



STUDY, ANALYSIS AND DEVELOPMENT OF GRAPHENE BASED EFFICIENT THERMO-ELECTRIC GENERATOR

¹Sneha Panchal, ²Sai Parab, ³SanatRathod, ⁴RajtaraIngavale, ⁵Ujvala Tade
snehapanchal098@gmail.com¹, parabesai69@gmail.com², sanat.rathod@somaiya.edu³,
rajtaraingavale29@gmail.com⁴, ujvala.tade@gmail.com⁵
LokmanyaTilak College of Engineering

ABSTRACT

This project proposes to develop an influence generator from waste heat from various sources. A Radioisotope Thermoelectric Generator (RTG) is an electrical generator that uses an array of thermocouples, which is a solid state device that converts heat generated by the decay of a radioactive material directly into electrical energy through a phenomenon called the Seebeck effect. Due to the various advantages of Thermoelectric power generators it has arisen as an alternative green technology. This type of generator which has no moving parts has been used which leads to its application in power sources in satellites, Navigation and unmanned remote control where use of solar cell is not practical. RTGs use heat from the natural radioactive decay of plutonium-238, in the form of plutonium dioxide. Such devices are often relatively simple, are often efficient, and that they are often readily adaptable to microcircuit interfacing. Due to unique shape and characteristics, graphene is most frequently used as nanofillers. They could potentially be used to generate enough power or running a small ultra-low power operation, if graphene films are closely stacked together, with minimum cost in a wide variety of applications for both research and industries.

Key Words :- Thermoelectric generator, seebeck effect, Thermocouple, graphene.

INTRODUCTION

A radioisotope thermoelectric generator, or RTG, uses the radioactive materials which generate heat as they decompose into non-radioactive materials. The heat used is converted into electricity by an arrangement of thermocouples which then power the spacecraft. A thermocouple may be a device which converts thermal energy directly into electrical energy. Basically, it's made from two sorts of metal which will both conduct electricity. They are connected to every other during a closed-loop system. If the two metals are at different temperatures, an electric potential will exist between them. When an electrical potential occurs, electrons will start to flow, making current. This is a way different technique than that employed by atomic power stations on Earth. That process is called fission, gets very high efficiency rates by literally "splitting" unstable radioactive materials (such as uranium) into smaller parts. Fission generates very large amounts of heat, but is much more complex than and not as reliable as simply using the heat produced by radioactive decay. Basically, fission gives you a huge release of energy and uses fuel rapidly. An RTG gives a steadier and much smaller amount of energy. Thermoelectric have enabled the human race to take the first exploratory steps into the outer Solar System and beyond into interstellar space. By virtue of having no moving parts (including no moving fluids) thermoelectric elements have shown themselves to be extremely reliable and long-lived.

THERMO ELECTRIC GENERATOR

A thermoelectric power generator is a strong state tool that provides direct power conversion from thermal energy (warmness) because of a temperature gradient into electrical power based on “Seebeck impact”. In truth, this phenomenon is applied to thermocouples which might be extensively used for temperature measurements. Based totally on this Seebeck effect, thermoelectric devices can act as electric energy generators.

Schematic of a single thermo-couple

An ordinary thermoelectric energy module is proven schematically. Within the following discern: n-kind and p-kind semiconductor thermo factors are linked in collection by tremendously- carrying out steel strips to shape a thermocouple. The two sides of the thermocouple are maintained at two exclusive temperatures. Due to this temperature distinction, waft of the rate providers’ takes place in each n-kind and p-type pellets constituting to the voltage distinction across load resistance.

