

# Design and Comparative Analysis of Thin Plate Micro Thermo Electric Generators for Energy Harvesting Application

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**Abstract:** In this work, a comparative study have been made to demonstrate the concept of micro machined generators-the thermo Electric Generators consisting of thin film metals. Two pairs of thin metals Gold-Nickel and iron-constantan have been identified, simulated and analyzed for their improved efficiency. The simulation results indicated that compared to output of Au-Ni pair(41.6 mV), the iron-Constantan TEG gave higher output(102 mV) and hence it can be employed for energy harvesting.

**Keywords:** Thin plate, MEMS, Thermo Electric Generators, Intellisuite<sup>TM</sup>, Energy harvester.

## 1. INTRODUCTION

Energy harvesting is attracting attention in this modern era since most of the untapped energy from natural and man-made devices can be channeled to power several wired and wireless devices. Harnessing energy from the environment has been touted as a potential means for fully powering or extending the battery life of autonomous robots, wireless sensor nodes, or low-power electronic devices [1]. But due to unavailability of continuous power generation options, not all energy harvesting devices are successful. A novel and quiet method of energy harvesting can be achieved by Thermo electric generators (TEG) which are in simple way, pile of thermocouple utilizing waste heat energy to convert them in to useful electric energy. They work on the basis of the seeback and peltier effects and have been proved to be reliable and efficient power generators. Additionally, TEG can output a relatively large and stable dc voltage, which can simplify the design of power management electronics. Unused heat from a large source can be diverted to a TEG in order to generate appreciable power.

This paper focuses on thermoelectric energy harvesting from [1]hot gas streams. The heat from the hot gases has been utilized by using Au-Ni Type thermocouple. The simulation was carried out using the same combination and in addition, output was compared with the iron-constantan type. The design and the dimensions of TEG from the reference paper [1] has been retained and simulated using Intellisuite software and results of two different combos of thermocouple thin metal plates are presented. Intellisuite Software is a user friendly tool to achieve promising results for complex circuits and devices.

## 2. BASIC DESIGN OF TEG MODULE

### A. Device Structure

The radial thermoelectric generator concept is shown above. Each thermoelectric module (13 mm in diameter and 0.36 mm thick) consists of two thermally isolated concentric silicon rings connected by a ~5- $\mu$ m-thick annular polyimide membrane. Thin-film thermo-elements Au- Ni radially patterned on this membrane for radial heat transfer. These flat spike-like thermoelectric structures are much easier to fabricate, as compared

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to the high-aspect-ratio out-of-plane thermo-elements and checker-board arrangement used in parallel-plate thermoelectric devices. This radial configuration also facilitates stacking of multiple modules to form a cylindrical heat exchanger, which can be further enhanced by creating micro-machined silicon fins on both the inner and outer sides [1].

