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Thermoelectric Power Generation as an Alternative Green Technology of Energy Harvesting

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Abstract

The vast majority of heat that is generated from computer processor chips to car engines to electric power plants, the need to use of excess heat creates a major source of inefficiency. Energy harvesters are thermoelectric materials which are solid-state energy converters used to convert waste heat into electricity. Significant improvements to the thermoelectric materials measured by figure of merit (ZT) .forconverting waste-heat energy directly into electrical power , application of this alternative green technology can be made and also it will improve the overall efficiencies of energy conversion systems. In this paper, the basic concepts of thermoelectric material and its power generation is presented and recent patents of thermoelectric material are reviewed and discussed.

Keywords

Thermoelectric power generation, thermoelectric materials, alternative green technology, electrical power

1. Introduction

Trends in current electronic technologies are reduction In terms of device size but increasing the performance. Wireless Sensor Networks have been utilized in various applications ranging from structural monitoring for buildings and home land security; agriculture etc. over the past decades, low power electronics technology has become more imperative as well widely used in consumer applications such as smart phones and cardiac pacemaker. The common device used to store the electricity is battery. Due to power drain, replacement and recharging of batteries will significantly increase the cost and lead to serious environmental pollution.

Thus, other possibilities need to look out to reduce dependency on batteries. A promising solution to this problem is to use energy harvesting technologies. Energy is found in the target environment of these devises in several forms such as kinetic, thermal and radiation energy. The process of extracting these energies in to electrical energy is known as energy harvesting negligible maintenance.
Efforts are require and unlimited power source can be provided using energy harvesting technique. There are two types of energy harvesters which are macro and micro types. Macro mainly focus to reduce carbon emission and for oil dependency. Typical power produce by macro-energy harvester ranges from kilowatts to megawatts. For micro-energy harvester, the ultimate goal is to power up wireless sensor network and wearable devices. Among the energy harvesting technologies, TEG is of special interest as a micro-energy harvester.

A thermoelectric power generator is a solid state device that provides direct energy conversion from heat due to a temperature gradient into electrical energy based on "See beck effect". The thermoelectric power cycle, with charge carriers serving as the working fluid, follows the fundamental laws of thermodynamics and resembles the power cycle of a conventional heat engine. Thermoelectric power generators offer following distinct advantages over other technologies. They are extremely reliable and silent in operation since they have no mechanical moving parts and require considerably less maintenance;

- They are simple, compact and safe;
- They have very small size and virtually weightless;
- They are capable of operating at elevated temperatures;
- They are suited for small-scale and remote applications;
- They are environmentally friendly;
- They are not position-dependent; and
- They are flexible power sources.

The major drawback of thermoelectric power generator is their relatively low conversion efficiency. This has been a major cause in restricting their use in electrical power generation to specialized fields with extensive applications where reliability is a major consideration and cost is not. Applications over the past decade included industrial instruments, medical and aerospace, and applications for portable or remote power generation. However, in recent years, an increasing concern of environmental issues of emissions, in particular global warming has resulted in extensive research into nonconventional technologies of generating electrical power and thermoelectric power generation has emerged as a promising alternative green technology. Vast quantities of waste heat are discharged into the earth's environment much of it at temperatures which are too low to recover using conventional electrical power generators. Thermoelectric power generation offers a promising technology in the direct conversion of low-grade thermal energy, such as waste-heat energy, into electrical power. Probably the earliest application is the utilization of waste heat from a kerosene lamp to provide thermoelectric power to power a wireless set. Thermoelectric generators have also been used to provide small amounts electrical power to remote regions. In this waste heat powered thermoelectric technology, it is unnecessary to consider the cost of the thermal energy input, and consequently thermoelectric power generators' low conversion efficiency is not a critical drawback . In fact, more recently, they can be used in many cases, such as those used in cogeneration systems, to improve overall efficiencies of energy conversion systems by converting waste-heat energy into electrical power.