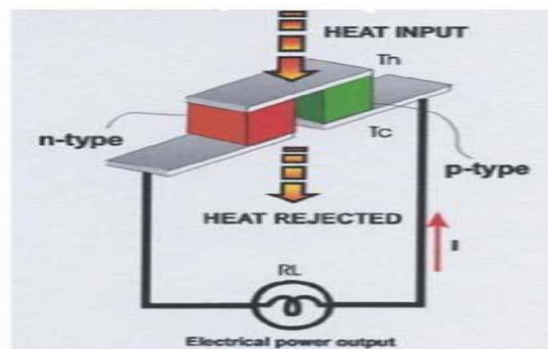


Fig 1 Single structure of thermocouple

A typical Thermoelectric Power Generator

A thermoelectric module is made from a number of thermocouples linked together electrically in collection and thermally in parallel. The diagram under indicates the 3-dimensional view of the standard Thermo electric powered Generator. Whilst warmness is absorbed on one facet of a TEG (crimson arrow) the movable price vendors begin to diffuse, ensuing in a uniform attention distribution inside the TEG alongside the temperature gradient, and generating the distinction inside the electric ability on each sides of the TEG. To maximize the electricity technology output, p-bars and n-bars (see circles) are related collectively in a mobile electrically in series and thermally parallel. Due to the thermoelectric effect, electrons flow through the n-type element to the colder side while in the p-type elements, the positive charge carriers flow to the cold side.. This illustrates how connecting the p-bar and the n-bar augments the voltage of each bar and the voltage of each unit cell.

Working Principle of TEG

Thermoelectric energy technology is based on a phenomenon called “Seebeck effect” observed by means of Thomas Seebeck in 1821. The Seebeck impact was first discovered in 1822 by using Seebeck, who determined an electric drift when one junction of assorted metals, jointed at locations, was heated whilst the other junction became kept at a decrease temperature.

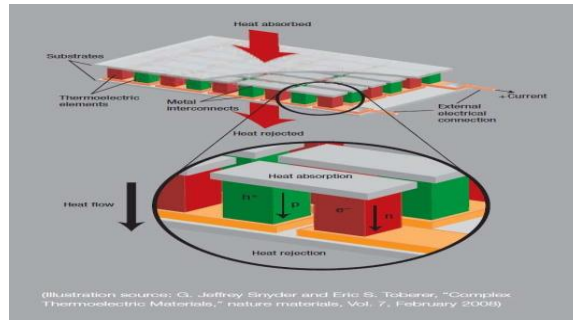


Fig 2 Complete structure of Thermo electric Generator

The semiconductor thermo elements which are sandwiched among the ceramic plates are linked thermally in parallel and electrically in series to form a thermoelectric tool (module). Multiple pair of semiconductors are usually assembled collectively to shape a thermoelectric module and in the module a couple of thermo elements is referred to as a thermocouple. The junctions connecting the thermo elements between the new and cold plates are interconnected the usage of noticeably engaging in steel (e.G. Copper) strips.

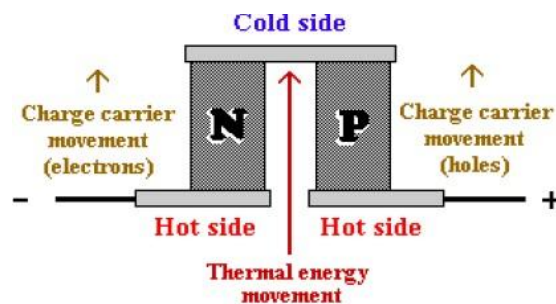
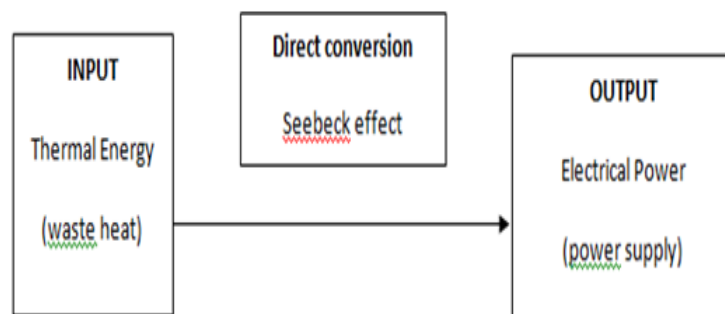


Fig. 3 Thermo Elements Sandwiched between Ceramic Plates

Electrons present at hot side of material is more energized than the electrons present at cold side. These hot energized electrons will flow from the hot side to the cold side. Electricity will flow continuously, if the circuit is complete. Semiconductor materials are the foremost efficient, and are combined in pairs of “p type” and “n type”. The electrons flow from hot too cold in the “n type”, while the holes flow from hot to cold in the “p type.” This allows them to be combined electrically in series.



Block diagram 1: Working principle of thermoelectric generator

ANALYSIS

Performance of TEG

Thermal Conductivity of the materials used, Thermal Expansion Coefficient of the materials used, Specific Heat of the materials used, Resistivity of the materials used and Seebeck coefficients of the materials used are some of the factors that govern the performance of TEG. Figure of merit and its efficiency is also taken into consideration.