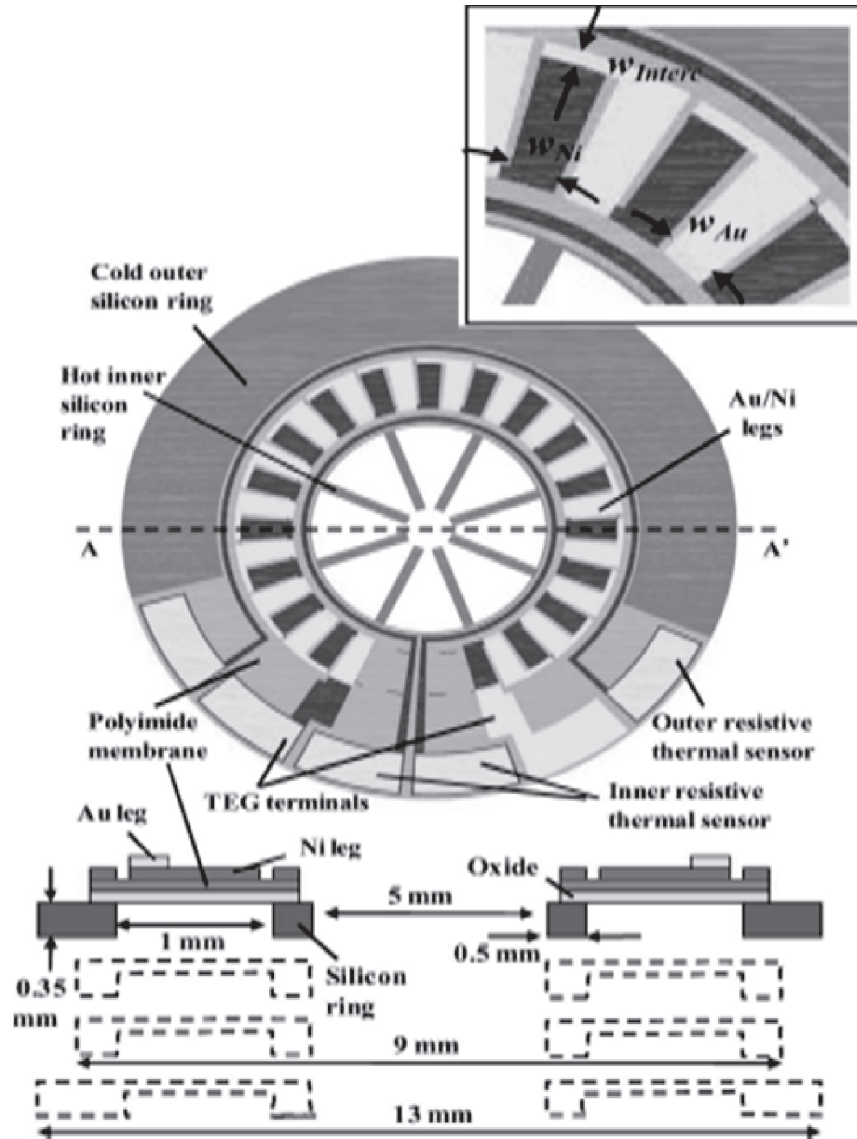


Figure 1: Top view and (cut A-A') cross section of thermoelectric generator module with hot center ring and cold outer silicon ring connected by a polyimide membrane [1]

### 3. OPERATION

During operation, hot gas flows through the finned central channel heating the inner surface, while outer annular fins exposed to the cooler ambient keep the outer surfaces cool. In this paper, simple fin architectures are used to demonstrate the concept (radial inner fins and annular outer fins). Within each module, the thermally insulating polymer membrane sustains a large uniform temperature gradient ( $\Delta T = T_{\text{hot}} - T_{\text{cold}}$ ) across the thermo-elements (1 mm long and 0.5  $\mu\text{m}$  in thickness) while providing mechanical support between the inner and outer silicon rings. For testing purposes, resistive temperature sensors (Ni) are included on the inner and outer silicon rings to measure  $T_{\text{hot}}$  and  $T_{\text{cold}}$ . To demonstrate the concept, three module designs with different number of Ni/Au thermocouple pairs ( $n$ ) are fabricated. Each TEG module has inner and outer diameters of 5 and 13 mm, respectively.

## 4. DESIGN OF TEG AND ANALYSIS USING INTELLISUITE SOFTWARE

### A. Simulation Process

Simulation is done in following four modules: Intelli Mask, Intelli FAB, 3D Builder and the Thermo Electro Mechanical module

### B. Single Module TEG Fab

**3D BUILDER:** In this module the Thermo couple design is directly made and then performed with certain mesh function to generate the desired design.

- i) *Entity 1:* After creating the entity 1 circle the alternate sections are given different color entities. These would form the thermo elements of the TEG module. 20 pairs of such elements were created.

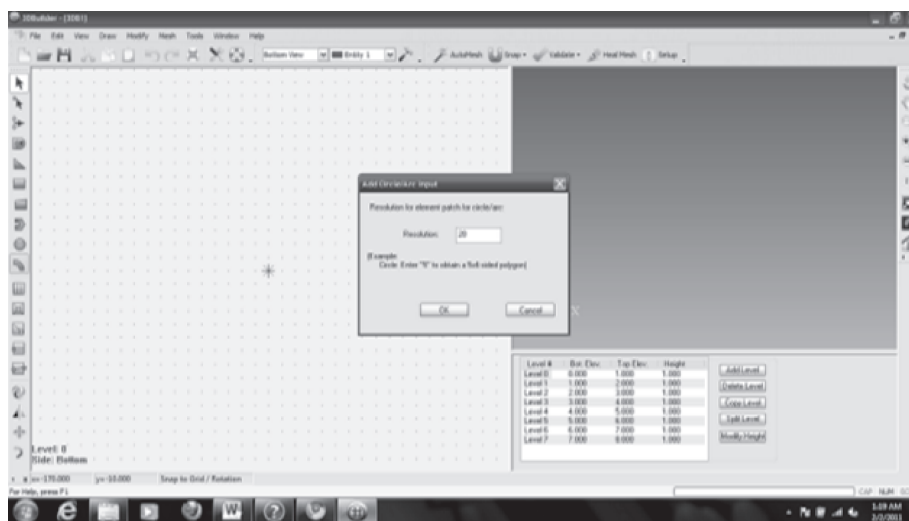


Figure 2: Entity 1

The Entity 1 of the module is made using the arc tool. The appropriate dimensions were given and 1<sup>st</sup> circle was created. This constitutes the inner and outer ring of the TEG

