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Generalized Programming Idea for Making the Thermoelectric Device Using MATLAB Software for Cu2Bi2Te3 and Cu2Sb2Te3

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Abstract

Device fabrication using simulation process and modeling are one of the most leading researches in present days. Here, the Thermoelectric Device performance is analyzed with basic coding using MATLAB software. The MATLAB based fabrication of thermoelectric generator lead to analysis the power efficiency and ZT performance for the materials (Cu2Bi2Te3 and Cu2Sb2Te3). All parameters were optimized and the function output (Figure of Merit) was 2.59 (no unit) for Cu2Bi2Te3 and 0.657 (no unit) for Cu2Sb2Te3.

Keywords: Thermoelectric Generator; MATLAB device manufacture; Device Performance Analysis, Device fabrication using MATLAB Programming; Thermoelectric Device.

1. Introduction

MATLAB provides a potent tool for modeling and analyzing sustainable energy systems, including thermoelectric energy conversion. Its flexibility and versatility, along with its built-in tools and features for numerical analysis and simulation, make it a useful platform for academics and engineers working in the field of sustainable energy [2, 5, 10-12]. For investigating the behavior of thermoelectric materials and devices, MATLAB is an effective tool because to its strengths in numerical methods, data processing, and visualization [6-9]. Optimization of the design and functionality of thermoelectric materials and devices is one potential application of MATLAB in sustainable energy modeling.

The performance of various thermoelectric device designs, such as thermoelectric generators and coolers, under various operating conditions can be simulated using the MATLAB model [3]. The device's efficiency, power output, and cooling capacity can all be predicted using the model, which may also be used to optimize the device's overall design. One of the advantages of the MATLAB model is its simplicity in including user-defined equations and functions, which enables researchers to adapt the model to their particular requirements [3]. Researchers with no programming experience can utilize the Simulink model since it has an intuitive user interface [4]. The simulation's material properties and boundary conditions must be accurate in order for the model to be accurate. Thus, it's crucial to carefully describe for the present thermoelectric generator work. The recent work p-type segment leg resulting Sb1.82In0.15Cu0.03Te2.98 sample had a ZT value of 1.06 at 623 K and a high ZT of 0.76 from 300 K to 673 K [17]. By manipulating electron & phonon transports, the Sb2Te3(SnMn0.08Te)10 achieved a peak ZT of approximately 1.3 at 773 K and an average ZT of around 0.78 between 300 and 823 K [18]. The FOM(ZT) of Bi2Te3 exhibited a peak value of 1.30 at 450 K and an average ZT of 1.14 between 300 and 500 K [19].The present work deals with material Cu2Bi2Te3 and Cu2Sb2Te3 for analyzing the Z-T-efficiency.

2. Method to create thermoelectric device

Thermoelectric generators (TEGs) are devices that can convert temperature differences into electrical energy using the Seebeck effect. MATLAB software can be used to model and simulate the behavior of TEGs. Here is a way to create a TEG model in MATLAB:

Step 1: Define the material properties of the TEG:

```
alpha = 0.01; % Seebeck coefficient in V/K
k = 2; % Thermal conductivity in W/mK
sigma = 1; % Electrical conductivity in S/m
T_hot = 1000; % Hot side temperature in K
T_cold = 300; % Cold side temperature in K
```

Step 2: Define the geometry of the TEG:

```
length = 0.01; % Length of the TEG in meters
area = 0.001; % Cross-sectional area of the TEG in square meters
```

Step 3: Calculate the voltage and power output of the TEG:

```
deltaT = T_hot - T_cold;
voltage = alpha * deltaT;
power = voltage^2 / (4 * length * (k / area) + (1 / sigma) * length * area);
```

Step 4: Plot the power output as a function of the hot side temperature:

```
T_hot_range = 300:10:1000; % Range of hot side temperatures to test
power_output = zeros(size(T_hot_range));
for i = 1:length(T_hot_range)
   T_hot = T_hot_range(i);
   deltaT = T_hot - T_cold;
   voltage = alpha * deltaT;
   power_output(i) = voltage^2 / (4 * length * (k / area) + (1 / sigma) * length * area);
end
plot(T_hot_range, power_output)
xlabel('Hot side temperature (K)')
ylabel('Power output (W)')
```

This code calculates the power output of the TEG for a range of hot side temperatures and plots the results. You can modify the material properties and geometry of the TEG to simulate different designs and optimize their performance.