The ability of a material to conduct heat is known as the Thermal conductivity. The thermoelectric materials selected for the TEG module must have high thermal conductivity.

$$\text{S.I unit} = \text{W/ (m-K)}$$

Thermal Expansion Coefficient is the change in the size of material with change in temperature.

$$\text{S.I unit} = /^{\circ}\text{C (or) } /^{\circ}\text{K}$$

Specific Heat is the heat capacity per unit mass of the substance where **heat capacity** is the amount of heat supply to increase the change in the temperature.

$$\text{S.I unit} = \text{J/ kg/ K}$$

Resistivity tells how strongly a material opposes the flow of electric current.

$$\text{S.I unit} = \Omega\text{-m}$$

Seebeck coefficient, represented by 'S', of a material measures the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material. If the temperature difference ΔT between the two ends of a material is small, then the thermopower of a material is defined approximately as,

$$S = -\frac{\Delta V}{\Delta T}$$

A thermoelectric voltage of ΔV is seen at the terminals. The negative sign indicates the flow of electrons and positive sign means flow of holes.

$$\text{S.I unit} = \text{V/ }^{\circ}\text{C}$$

The figure of merit Z for thermoelectric devices is defined as,

$$Z = \frac{\sigma S^2}{\kappa}$$

Where σ is the electrical conductivity, κ is the thermal conductivity, and S is the Seebeck coefficient. The dimensionless figure of merit ZT is formed by multiplying Z with the average temperature.

$$\bar{T} = \frac{(T_2 + T_1)}{2}$$

Higher the ZT, greater the efficiency, subject to certain provisions, particularly that the two materials in the couple have similar Z.

ZT is therefore a method for comparing the potential efficiency of devices using different materials. Values of 1 are considered good; values in the 3–4 range are essential for thermoelectric to compete with mechanical devices in efficiency. To date, the best reported ZT values are in the 2–3 range.

Efficiency of a thermoelectric device for electricity generation is given by η .

$$\eta = \frac{\text{energy provided to the load}}{\text{heat energy absorbed at hot junction}}$$

CALCULATIONS

OBSERVATION:

VOLTAGE= 58 mV

CURRENT= 2.63 mA

CALCULATIONS:

I. HEAT SOURCE CALCULATION.

- POWER (P):

$$P = V \cdot I$$

$$P = 58 \cdot 2.63$$

$$\text{POWER} = 150 \mu\text{W}$$

- HEAT SOURCE (H):

$$H \cdot 0.07 = 150$$

$$\text{HEAT SOURCE} = 2.14 \text{ mW}$$

- ASSUMING THERMAL LOSS = 20%

$$Y \cdot 0.8 = 2.14 \text{ mW}$$

$$Y = 2.675 \text{ mW}$$

- DECAY HEAT POWER DENSITY IS GIVEN BY 0.96/W

$$(2.675 \text{ mW} / 0.91) = 2.9395 \text{ mg}$$

- CURIE FACTOR (C)= 140

$$C = 2.9395 \text{ mg} \cdot 140$$

$$C = 0.411 \text{ Ci}$$

The calculations above are done considering semiconductor based thermoelectric generator. The losses in this type of generators are more. To prevail over this situation we are developing Graphene based thermoelectric generator.

GRAPHENE BASED THERMOELECTRIC GENERATOR

Graphene is a two-dimensional(2D) material with high electric conductivity, elasticity, stiffness, biocompatibility and stability at high temperature i.e above 3400K. For same applications such as TEG, such properties make it universally suitable material and a potential candidate for post-silicon electronic era. Different carbon material including carbide compound and graphite and chemically modified graphene, which is usually referred to as reduce graphene oxide (rGO) or simply graphene oxide (GO). GO is adaptable to wide variety of application and is prepared by colloidal suspension with advantages such as low cost, flexible, scalable. In this paper we propose a study analysis and development of graphene based efficient TEG. Fig(a) shows the fabrication steps of graphene based TEG. The fabrication steps include mainly 4 steps : Layering, depositing GO, deoxidization and finally testing.