- ii) *Entity 2:* The Entity 2 comprises of creating a separation layer between the two Si rings-outer and the inner ring as shown.

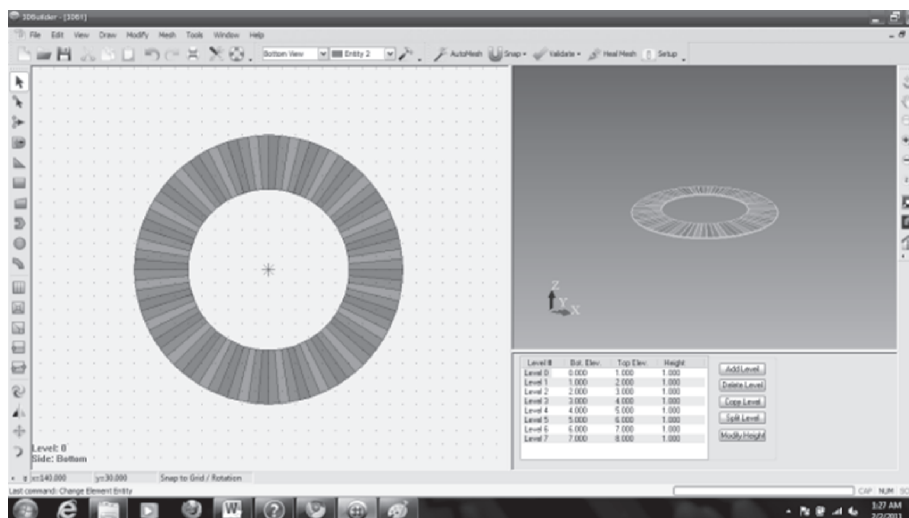


Figure 3: Entity 2

- iii) *Entity 3*: The Entity 3 of the module comprises of placing 20 pairs of TEG elements in between the spaces between the polyamide layers. Entity 3 would be the outer silicon ring that is formed using same dimension.

