International Research Journal of Natural and Applied Sciences
ISSN: (2349-4077)
Impact Factor- 5.46, Volume 4, Issue 12, December 2017
Website- www.aarf.asia, **Email** : editor@aarf.asia , editoraarf@gmail.com

"THERMOELECTRIC APPLICATIONS, MATERIALS AND MODELLING"

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ABSTRACT

It is the conversion of differences in temperature into electric voltage and electric voltage into temperature differences via a thermocouple. Thermoelectric materials are important for devices which are designed from this conversion. High efficiency TE creates power generation devices. There are three effects which are used in thermoelectric i.e., Seebeck effect, Peltier effect and Thomson effect. Whenever the current is passed through a material the heat is generated, it is termed as Joule heating. It is not termed as thermoelectric effect as it is not reversible like Peltier–Seebeck and Thomson effects. They are thermodynamically reversible but Joule heating is not.An extension of the Peltier–Seebeck effect is Thomson effect which is invented by Lord Kelvin. They are used in solid state refrigeration devices. applications of thermoelectricity Avionics, Black box cooling, Calorimeters, CCD (Charged Couple Devices), CID (Charge Induced Devices), Cold chambers, Cold plates, Compact heat exchangers, Night vision equipment, Osmometers, Parametric amplifiers etc.

OBJECTIVES

- Description of thermoelectricity
- Understanding of 3 Effects used in thermoelectricity
- Applications of thermoelectricity

- Understanding of thermoelectricity materials
- 3-D Structure of thermoelectricity

KEYWORDS

- Thermoelectricity
- Seebeck effect
- Peltier effect
- Thomson effect
- Figure of merit
- Thermoelectric generators
- Thermoelectric coolers
- Ceramic insulators
- P- and n-type conductors

INTRODUCTION

Thermoelectricity

It is the direct conversion of heat into electricity or electricity into heat. It is the conversion of differences in temperature into electric voltage and electric voltage into temperature differences via a thermocouple. It is called thermoelectric effect and also known as Peltier-Seebeck effect. When there is a different temperature on each side of a material the thermoelectric device creates a voltage. Similarly, it creates a temperature difference on each side when a voltage is applied to it. These conversions done by two mechanisms one is **Seebeck effect** and other is **Peltier effect.**

Measure temperature or change the temperature of the material or object, or to generate electricity, this phenomenon is applied. Thermoelectric devices are used as temperature controllers as the cooling and heating is determined by the polarity of the applied voltage.

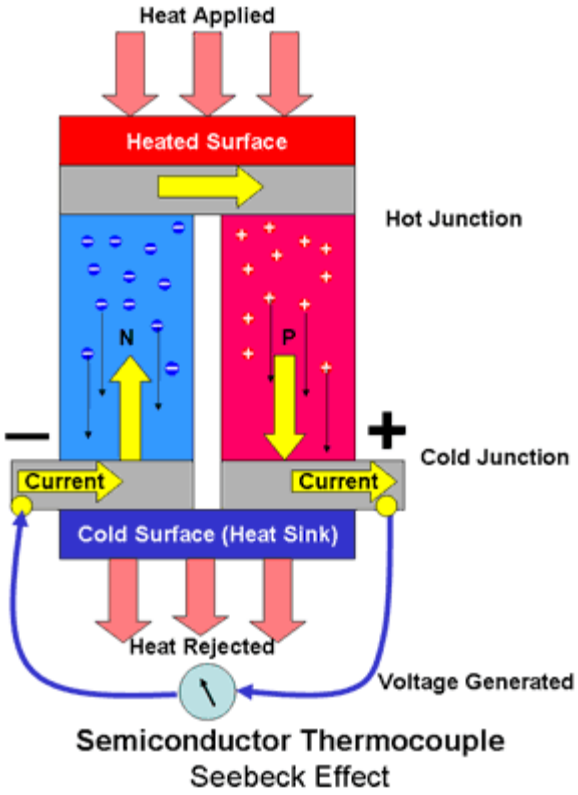
Whenever the current is passed through a material the heat is generated, it is termed as Joule heating. It is not termed as thermoelectric effect as it is not reversible like Peltier–Seebeck and Thomson effects. They are thermodynamically reversible but Joule heating is not.

An extension of the Peltier–Seebeck effect is Thomson effect which is invented by Lord Kelvin.

INVENTION

In thermoelectricity there are major discoveries which are made by 3 scientists. And processes are named after these scientists.

Seebeck effect was discovered by Baltic German physicist Thomas Johann Seebeck in 1820s. An electric potential is formed using temperature differential in two dissimilar metals is called Seebeck effect.