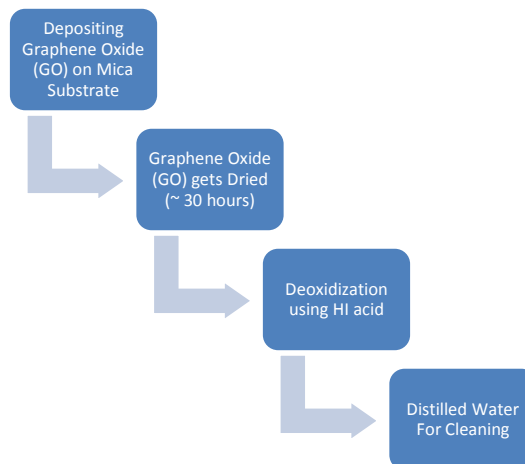
ABOUT GRAPHENE

Graphene may be a single layer (monolayer) of carbon atoms, tightly bound during a hexagonal honeycomb lattice. It is an allotrope of carbon in the form of a plane of sp^2 -bonded atoms with a molecular bond length of 0.142 nanometers. Layers of graphene stacked on top of every other form graphite, with an interplanar spacing of 0.335 nanometers. The separate layers of graphene in graphite are held together by van der Waals forces, which may be overcome during exfoliation of graphene from graphite.

Graphene is the thinnest compound known (one atom thick). It is the lightest material known (with 1 square metre weighing around 0.77 milligrams) and also the strongest compound discovered, stronger than steel (between 100-300 times stronger) with 130 GPa tensile strength and a Young's modulus of 1 TPa - 150,000,000 psi), the best conductor of heat at room temperature (at $(4.84 \pm 0.44) \times 10^3$ to $(5.30 \pm 0.48) \times 10^3 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$) and also the simplest conductor of electricity known (studies have shown electron mobility at values of more than $200,000 \text{ cm}^2 \cdot \text{V}^{-1} \cdot \text{s}^{-1}$). Other notable properties of graphene are its potential suitability for use in spin transport and its uniform absorption of light across the visible and near-infrared parts of the spectrum ($\pi\alpha \approx 2.3\%$).

FABRICATION METHODOLOGY

As density (ϕ) is the ratio of the mass to volume. The number of graphene layers per unit volume deposited on a given surface area and GO density can be calculated by adjusting the density and controlling the volume of the GO, the desired number of graphene layers can be controlled. 2mg/ml solution of GO is taken to prepare graphene films. The GO is poured on the surface of 2 inch diameter and 0.3 mm thick mica substrates where the single layer of graphene is as thin as 1nm, then it is dried for approximately 30 hours. Once it is totally dried, GO is reduced to graphene by using hydrogen Iodide acid for at least 15 mins. Then, the graphene/mica film's pH close to 7 is obtained by washing it in DI water (distilled water).



RADIOISOTOPE (HEAT SOURCE)

Radioactive materials such as Plutonium-238 (^{238}Pu), Strontium-90 (^{90}Sr), Polonium-210 (^{210}Po), Americium-241 (^{241}Am) can be used as heat source for thermoelectric generator. These four radioactive material are chosen cause they fulfil the requirements needed by any potential thermoelectric generator.

Periodic Table of the Elements

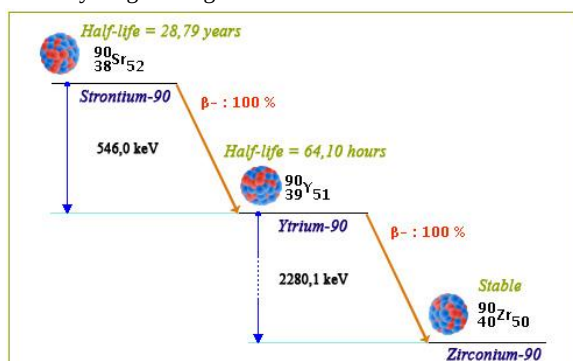
Among these four elements we have used Strontium-90 (^{90}Sr) as our heat source as it best suits our needs for a Graphene based thermoelectric generator, after comparing all four elements.