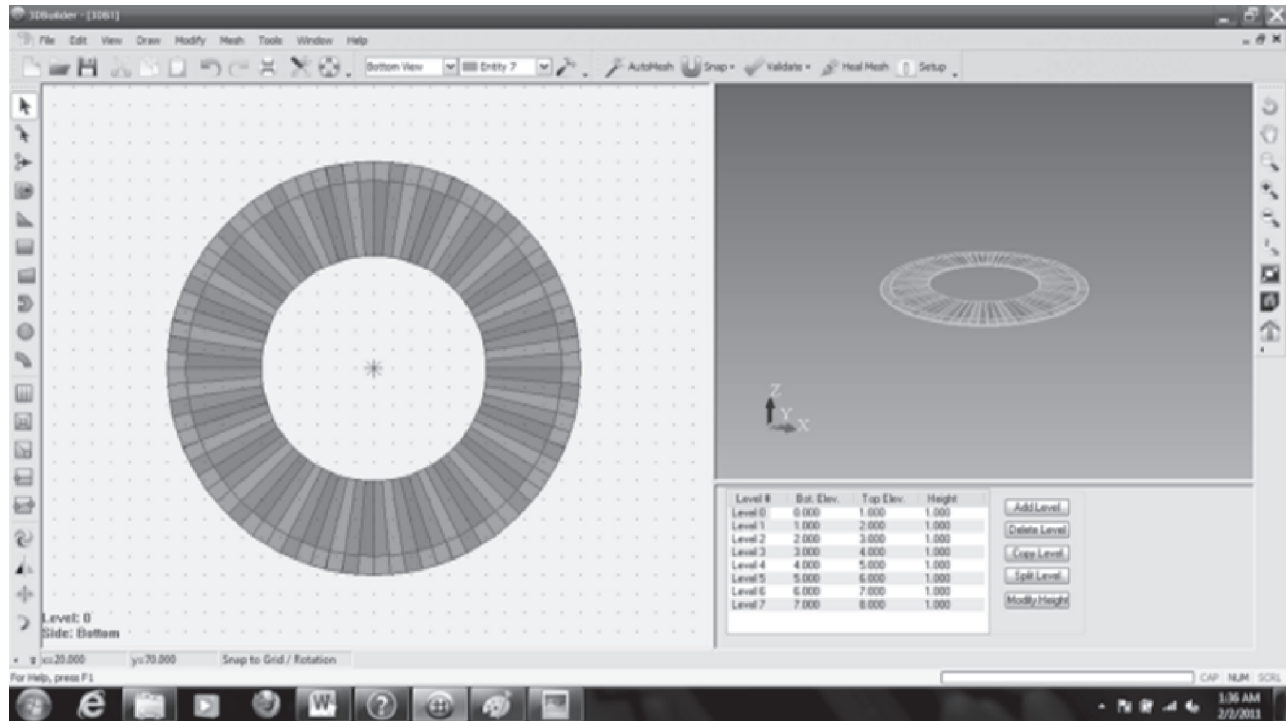


Figure 4: Entity 3

- iv) *Entity 4*: Entity 4 comprises of backing layer made of Si to support the TEG and intermediate polyamide layer as shown

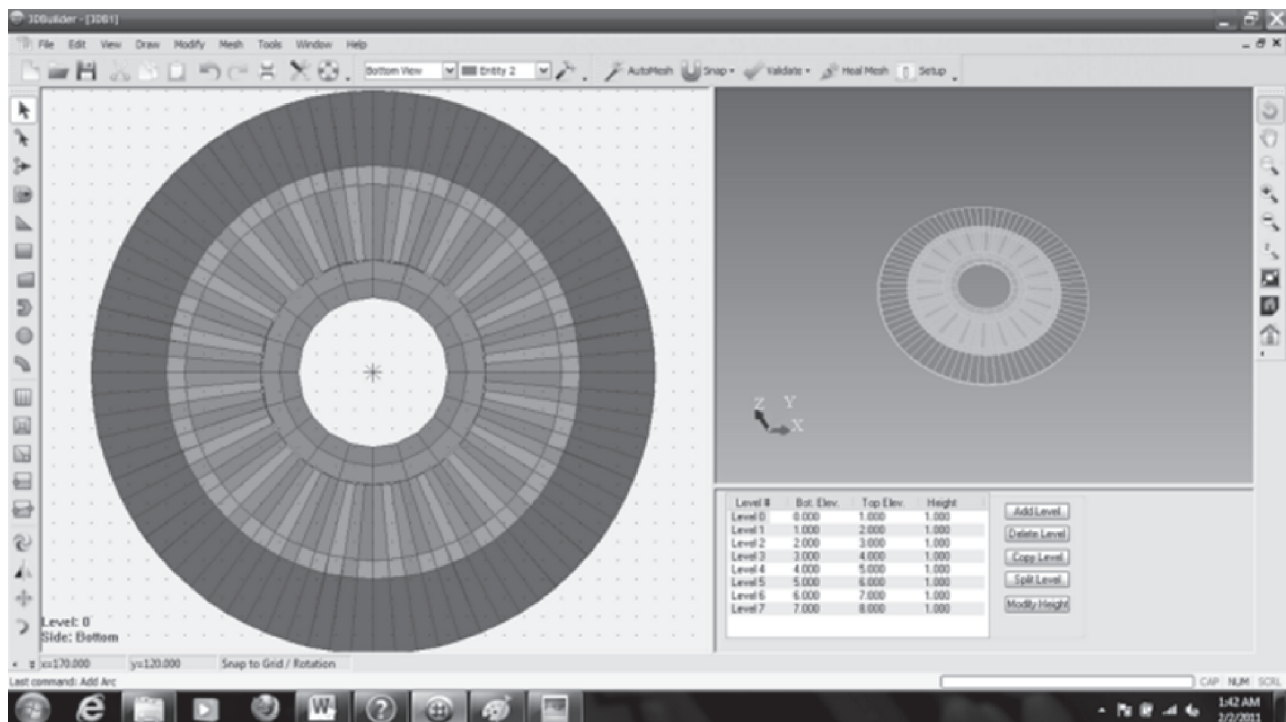


Figure 5: Entity 4

v) *Entity 5*: This is the last entity and forms the innermost polyamide layer ring.