3. Result and Discussion

The result and discussion of a thermoelectric generator simulation using MATLAB software will depend on the specific model and parameters used. However, here the fig.1 and fig.4 shows the efficiency vs. Z graph; then fig.2 and fig.5 shows the efficiency vs. K and the fig.3 and fig.6 shows the ZT. The output power of a thermoelectric generator depends on the temperature difference between the hot and cold sides of the device. As the temperature difference increases, so does the power output. The voltage output of the generator is also directly proportional to the temperature difference. The Cu2Bi2Te3 and Cu2Sb2Te3 material properties of the thermoelectric generator should optimize for its performance. By changing the dimensions and materials of the generator, it is possible to enhance its efficiency and Z-T output.

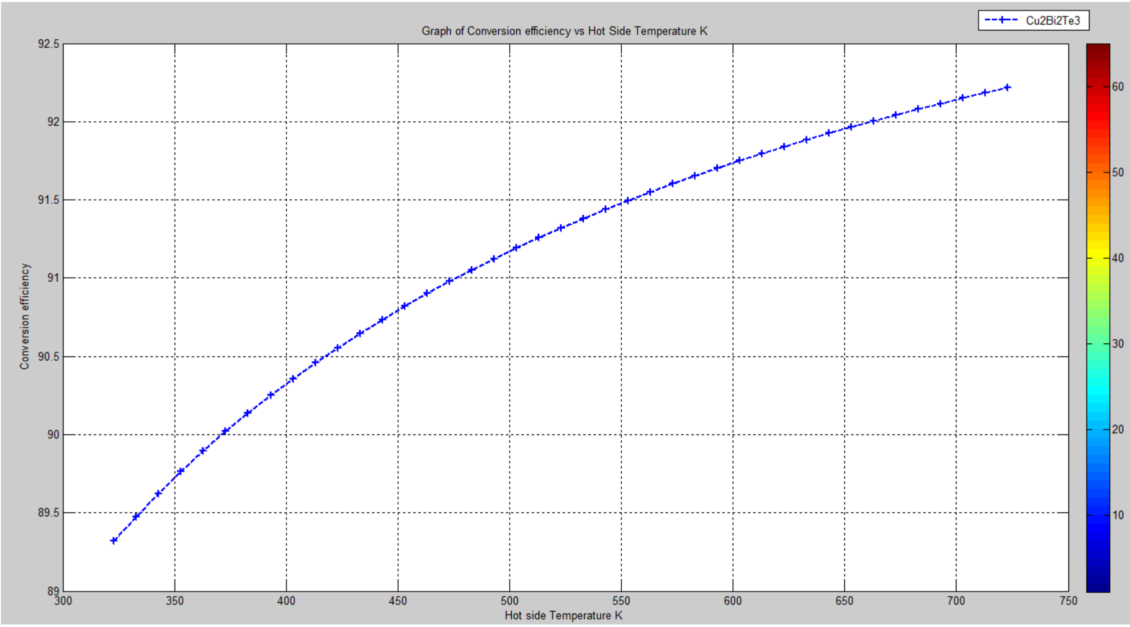

Fig. 1. Efficiency vs Z of Cu2Bi2Te3

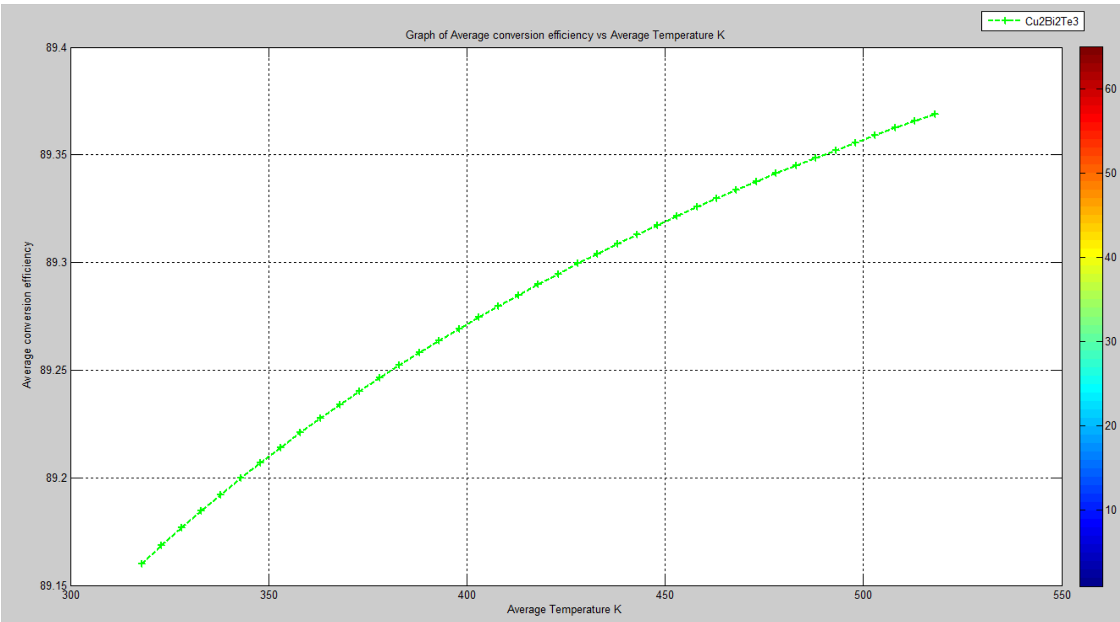