An important objective in thermoelectric power generation using waste heat energy is to reduce the cost-per-watt of the devices. Moreover, cost-per-watt can be reduced by optimizing the device geometry, improving the manufacture quality and simply by operating the device at a larger temperature difference. Their performance and economic competiveness appear to depend on successful development of more advanced thermoelectric materials and thermoelectric power module designs. In this paper, a background on the basic concepts of the thermoelectric power generation is presented through the applications implemented in the recent patents of thermoelectric power generation relevant to waste-heat energy

2. Basic theory of a thermoelectric power generator

The basic theory and operation of thermoelectric based systems have been developed for many years. Thermoelectric power generation is based on a phenomenon called "See beck effect" discovered by Thomas See beck in 1821. When a temperature difference is established between the hot and cold junctions of two dissimilar materials (metals or semiconductors) a voltage is generated, i.e., Seebeck voltage. In fact, this phenomenon is applied to thermocouples that are extensively used for temperature measurements. Thermoelectric devices can act as electrical power generators which are based on the See beck effect, a schematic diagram of a simple thermoelectric power generator operating based on See beck effect is shown in Fig. (1). as shown in Fig. (1), heat is transferred at a rate of H Q from a high-temperature heat source maintained at TH to the hot junction, and it is rejected at a rate of L Q To a low-temperature sink maintained at TL from the cold junction. Based on Seebeck effect, the heat supplied at the hot junction causes an electric current to flow in the circuit and electrical power is produced. Using the first-law of thermodynamics (energy conservation principle) the difference between H Q and L Q is the electrical power output e W. It should be noted that this power cycle intimately resembles the power cycle of a heat engine (Carnot engine), thus in this respect a thermoelectric power generator can be considered as a unique heat engine.

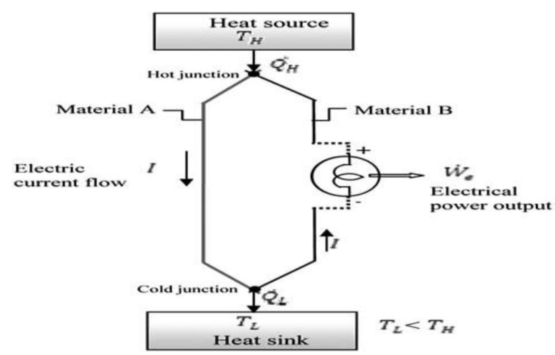

Fig. (1). Schematic diagram showing the basic concept of a simple thermoelectric power generator operating based on See beck effect

3. Composition and specifications of a thermoelectric power generator

Figure 2 shows a schematic diagram illustrating components and arrangement of a conventional single-stage thermoelectric power generator. The Fig (2) shows , it is composed of two cerami substrates that serve as a foundation, providing mechanical integrity, and electrical insulation for n-type and p-type semiconductor thermo elements. In thermoelectric materials, electrons and holes operate as both charge carriers and energy carriers. There are very few modules without ceramic substrates, which could eliminate the thermal resistance associated with the ceramic substrates, but might lead to mechanical fragility of the module. More than one pair of semiconductors are normally assembled together to form a thermoelectric module and within the module a pair of thermoelements is called a thermocouple. The junctions connecting the thermoelements between the hot and cold substrates are interconnected using highly conducting metal strips as shown in Fig. (2).The sizes of conventional thermoelectric devices vary from 3 mm2 by 4 mm thick to 75 mm2 by 5 mm thick. Most of thermoelectric modules are not larger than 50 mm in length due to mechanical consideration. The height of singlestage thermoelectric modules ranges from 1 to 5 mm. The modules contain from 3 to 127 thermocouples.

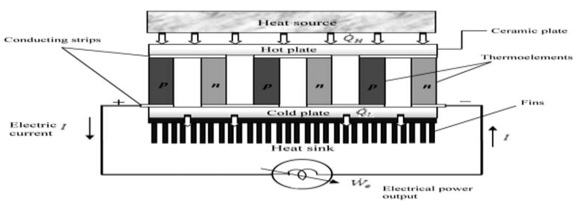

Fig. (2). Schematic diagram showing components and arrangement of a typical single-stagethermoelectric power generator.