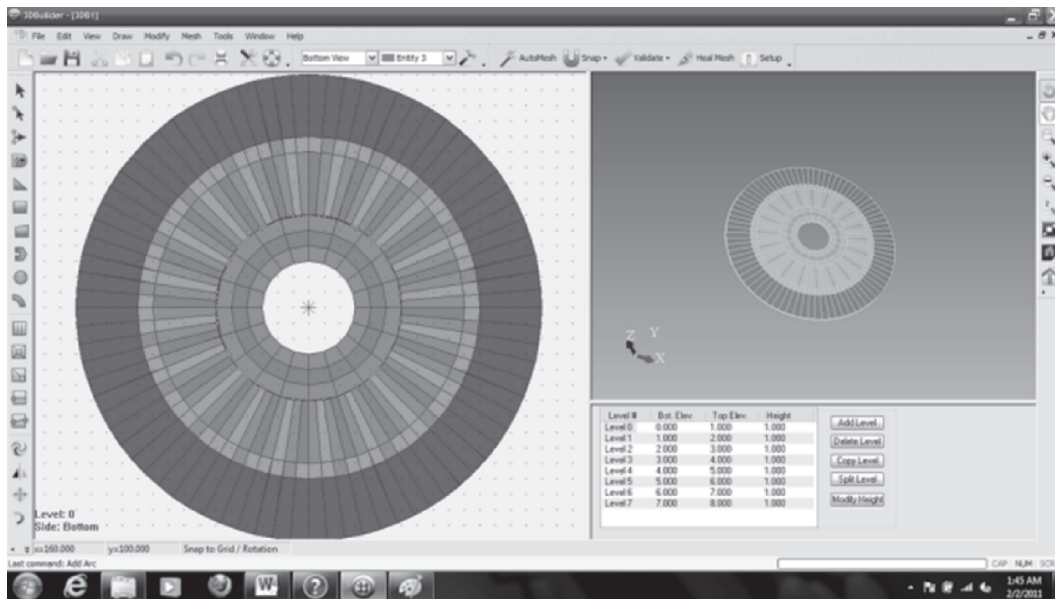


Figure 6: Entity 5

The dimensions for the layer were defined by selecting modify height option. The design is saved and exported to TEM analysis.