Semiconductor Thermocouple
Seebeck Effect

Thermocouple is the device to measure temperatures. It consists of at least two metals joined to form two junctions. As shown in the picture metals are cold at one end and hot at another end. When two different metals are combined with different temperatures the current is generated between the two junctions. Thermocouple is the device to measure temperatures. It consists of at least two metals joined to form two junctions. As shown in the picture metals

are cold at one end and hot at another end. When two different metals are combined with different temperatures the current is generated between the two junctions. One metals has electrons at one end that move to the hot end these electrons are called n-type and this metal is called n-type metal. When there is no electrons that metal has positively charged holes that move to the cold end, these holes are p-type and this metal is known as p-type metal. The cold ends of the metal form a potential in between the ends with the movement of electrons and holes.

Formula for Seebeck effect:

$V=a\ (T_h - T_c)$

V- Voltage difference between two dissimilar metals

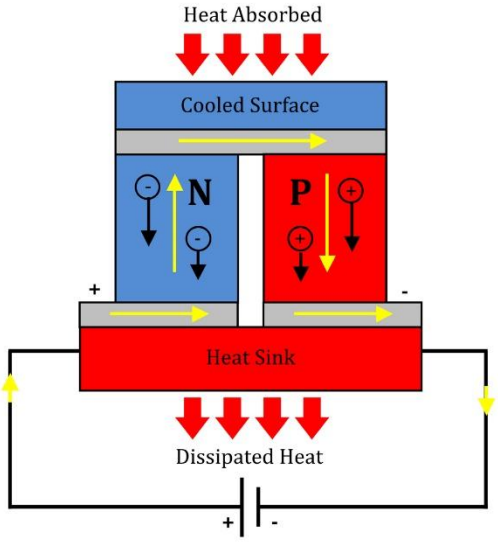
a- Seebeck coefficient

$T_h - T_c$ - Temperature difference between hot and cold junctions

The voltage or electromotive force(EMF) is directly proportional to the temperature differences. The voltage is greater when the difference in the temperature between any side of the metals is bigger. Seebeck Coefficient or thermoelectric sensitivity is the constant value which is the change in material voltage with respect to change in temperature.

One use of Seebeck effect is thermometers, power generators etc.

The **Peltier Effect** is discovered by a French Scientist Jean Charles Athanase Peltier in 1834. The effect is opposite of Seebeck effect. The presence of cooling or heating a junction in which current is flowing of two different metals. In this effect the temperature differential is created when current is passed in two different metals.



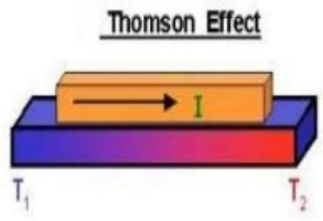
It depends on the direction of the current flows in the circuit the junctions can be made cold or hot. As shown in the picture this effect usually makes the junction cold where two metals are joined. The voltage applied to the materials is directly proportional to the temperature differences is created as same as the Seebeck effect. Peltier Coefficient is the proportionality constant. When an electromotive force is applied between two conductors through an electronic junction the heat is removed. Between two plates multiple junctions are made to make a typical pump. In this one side cools and one side heats. A device is attached to the hot side of the material is called dissipation device. It allows to maintain cooling effect on the cold side. Heat pump devices are made using Peltier Effect. The current runs through thermocouple to make the it colder and it involves multiple junctions in series. In small applications Peltier coolers are used like mini refrigerators.

Peltier heat=π I

here π is the Peltier coefficient which depends on metals forming the junction and the temperature. I is an electric current passed between the junctions.

Thomson effect was invented by Lord Kelvin(William Thomson) in 1851. This effect unites above two effects. It defines the relationship between the current flowing in a single piece of material and the heat it absorbs or produces. It cuts down the use of other metal/material to find the Seebeck and Peltier coefficients. With a temperature rise it describes the cooling or heating of a current carrying conductor. When electric current passes through a circuit that has a temperature difference along its length and it is composed of single material then the

heat is absorbed or evaluated. This phenomenon is Thomson effect. The heat which is transferred on the common production of heat is superimposed associated with the electrical resistance to currents in conductors when one of the conductor is hot and other is cold.



Small temperature difference dT if two ends of the material is same, then the potential difference is proportional to dT dV α dT or dV=σdT where σ is the constant of proportionality and is known as Thomsoncoefficient.

