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Alternative Energy Source: Thermoelectric Materials and their Applications

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Abstract

The use of waste heat emitted by nuclear reactor, automobiles furnaces, factories etc is a good research area and it help to reduce the global warning effect because it uses waste heat that goes direct in the environment and increase the atmosphere temperature. The method which use in to convert waste heat in to electric energy is called thermoelectric effect and, in that materials, use in that are called thermoelectric materials. The thermoelectric devices convert heat into electrical energy. So thermoelectric materials are becoming more important as an alternate energy source, and applications for these materials are increasing. The thermoelectric effect involves generation of electrical energy from a heat source or removal of heat when an electric current is passed through the material. Thermoelectric devices are used for power generation and cooling. They are being developed for power generation from waste heat sources (automobiles, heavy trucks, industrial processes, chemical processes, steel industry for example), space power, remote low-voltage power sources, personnel cooling, automobile cooling, cooling of electronics, and refrigeration. This technology is based on the Seebeck effect, which relates the voltage (power) generated in the material when a temperature difference is applied across it (heat flux). Recently, there have been significant advances in enhancing the figure of merit of thermoelectric materials and also to find new materials for the thermoelectric purpose. Low thermal conductivity is the key for a promising thermoelectric material that can be achieved through the complex structures.

Keywords: thermoelectric effect, seebeck effect, heat flux, thermal conductivity,

Introduction

Globalization came about as the industrialized countries began to exploit global fossil fuel and mineral reserves in pursuit of greater economic efficiency. There is an increasing demand for a cost-effective renewable source of energy. Fossil fuels are assumed to offer low prices and greater potential. Coal, Oil and Gas are called "fossil fuels" because they have been formed from the fossilized remains of prehistoric plants and animals. They provide around 66% of the world's electrical power, and 95% of the world's total energy demands. But the basic disadvantage of fossil fuels is pollution. Burning any fossil fuel produces carbon dioxide, which contributes to the "greenhouse effect" adding to global warming. The fundamental economic reality of fossil fuels is that they are found in relatively small number of locations across the globe, yet consumed everywhere. This has led to an increased interest in renewable sources of energy such as thermoelectric energy, solar, hydroelectric and wind. In thermoelectric effect use the temperature deference in which one end is higher temperature to other end and this temperature deference is cause the generation of electric energy. In thermoelectric effect method use the transport and exchange of energy by and between electrons and phonons or lattice vibrations in a solid. This method can be described by the Seebeck, Peltier, and Thomson effect. As such these methods may be use to generate electrical power from waste or primary sources of heat, or inversely to provide all-solid-state heat pumping. Thermoelectric refrigeration is an environmentally “green” method of small scale, localized cooling in computers, infrared detectors, electronics, and optoelectronics as well as many other applications. However, most of the electronics and optoelectronics technologies typically require only small-scale or localized spot cooling of small components that do not impose a large heat load. Over the past decade, there has been heightened interest in the field of thermoelectric, driven by the need for more efficient materials for electronic refrigeration and power generation. Some of the research efforts focus on minimizing the lattice thermal conductivity, while other efforts focus on materials that exhibit large power factors. Proposed industrial and military applications of thermoelectric (TE) materials are generating increased activity in this field by demanding higher performance high-temperature TE materials than those that are currently in use. The demand for alternative energy technologies to reduce our dependence on fossil fuels leads to important regimes of research, including that of high temperature energy harvesting via the direct recovery of waste heat and its conversion into useful electrical energy. Thus, the development of higher-performance TE materials is becoming ever more important. Power-generation applications are currently being investigated by the automotive industry as a means to develop electrical power from waste engine heat from the radiator and exhaust systems for use in next-generation vehicles. In addition, TE refrigeration applications include seat coolers for comfort and electronic component cooling.

Thermoelectricity

Thermoelectricity is a phenomenon in that electricity is produced by thermal effect. The study of thermoelectric effect started in the year 1794. The theory of Thermoelectricity is based on the heat transformation in to electric energy, which is explain on the basis of Seebeck effect, Peltier effect and Thomson effect. It employs thermoelectric materials and transforms thermal energy to electricity.

Seebeck Effect

The Seebeck Effect was invented in 1794 via Italian scientist Alessandro Volta, it is named after the Baltic German physicist Thomas Johann Seebeck, who in 1821 independently rediscovered it. The Seebeck effect is a phenomenon in that a current flow in the circuit consist of two different materials when a temperature difference is maintaining between the two junctions. The current produced during the heating of a junction is called thermoelectric current and above effect is known as Seebeck effect the junction of two dissimilar metals called thermocouple. The voltage deference will be occurring when the temperature difference present onto these materials. Electron get the excitation energy when we applied the heat at one of the two conductors or semiconductors. So, electron move from heating end to cooler end by the motion of these electron an electric field will be developed between hot end and cooler end if we connect these two-end hot end and cool end by making a close circuit a direct current will flow in the circuit. Normally the voltage difference develop by the Seebeck effect is low of order microvolts. If we apply the large temperature difference and use good thermoelectric materials, we can get the voltage difference up to millivolts order. For better application connect the circuits in parallel form. By using Seebeck effect we can calculate the electromotive force E_{emf} by below equation. And with the help this electromotive force we can calculate the current density J which is also depends on the electric conductivity σ. Seebeck did not recognize that there was an electric current involved, so he called the phenomenon "thermomagnetic effect". Danish physicist Hans Christian Ørsted rectified the oversight and coined the term "thermoelectricity". Seebeck effect is the best example of electromotive force E_{emf} which is calculated as.