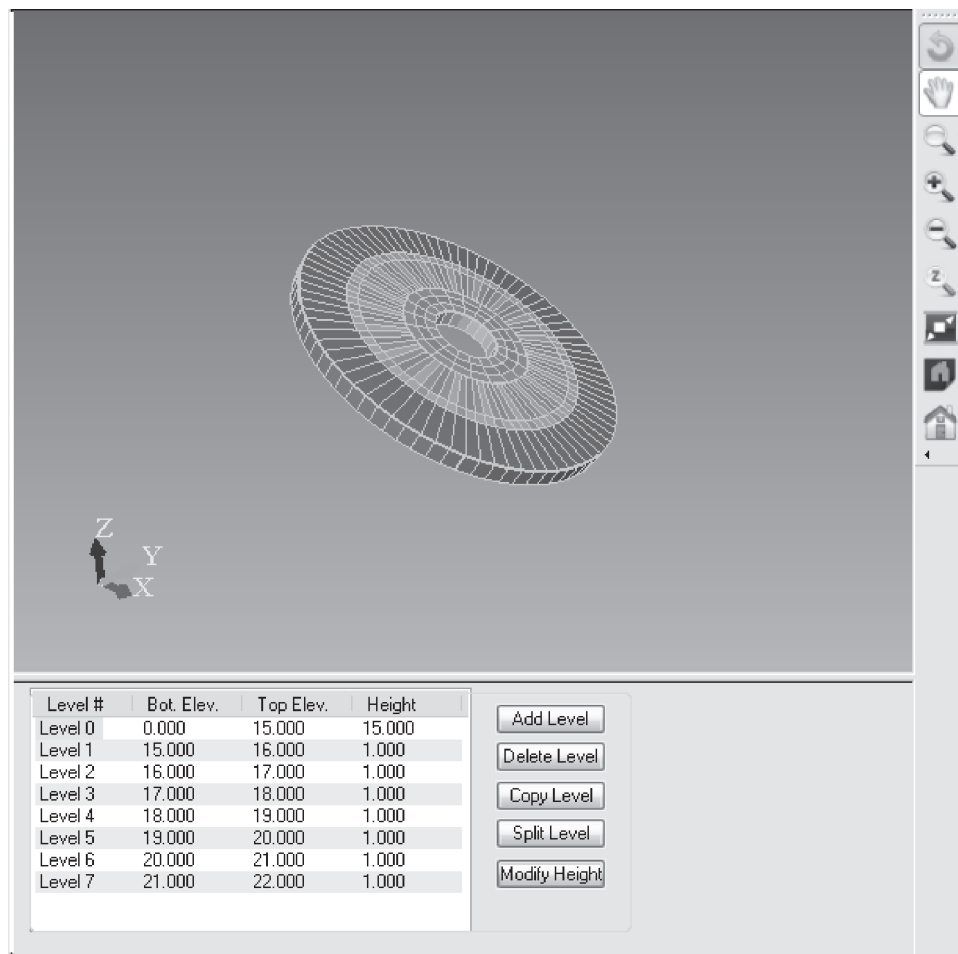


Figure 7: Entity 6

### C. Thermo Electro Mechanical Module

This is the analysis where all material properties, boundary conditions, load is defined to the structure and then after analysis output result are obtained.

### D. Material Properties

The outermost layer is the silicon substrate ring. Innermost layer is the Polyamide layer that provides insulation and does not allow heat to escape. For the analysis different thermo-couple pairs are used and corresponding output temperature difference is noted down.

### E. Load Conditions

A temperature of  $200^{\circ}\text{C}$  and  $30^{\circ}\text{C}$  was given at the inner and the outer faces of the module respectively.

### F. Analysis and Simulation Result

Static Analysis was carried out by applying the temperature as the load and the Simulation setting set to HEAT TRANSFER. Result is obtained for different THERMO ELEMENTS.