Comparison of the four elements is shown below

Element	Beta decay (MeV)	Decay products	Half-life (years)	Neutrons	Protons	Shielding	Power Density (W/g)
Strontium-90	0.546	^{90}Y	28.79	52	38	High	0.46
Plutonium-238	5.593	^{234}U	87.7	144	94	Low	0.54
Polonium-210	5.3407	^{206}Pb	0.378	126	84	Low	140
Americium-241	5.486	^{237}Np	432	146	95	Medium	0.114

Reasons to choose Strontium-90 are:

- Strontium-90 is with cesium-137 (two major radioactive isotopes found in nuclear waste) a major radioactive product of nuclear fission. After the atomic bomb explosion or within a nuclear reactor, it's abundant: 5.8% of uranium-235 fissions produces this radioelement. There was mention of strontium-90 during testing atomic bombs within the atmosphere of the 1960s.
- In the Mendeleev classification, chemically, strontium is close to calcium.
- Strontium-90 does not emit gamma rays. Its presence is difficult to identify owing to the absence of very characteristic energy rays which would sign its presence. This absence of gamma rays also means less external exposures
- Its decay diagram is given below



CONCLUSION

From above thesis we infer, Thermoelectric technology can be used to generate a small amount of electrical power, typically in the μW or mW range, if a temperature difference is maintained between two terminals of a thermoelectric module. In Graphene based TEG Seebeck coefficient is higher than the any other induced voltage

method. Seebeck coefficient increases as graphene layer increases. Moreover, Graphene based thermos TEG is more Efficient, Reliable, compact, light in weight and Pollution free, all above stated advantages leads potentially a wide variety of applications in science and engineering

REFERENCE

1. Woerner, D., et al. "Next-Generation Radioisotope Thermoelectric Generator Study Final Report." JPL D- 99657, NASA Radioisotope Power Subsystem Program, Jet Propulsion Laboratory, California Instituten of Technology, 2017.
2. Space Studies Board and National Research Council. (2012). Vision and voyages for planetary science in the decade 2013-2022. National Academies Press
3. Rowe, D. M. (Ed.). (2005). Thermoelectrics handbook: macro to nano. CRC press.
4. G. L. Bennett, J. J. Lombardo, and B. J. Rock, "U.S. Radioisotope Thermoelectric Generator Space Operating Experience (June 1961 - December 1982)", paper 839171, Proceedings of the 18th Intersociety Energy Conversion Engineering Conference, held in Orlando, Florida, 21-26 August 1983. (This paper was reprinted as "US Radioisotope Thermoelectric Generators in Space" in The Nuclear Engineer, Vol. 25, NO. 2, pp. 49-58, MarCh/April 1984.)
5. G. L. Bennett, "Space Applications", Chapter 41 of CRC Handbook of Thermoelectrics, David M. Rowe, editor, CRC Press, Inc., Boca Raton, Florida, 1995.
6. P. J. Dick and R. E. Davis, "Radioisotope Power System Operation in the Transit Satellite", Paper No. CP 62-1173, AIEE Summer General Meeting, held in Denver, Colorado, 17-22 June 1962.
7. Hittman Associates, Inc., Radioisotope Powered Space Systems, NY0-3165-11, 23 August 1963.
8. Johns Hopkins University Applied Physics Laboratory, Artificial Earth Satellites Designed and Fabricated by the Johns Hopkins University Applied Physics Laboratory, JHU/APL Report SDO-1600 (revised), August 1980.
9. A. W. Fihelly and C. F. Baxter, "Orbital Performance of the SNAP-19 Radioisotopic Thermoelectric Generator Experiment", Paper 719 152, Proceedings of the 6th Intersociety Energy Conversion Engineering Conference, held in Boston, Massachusetts, 3-5 August 1971.
10. E. A. Skrabek and D. S. Trimmer, "Properties of the General TAGS System", Chapter 22 of CRC Handbook of Thermoelectrics, David M. Rowe, editor, CRC Press, Inc., Boca Raton, Florida, 1995. [12] C. J. Goebel, "SNAP-19 Pioneer 10 and 11 RTG Deep Space Performance", Paper 759 130, Record of the 10th Intersociety Energy Conversion Engineering Conference, held in Newark, Delaware, 18-22 August 1975.
11. W. M. Brittain, "SNAP-19 Viking RTG Mission Performance", Paper 769255, Proceedings of the 11th Intersociety Energy Conversion Engineering Conference, held in State Line, Nevada, 12-17 September 1976.
12. W. M. Brittain and E. A. Skrabek, "SNAP 19 RTG Performance Update for the Pioneer and Viking Missions", Proceedings of the 18th Intersociety Energy Conversion Engineering Conference, held in Orlando, Florida, 21-26 August 1983
13. A. A. Pitrolo, B. J. Rock, W. C. Remini, and J. A. Leonard, "SNAP-27 Program Review", Paper 699023, Proceedings of the 4th Intersociety Energy Conversion Engineering Conference, held in Washington, D. C., 22-26 September 1969.