$$E_{emf} = -S\blacktriangledown T$$

Where ▼T is the temperature difference between wormed end and cool end S is the Seeback coefficient

The current density can be calculated as using $E_{emf.}$

$$J = \sigma(-\blacktriangledown V + E_{emf})$$

Where E_{emf} is generated electromotive force the ▼V is local voltage, and σ is the conductivity of materials. In general, the Seebeck effect is described locally by the creation of an electromotive field

Peltier Effect

If a current pass through a thermocouple by external source of current connected in thermocouple circuitin the same direction of in which thermoelectric current flow then heat is evolved in one junction and absorbed in other junction to maintain both the junction are kept at the same temperature. If we reverse the direction of current the junction which was absorbed will now emit the heat while other will now absorbed the heat. The above reversible effect was invented by Jean C. A. Pelteier in 1834 and this effect known as Peltier effect. When a current is pass through a junction in between two conductors, A and B, heat may be generated or removed at the junction by above method. The Peltier heat evolved at the junction per unit time is.

$$Q = (\pi_A - \pi_B)\, I$$

Where π_A and π_B are the Peltier coefficients of conductors A and B, and I is the electric current (from A to B).The Peltier coefficients is defined as the e.m.f. at the junction of a thermocouple. The heat liberated or absorbed at the junction when unit charge flows through the junction it is denoted by π. The Peltier effect is a reversible effect to the Seebeck effect. The relationship between Peltier coefficient and Seebeck coefficient effects is given as $\pi=TS$. In a Peltier heat pump a multiple junctions arranged in series. Thermoelectric heat pumps found in thermoelectric cooling devices such as refrigerators. Peltier effect is a reversible effect so the thermocouple can be imagined as a Carnot engine that absorbing heat and convert it into work.

Thomson effect

It is seen that heat is evolved when a current flow from the hot end to the cold end of an unequally heated metal bar and heat is absorbed after reversing the direction of current. So there is a potential gradient must be exist along the bar. In the metal the number of free electrons depending on the temperature. Hence potential gradient should be accompanied with a temperature gradient this effect known as Thomson effect. This Thomson effect was predicted and observed in 1851 by Lord Kelvin (William Thomson). Thomson effect is said to be positive when the e.m.f. is directed from lower temperature to higher temperature and negative when directed from higher temperature to lower temperature. The generated e.m.f. between two point of a metal bar at temperature gradient dT is $\kappa \blacktriangledown T$ where k is the Thomson coefficient and $\blacktriangledown T$ is the temperature gradient. The equation of heat produced per unit volume will be obtain when a current density J is passed through a homogeneous conductor, with temperature gradient $\blacktriangledown T$. Then the heat produce per unit volume is given as.

$$q = -\kappa J \cdot \blacktriangledown T$$

Where $\blacktriangledown T$ is the temperature gradient, and κ is the Thomson coefficient. The Thomson coefficient is related to the Seebeck coefficient as $\kappa = T\, dS/dT$.

Thermoelectric Equations

The flow of energy must be considered To explain the Peltier and Thomson effects. With the start, the dynamic case where both charge and temperature may be varying with time can be considered. The full equation of thermoelectric effect for the energy is

$$e = \blacktriangledown \cdot (\sigma \blacktriangledown T) - \blacktriangledown \cdot (V + \pi) J + q_{ext}$$

Where σ is the thermal conductivity. The first term is the Fourier's heat conduction equation, and the second term shows the energy carried due to flow of current density J. The third term, q, is the external heat added by the external source.

$$-q_{ext} = \blacktriangledown \cdot (\kappa \blacktriangledown T) + J \cdot (\sigma^{-1} - J) - TJ \cdot \nabla S$$

Thomson Relations

By using Seebeck effect Peltier effect and Thomson effect in 1854, Lord Kelvin found relationships between the three coefficients are

The first Thomson relation is

$$K = d\pi/dT - S$$

Where T is the absolute temperature, K is the Thomson coefficient, Π is the Peltier coefficient, and S is the Seebeck coefficient. The Thomson coefficient is related to Seebeck coefficient as.

$$K = T\, d S /dT.$$

The second Thomson relation is

$$\Pi = TS$$

This relation show that the fundamental connection between the Peltier effect and Seebeck effects if the material is placed in a magnetic field then the second Thomson relation does not take the simple form shown here.The Thomson coefficient is unique among the three main thermoelectric coefficients. The Seebeck coefficients and Peltier cofficient can be easily determined for pairs of two materials hence, so it is difficult to find values of absolute Peltier coefficient and Seebeck for a single material.