Fig. 2. Efficiency vs K of Cu2Bi2Te3

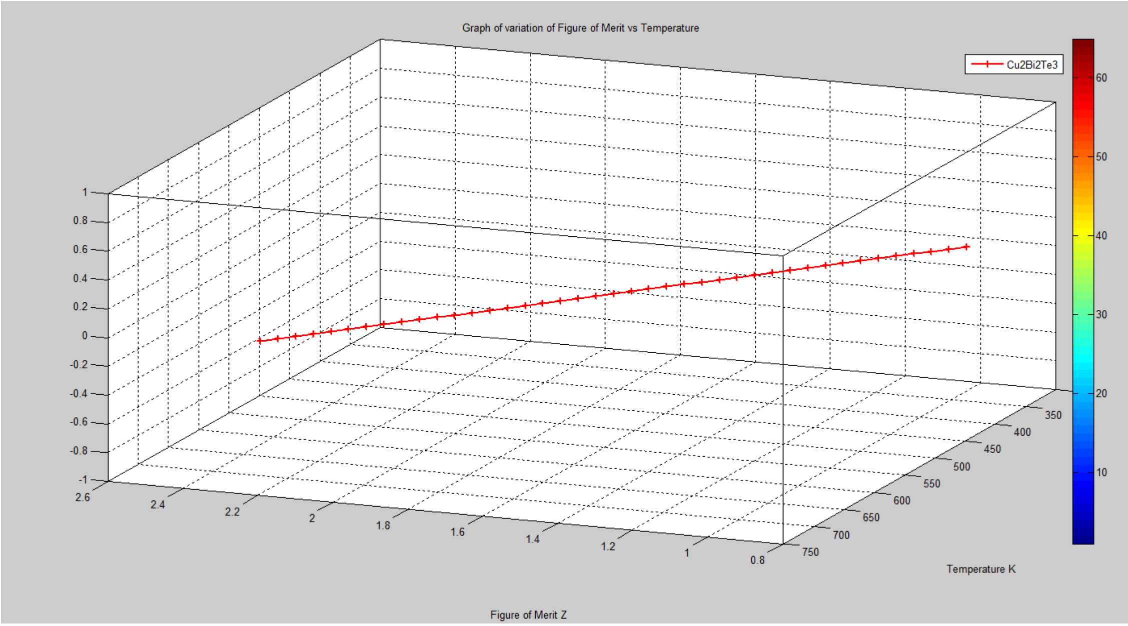

Fig. 3. ZT of Cu2Bi2Te3

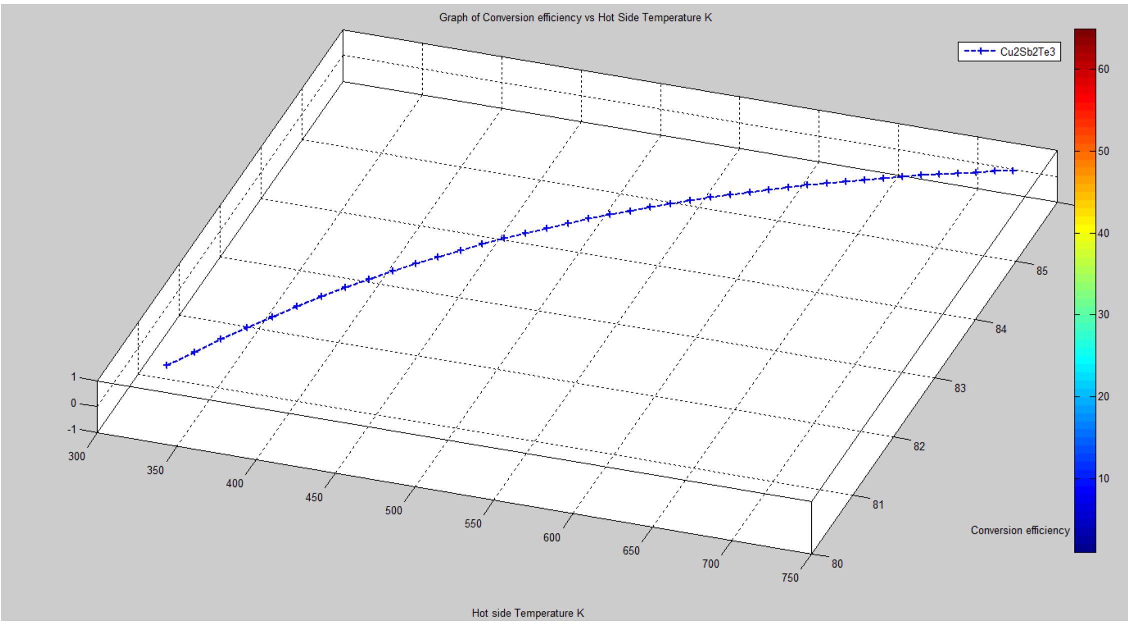

Fig. 4. Efficiency vs Z of Cu2Sb2Te3

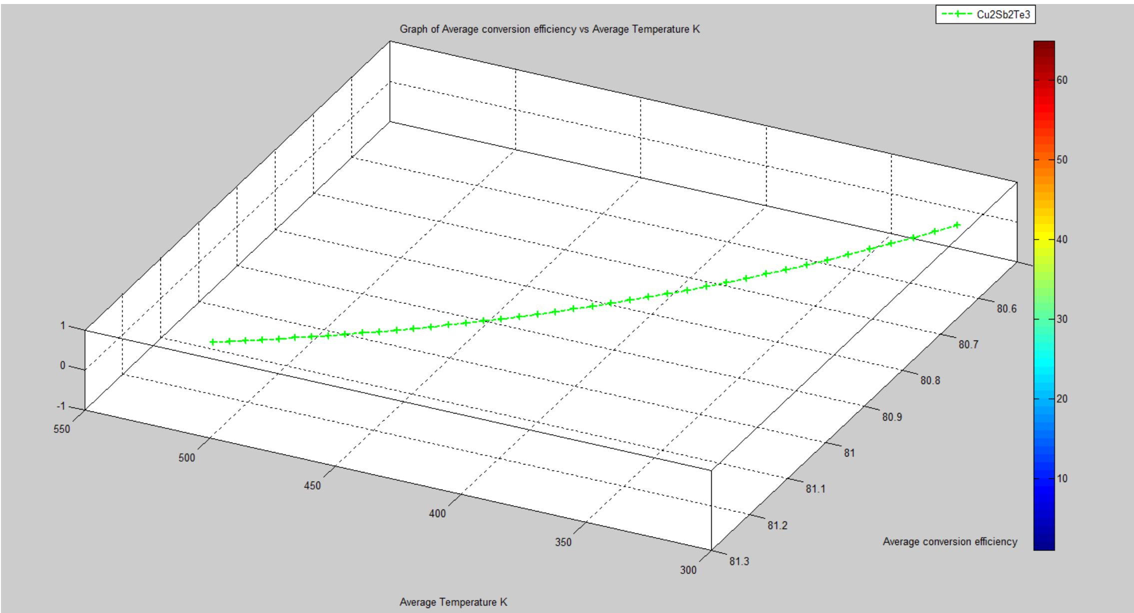

Fig. 5. Efficiency vs K of Cu2Sb2Te3

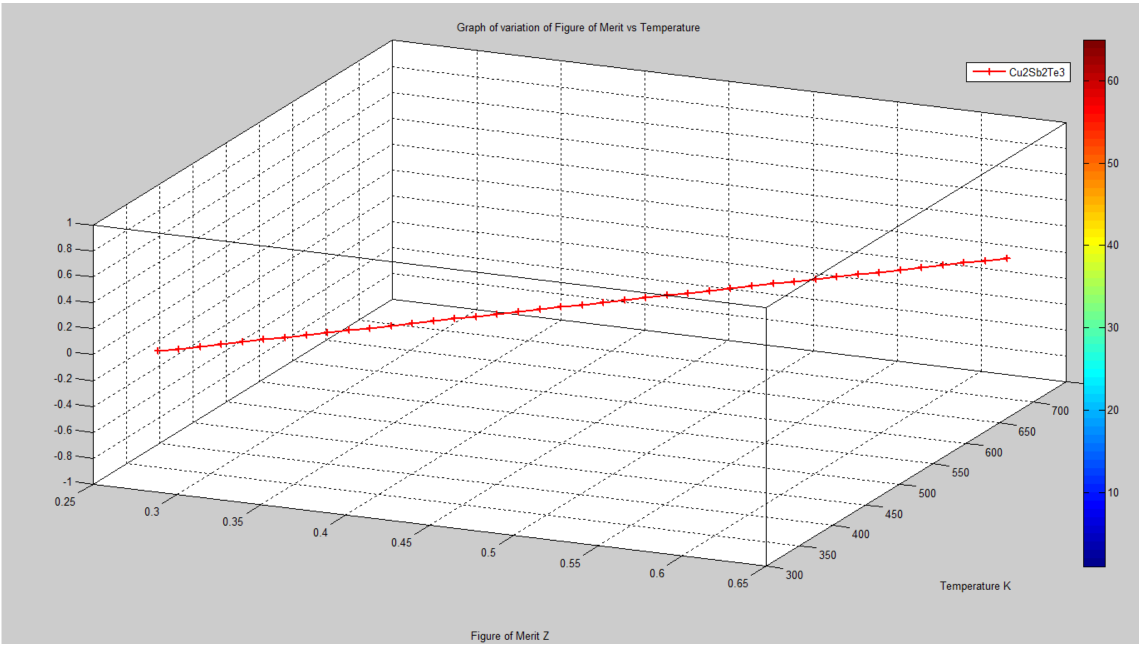

Fig. 6. ZT of Cu2Sb2Te3

One important consideration when designing a thermoelectric generator is the tradeoff between efficiency and power output. Increasing the efficiency of the generator often comes at the cost of reducing its power output, and vice versa. Therefore, designers must carefully balance these factors to achieve the desired performance. Here, Table 1 shows the results of Cu2Bi2Te3 and Cu2Sb2Te3 Thermoelectric Generator Device and it was compared with Bi2Te3 and Sb2Te3 materials. Cu2Bi2Te3 has a higher energy capacity (CC) of 122.4 compared to Cu2Sb2Te3, which has a CC of 98.75. However, Cu2Sb2Te3 has a higher density of 2.154 Kg/m3, whereas Cu2Bi2Te3 has a lower density of 1.156 Kg/m3.