### G. Single Module Simulation

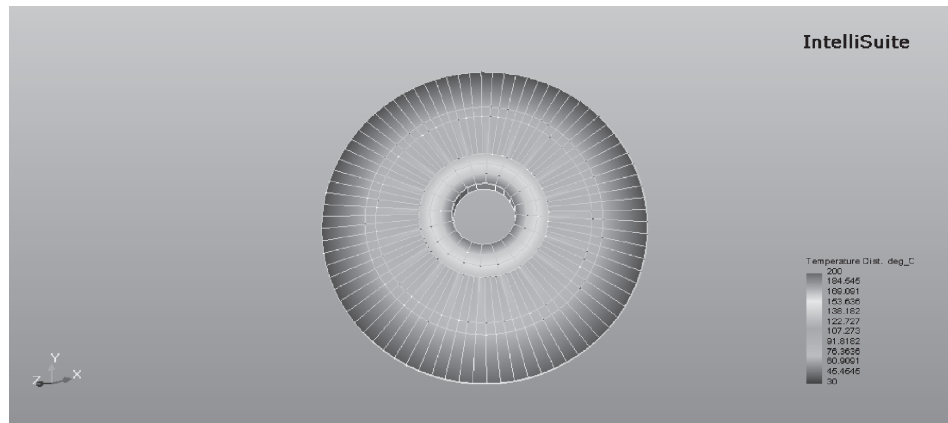


Figure 8: Gold- Nickel

### H. Simulation II

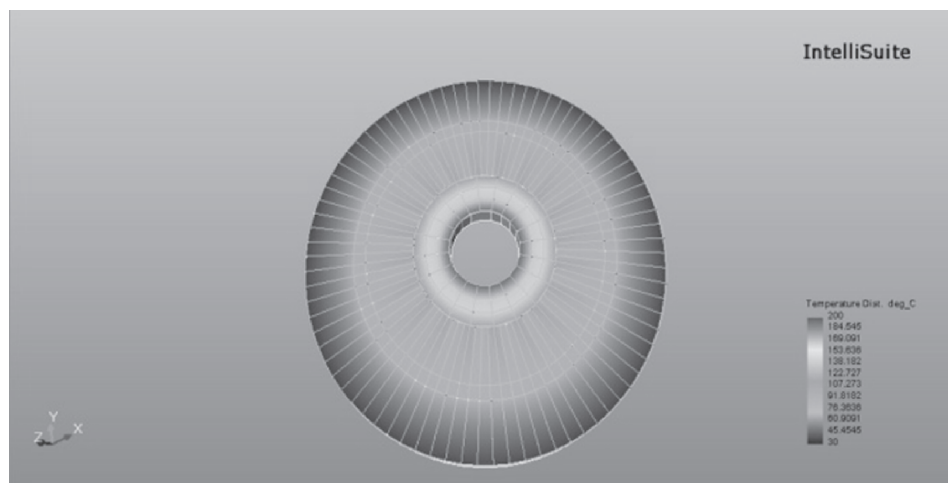


Figure 9: Iron – Constantan

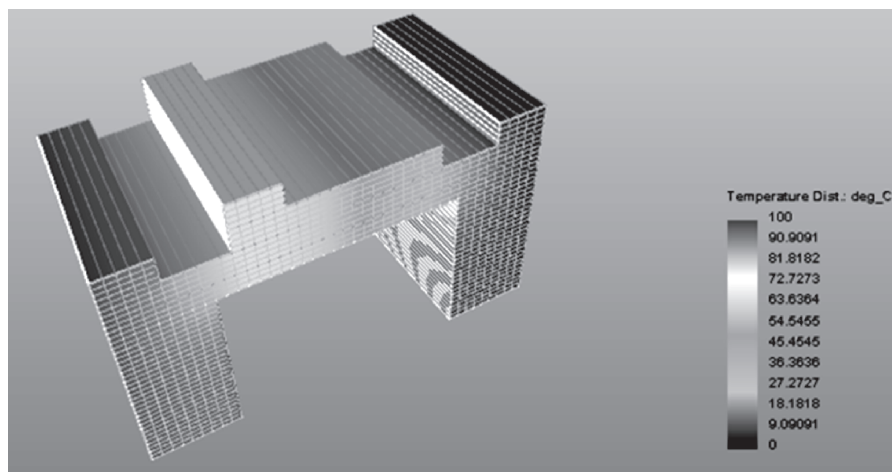


Figure 10: Simulation output

## 5. CALCULATION

For single TEG module,

$$\Delta T = 90 - 11 = 79^{\circ}\text{C}$$

$$A(\text{Au} - \text{Ni}) = 23.6 \mu\text{V}/^{\circ}\text{C}$$

$$V_{\text{OC}} = \Delta T \times (\alpha_{\text{Au} - \text{Ni}})n = 79 \times 23.6 = 1.84 \text{ mV}$$

For stacked TEG module – Au-Ni: ( $n = 20$ )

$$\Delta T = 154 - 65 = 89^{\circ}\text{C}$$

$$A(\text{Au} - \text{Ni}) = 23.6 \mu\text{V}/^{\circ}\text{C}$$

$$V_{\text{OC}} = \Delta T \times (\alpha_{\text{Au} - \text{Ni}})n = (89 \times 23.6 \times 10^{-6} \times 20) = 41.6 \text{ mV}$$

FOR Fe – Constantan: ( $n = 20$ )

$$\Delta T = 150 - 55 = 95^{\circ}\text{C}$$

$$\alpha_{\text{Au} - \text{Ni}} = 523.6 \mu\text{V}/^{\circ}\text{C}$$

$$V_{\text{OC}} = \Delta T \times (\alpha_{\text{Au} - \text{Ni}})n = (95 \times 52.3 \times 10^{-6} \times 20) = 102. \text{ mV}$$

## 6. RESULT OF SIMULATION I

Temperature in $^{\circ}\text{C}$	Material (Thermo Couple)	$\Delta T = T_{\text{hot}} - T_{\text{cold}}$
100 – 30	Au – Ni	79 (approx.) [90 – 11]

## 7. RESULT OF SIMULATION II

Temperature in $^{\circ}\text{C}$	Material (Thermo Couple)	$\Delta T = T_{\text{hot}} - T_{\text{cold}}$
200 – 30	Au – Ni	89 (approx.) [154 – 65]
200 – 30	Fe – Constantan	95 (approx.) [150 – 55]

## 8. CONCLUSION

Miniaturized TEG modules have been explored for energy harvesting applications using the waste thermal energy from [1] hot gas streams. To demonstrate the concept, micro machined generators consisting of

thin-film metals (Au and Ni) were simulated. By combining superior thermoelectric materials with the cylindrical silicon/polymer platform would result in higher power generation from a hot gas stream. To a first-order approximation, analytic models indicate that replacing the metal thermo elements with higher performing semiconductor alloys can increase the output power. The simulation results prove the same.

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