Thomson coefficient and Peltier coefficient are related to thermopower

π=Ts=T(dE/dT)

and σ =-T(ds/dT) = -T(d^2E/dT^2)

APPLICATIONS OF THERMOELECTRICITY

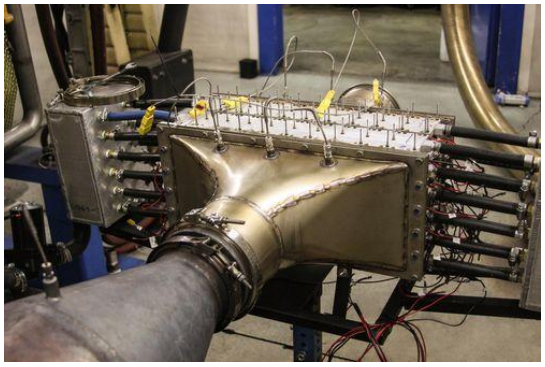
Thermoelectric modules can be applicable in wide spectrum of product areas. Its application isimplemented in various equipment used by industrial, scientific, medical, military,telecommunications organizations, in small probe applications and many more.

Seebeck effect applications

- Seebeck effect is used in thermoelectric generators, which function like heat engines. A thermoelectric generator is also used in space travel when spacecrafts are not able to use solar power as a source of producing electricity.
- Seebeck effect is also used in power plants as a role of energy recycler by converting waste heat into additional electrical power and in automobiles for increasing fuel efficiency as automotive thermoelectric generators.
- Seebeck Effect is used in thermometers, this kind of thermometer is commended for its accuracy and its ability to measure temperatures quickly without changing the

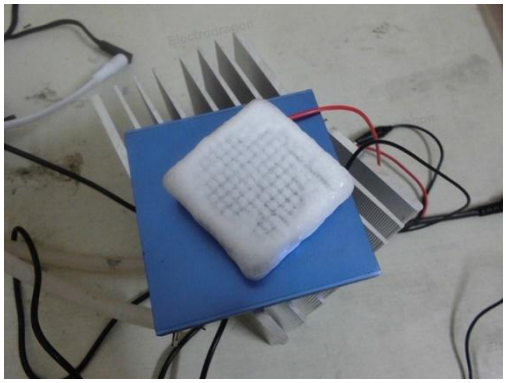
temperature of the thing being measured. The temperature differential gets greater when the probe gets hotter and therefore the voltage is greater.

- Seebeck effect used in temperature measurement also. The two popular devices,
- thermocouple and thermopile used for temperature measurement is based on the principal of Seebeck effect. Thermocouples are often used to measure high temperatures whilethermopiles use number of thermocouples connected in series or parallel for measurements of very small temperature differences.
- High-frequency electrical power sensors – Seebeck effect has been useful in obtaining the precise amplitude of sinusoidal waves. This has assisted in detection of the hyper frequency electrical power produced in a system and notify the operators.
- Power generation is the another use of Seebeck effect. Thermoelectric generators are used in large machines which put out waste heat.



TEG are used to boost efficiency by converting the waste heat into electricity. In the fig shown to recapture the heat energy generators are used and exhausted by diesel vehicles.

Thermoelectric generators are used in space travel. Thermoelectric generators are useful to create electricity when the spacecraft goes too far from sun and not able to use solar power.



Peltier effect use in thermoelectric applications. Peltier module has been used in many

applications such as Thermoelectric generator, Thermoelectric cooler, Medical Freezer, thermal cyclers etc. It can be used either for heating or for cooling, but cooling is the main application of Peltier effect.

The thermoelectric coolers are applicable for working heat removal ranging that can vary from mill watts to several thousand watts. To increase the total heat performance multiple modules are mounted thermally. Thermoelectric coolers can also be used to cool computer components like chip, photon detectors used in astronomical telescopes, digital cameras, wine coolers. It is also used in spacecrafts and satellites to reduce the sunlight temperature. It is also widely used in submarine or railroad car and in semiconductor manufacturing lines.

The Peltier effect is used by many thermal cyclers, an apparatus used in laboratory to amplify DNA segments. It is also used in laboratories to support temperature – sensitives reactions.

The Peltier Effect is commonly used in modern PCR machines.

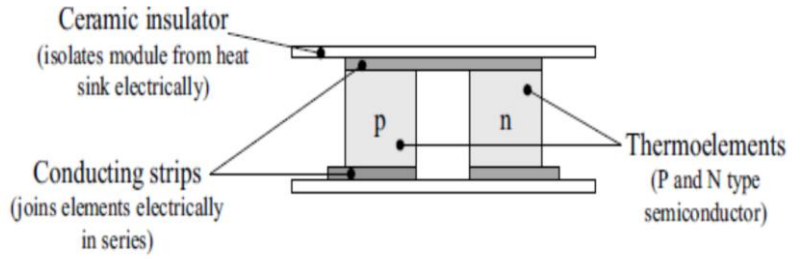
- PE can be use to facilitate highly stable temperature controllers that either heats or cools. It can keep desired temperature within ±0.01 °C that are used for laser applications.
- Peltier heat pump is used in thermoelectric dehumidifiers to cool a surface and to extract water from the air.
- Thomson Effect it has cooling as well as heating effect. It is reversible. it is produced when the two ends are at different temperatures of same conductor. It depends on the nature of conductor.