Cu2Sb2Te3 also has a higher SFC of 264 gm/K-1W-1hr compared to Cu2Bi2Te3, which has an SFC of 224. In terms of power, Cu2Bi2Te3 has a higher value of 6.61 kW compared to Cu2Sb2Te3, which has a power value of 4.51 kW. However, Cu2Bi2Te3 has a slightly lower volumetric efficiency of 97 compared to Cu2Sb2Te3, which has a volumetric efficiency of 91. The specific heat capacity (Cp) of Cu2Bi2Te3 is slightly higher at 1.12 KJ/Kg-1K compared to Cu2Sb2Te3, which has a Cp of 1.09 KJ/Kg-1K. Both materials have the same high and low temperature limits of 725 K and 325 K. Thus, MATLAB software can be used to simulate the behavior of a thermoelectric generator and investigate the effect of various design parameters [1, 3, 4]. This can help researchers and engineers optimize the performance of their devices before building physical prototypes. Overall, the use of MATLAB software for thermoelectric generator design and analysis can lead to more efficient and effective devices with higher power output. The current result of Figure of Merit is 2.59 (no unit) for Cu2Bi2Te3 material. The Figure of Merit for Cu2Sb2Te3 material is 0.657 (no unit).

Table 1. Thermoelectric Generator Results

	Material		***Comparative results***	
Parameter	**Cu2Bi2Te3**	**Cu2Sb2Te3**	**Bi2Te3**	**Sb2Te3**
Energy capacity **(CC)**	122.4	98.75	117.5 [13]	100.85 [15]
Density **(Kg/m^3)**	1.156	2.154	0.923 [14]	1.953 [16]
SFC **($gm/K^{-1}W^{-1}hr$)**	224	264	188 [13]	253 [16]
Power **(kW)**	6.61	4.51	4.54 [14]	4.39 [15]
Volumetric Efficiency	97	91	117 [14]	99 [15]
Cp **($KJ/Kg^{-1}K$)**	1.12	1.09	0.925 [14]	0.863 [16]
High Temperature **(K)**	725	725	random	random
Low Temperature **(K)**	325	325	random	random

4. Conclusions

MATLAB software can be a useful tool for designing and analyzing thermoelectric generators. By using MATLAB to simulate the behavior of a TEG, researchers and engineers can investigate the effects of various design parameters, such as the dimensions and material properties of the device, and optimize its efficiency and power output. MATLAB's flexibility and extensive library of functions and tools make it well-suited for modeling and simulating complex systems like TEGs. With MATLAB, it is possible to create detailed and accurate models of TEGs and investigate their performance of Cu2Bi2Te3 and Cu2Sb2Te3. In addition to its usefulness in TEG design and analysis, MATLAB can also be used to control and monitor TEGs in real-time, allowing for more precise and efficient operation of these devices. Overall, the use of MATLAB software in thermoelectric generator research and development can lead to more efficient and effective TEGs with higher power output, ultimately contributing to the development of more sustainable and renewable energy systems.

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