Main thermoelectric materials

Seebeck grouped several metals and alloys in the series that series is known as thermoelectric series. For a thermocouple it is formed by any two metals or alloys by the series Sebaeck grouped 35 metals and alloys in the thermoelectric series bismuth in first number and antimony at the last number. On the basis of thermoelectric series Some combination of materials are explain below

Bismuth Telluride (Bi2Te3)

Bismuth (Bi) has atomic number is 83 and Tellurium (Te) has atomic number is 52. The stable compound of element Bi and Te, Bi_2Te_3 has the largest molecular weight. The melting point of Bi_2Te_3 is 585ºC, and the density is 7.86g/cm3. The stoichiometry of $Bi_2Te_3$is control during the growth of the crystal of Bi_2Te_3. For compound semiconductors, chemical ratio has a significant role in crystal property. The p-type material will be obtained when we exceed the ratio of Bi in Bi_2Te_3 and n-type material will be obtained If we increase the ratio of Te in compound of Bi_2Te_3. Thermoelectric properties of melt Bi_2Te_3 and its alloys are distinct between parallel and vertical to the cleavage plane. At 300K, Bi_2Te_3thermoelectric unicouple reaches the largest optimum value. 1.0×10-5 m Ω is the electrical resistivity of p-type and n-type materials of Bi_2Te_3. 185 V K µ is the Seebeck coefficients for p-type and -205 V K µ is the Seebeck coefficients for n-type Bi_2Te_3. Thomson coefficient is about 1.9 W m K •. Bi_2-xSbxTe_3 is the best composition for the p-type thermoelectric material where x≈1.5. Bi_2Te_3-ySey is the best composition for n-type thermoelectric material where y≈0.3.

Lead Tellurid (PbTe) and its alloys

By using Seebeck series a compound PbTe can formed for thermoelectric effect. It is a compound of lead and tellurium it has a cubic crystal structure. It is occurred naturally as the mineral altaite. It has a narrow band-gap with the order .30 eV. It works as a thermoelectric power generation in the range of temperature 300-900K. PbTe also use in Infra-red detectors.

Sillicon Germanium (SiGe) alloys

Si is the exception of Seebeck series because it does not include in the Seebeck series but its compound with Ge give the property of thermoelectric effect. It the best high-temperature thermoelectric material as the thermal conductivity of crystal is lowered greatly. This compound also use in microelectronics devices and integrated circuit, photovoltaic cells. At high temperature greater then 600^oC SiGe alloys have a high thermoelectric efficiency.

Applications of Thermoelectric Materials

The use of thermoelectric materials based on the law of Peltier effect, Seebeck effect and Thomson effects. The Peltier effect of materials can be used in thermoelectric cooling devices. The Seebeck effect can be use where we need to convert waste heat into electricity by making of thermoelectric generators. Such as thermal power plants automobiles etc by using waste heat of these plants and give extra electric power. And play a good role in sustainable developments of world. But for commercial power conversion of heat in to electric energy applications have not been reached until today because of the low conversion efficiencies of the materials. While Thermocouples and thermopiles are devices that use the Seebeck effect to measure the temperature difference between two objects. Thermocouples are often used to measure high temperatures, holding the temperature of one junction constant or measuring it independently (cold junction compensation).

Thermopiles use many thermocouples electrically connected in series, for sensitive measurements of very small temperature difference. Recent uses include stove fans, lighting powered by body heat and a smartwatch powered by body heat. The Peltier effect can be used to create a refrigerator that is compact and has no circulating fluid or moving parts. Such refrigerators are useful in applications where their advantages outweigh the disadvantage of their very low efficiency. lead telluride or one of its alloys, or silicon-germanium alloys due to their fitting operational temperature range. Lead telluride material can be used at temperatures of up to 900K, while SiGe enables higher temperatures of up to 1300K.

Aim of the study

To grow thermoelectric material (PbTe) and its nanostructured thin films

Conclusion

The temperature-electricity technology can achieve good effect of energy-saving with relatively low cost. Recently, there are many new concepts and practices springing up in the thermoelectricity field, including the high energy density thermoelectric power generation module, the cogeneration system and the heating cycle thermal combustion system. With the research on thermoelectric materials going deep and the manufacturing technology becoming mature, thermal performance and thermoelectric technology will be more advanced. Industrial waste and waste heat from waste incineration will be employed and served for more use. We believe thermoelectric technology will bring great changes and innovation to our life. So, our aim to make a good quality thermoelectric material like lead telluride by using Lead and Tellurium in stoichiometric ratio by VDS method and also make a nanostructured thin film varies substrate temperature by using thermal evaporation method.

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