These are the applications of thermoelectricity Thermal cycling devices (DNA and blood analyzers), Semiconductor wafer probes, Stir coolers, Electrophoresis cell coolers, Environmental analyzers, Heat density measurement, Ice point , references, Photomultiplier tube housing, Power generators (small), Vidicon tube coolers, Thermostat calibrating baths, Long lasting cooling devices, Low noise amplifiers, Microprocessor cooling, Microtome stage coolers, Self-scanned arrays systems, Wafer thermal characterization, Water and beverage coolers, NEMA enclosures, Infrared seeking missiles, Laser collimators, Laser diode coolers, Wet process temperature controller, Wine cabinets , Night vision equipment, Tissue preparation and storage, Avionics, Black box cooling, Calorimeters, CCD (Charged

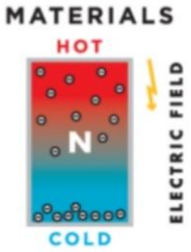
Couple Devices), CID (Charge Induced Devices), Cold chambers, Cold plates, Compact heat exchangers, Constant, temperature baths, Dehumidifiers, Dew point hygrometers, Electronics package cooling, Infrared detectors, Osmometers, Precision device cooling (lasers and microprocessors), Refrigerators and on-board refrigeration systems (aircraft, automobile, boat, hotel, insulin, portable/picnic, pharmaceutical, RV), Restaurant portion dispenser.

THERMOELECTRICITY MATERIALS

The thermoelectric materials are the materials which are good in conversion of heat into electricity. To solve the global energy crises the materials are critical in energy conversion technologies. The materials has been proved to be suitable in spacecrafts and missiles as they are high end technologies applications. Type of materials used are the primary factor for performance in thermoelectric devices. And also thermal conductivity, Seebeck coefficient, thermal stability and electrical conductivity are material properties. Classic inorganic materials are also in use these days. They are important because of their thermoelectric responses as compared to organic materials.



There are different thermoelectric materials exists today and many of them has been used for decades and known and some are the result of recent development of advanced production processes or physics. Categories of thermoelectric materials are like cost, conversion efficiency, temperature range and crystal structure. Hundreds of elements have been used in thermoelectric modules. They are constructed as high temperature generators or Peltier coolers which are using the same materials and also produce power. The only difference in these are how the the rmoelements are joined to the conducting strip. Many materials in Seebeck' s effect has been considered to generate thermoelectricity. Electricity conductors and semiconductors are the main elements in first thermoelectric generators like copper, iron, zinc, lead, antinomy, bismuth and different alloys. Ceramics and composites thermoelectric materials are used in 20^{th} century were developed. For the production of thermoelectric effects, the basic thermoelectric materials are used.



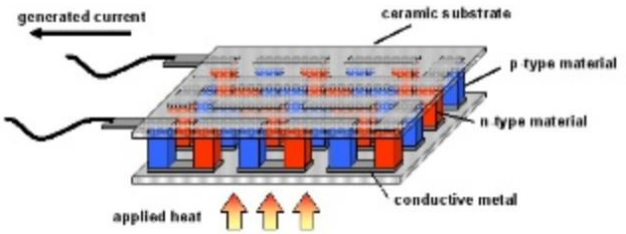
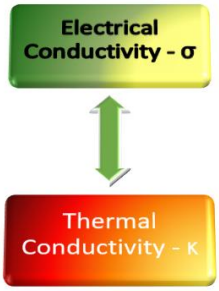


Figure-of-merit represented by zt dependent of temperature characteristic. Quality of materials are represented by figure-of-merit. It is the relation between Seebeck coefficient (α), electrical resistivity (σ), and thermal conductivity (K).

