electric generator or Thermo-electric cooler having graphene results in a higher output of current and heat absorbed is larger. Hence, it is clear that graphene works efficiently as a thermoelectric material.

Table 3.2 Comparison of Generated Current and Heat absorbed between Bi_2Te_3 and Graphene.

TYPE	Current Generation (Ampere)	Heat absorbed (Watt)
P and N junction Bi_2Te_3	84.40	54.60
P junction graphene and N junction Bi_2Te_3	94.46	1311.8

4. CONCLUSION

The design and analysis of two different TEC materials is carried out in this project work. The results from the analysis are as follows:

- The Thermo-electric generator with graphene based, gives a larger output of current and heat absorbed is larger than Bi_2Te_3.
- Thus, for cooling of solar panel using TEC method, Graphene incorporated TEC is preferred.

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