$$z=\alpha^2 \sigma/K$$

Wiedemann-Franz Law:

$$K/\sigma=LT$$

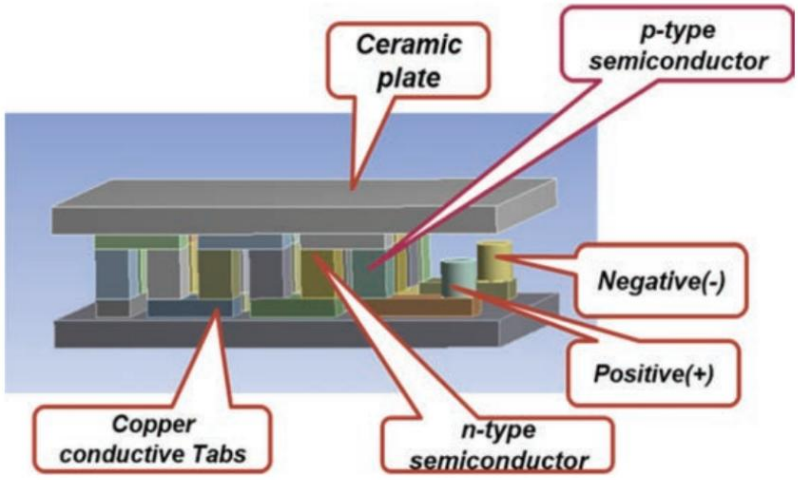


Electrical conductivity and thermal conductivity of metals are related to each other at given temperature. So, the thermoelectric applications must possess a high Seebeck' s coefficient in which metals are best suited. In constructions the metals or materials used are very useful in controlling the performance. In thermoelectric applications potential of a material is measured by figure of merit.

BISMUTH TELLURIDE MATERIAL: Crystalline Bismuth Telluride material has numerous characteristics. Bi_2Te_3 is highly anisotropic in nature due to its crystal structure. So, its material's electrical resistivity is four times greater. It is parallel to the axis of crystal growth(C-axis) than in the perpendicular orientation. In addition, thermal conductivity is about two times greater parallel to the C-axis than in the perpendicular direction. Bi_2Te_3 crystals are made up of hexagonal layers of similar atoms.

THREE-DIMENSIONAL STRUCTURE OF THERMOELECTRIC GENERATORS(TEG)

3-D structure of thermoelectric generators are composed of numerous slabs which consists of n- type and p-type semiconductors forming thermocouples. These thermocouples are connected thermally in parallel and electrically in series. Through conductive copper tabs the semiconductor slabs are connected to each other and they are inserted between two ceramic plates. The ceramic plate conduct heat but behaves as a insulator to electric current. This shows in fig of 3-D multielement TEG.



Waste heat can be supplied to top ceramic plate of thermoelectric generators. This waste heat comes from industry and infrastructure-heating activities, automobile engines exhaust and geothermal.

Hot side of TEG is defined by top surface of p- and n-type semiconductors. Heat flows through the copper-conductive tabs and ceramic plates first before reaching the hot side of TEG. The bottom ceramic plate is maintained at low temperature than top ceramic plate. It produces high temperature gradient through heat sink. This will lead to high power output. P- and n-type slabs materials are used to allow temperatures on top and bottom ceramic plates. Low thermal conductivity is been possessed by p- and n-type materials which are designed to restrict. It maintain temperature and heat flow through the semiconductors between hot and cold sides of TEG.

Models are used to simulate their behaviours and analyse their performance. Mathematical models of thermoelectric models for thermoelectric generators have been developed. Simulation and modelling used for optimization , design and analysis of thermoelectric models to cut down the design cycle. Using SPICE software equivalent circuit models of TEMs have been developed for easy module analysis. Also in commercial datasheets for further extraction of model parameters from specifications in recent era. For simulation of power electronics applications circuit models are implemented using SPICE. Using Matlab/Simulink, for a control purpose models are built. For the development of temperature control and maximum power point tracking (MPPT) the Sim Power System Tool is used in TEG applications.

ADVANTAGES OF THERMOELECTRICITY

Thermoelectricity is environmental friendly as it do not have chlorofluorocarbon so it is not polluted. It is reliable source of energy and it recycles wasted heat energy. Maintainance is not required frequently as there is no moving parts in it. This device can be applied to any size heat source from a water heater to a manufacturers equipment, that means it is scalable.

DISADVANTAGES OF THERMOELECTRICITY

Thermoelectricity requires relatively constant heat source and it is slow technology progression. Its efficiency rate is very low and it is able to dissipate limited amount of heat flux. It is transferred to low heat flux applications. It has lower coefficient of performance than vapour compression systems. Because of lack of industry/customer education about thermoelectric generators these are in less use.

CONCLUSIONS

Using thermoelectric modules in various regions the units of energy production can be developed. Pollution is very harmful to the society so this technology will play very important role in future. It is also known as “Green Technology” to generate electricity without pollution. The waste heat can be used by this technology and can be recycled after the conversion.

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