There are multistage thermoelectricdevices designed to meet requirements for large temperature differentials. Multi-stage thermoelectric modules can be up to 20 mm in height, depending on the number of stages. Photographs of single and multi-stage thermoelectric modules are shown in Fig. (3).The power output for most of the commercially-available thermoelectric power generators ranges from microwatts to multi-kilowatts.

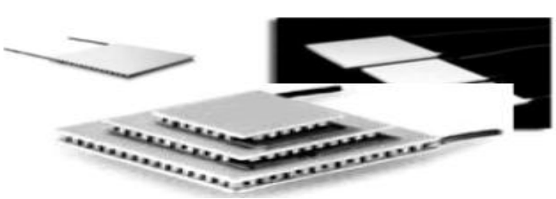

Fig. (3). Photographs of (a) single-stage, and (b) three-stage thermoelectric modules. (c)

specifications, such as module geometry (i.e. cross-sectional area and thermoelement length), thermoelectric materials and contact properties. as shown in Fig. (3a), the maximum power output follows a clear trend and increases with a decrease in thermoelement length for a given module cross-sectional area.

For example, a thermoelectric material with an average figure-of-merit of 3x10-3 K-1 would have a conversion efficiency of approximately 23% when operated over a temperature difference of 600K.

4. Thermoelectric Materials For Power Generators

From the large number of materials known to us , only a few are identified as thermoelectric materials. As reported by Rowe, thermoelectric materials can be categorized into established (conventional) and new (novel) materials, which will be discussed in the next sections. Today's most thermoelectric materials, such as Bismuth Telluride (Bi2Te3)-based alloys and PbTe-based alloys, have a *ZT* value of around unity (at room temperature for Bi2Te3 and 500-700K for PbTe). However, at a *ZT* of 2-3 range, thermoelectric power generators would become competitive with other power generation systems. The figure-ofmerit*Z*of a number of thermoelectric materials together

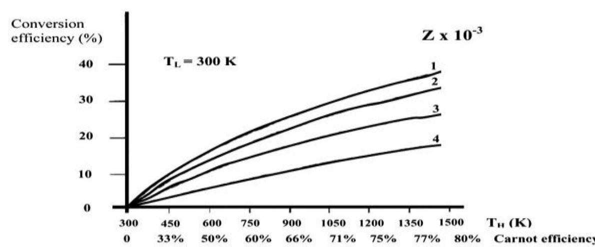

Fig. (4). Conversion efficiency as a function of temperature

The good thermoelectric materials should have a high electrical conductivity and low thermal conductivity. There is lot of research going on thermoelectric materials, which has focused on increase the efficiency as well Seebeck coefficient and reducing the thermal conductivity, especially by using the nanostructure of the thermoelectric materials.

Thermoelectric Materials

The thermoelectric materials those which are employed in commercial applications can be generally divided into three classes which are based on the temperature range of operation. Alloys based on Bismuth (Bi) in combinations with Antimony (An), Tellurium (Te) or Selenium (Se) are referred to as low temperature materials and can be used at temperatures up to around 450K. Theintermediate temperature range - up to around 850K is the regime of materials based on alloys of Lead (Pb) while thermo elements employed at the highest temperatures are fabricated from SiGe alloys and operate up to 1300K. Although the above mentionedmaterials still remain the cornerstone for commercial and practical applications in thermoelectric power generation, significant advances have been made in synthesizing new materials and fabricating material structures with improved thermoelectric performance. Efforts have focused primarily on improving the material's figure-of-merit, and hence the conversion efficiency, by reducing the lattice thermal conductivity

Novel Thermoelectric Materials And Module Configurations

It was recently reported in that a material which is a promising candidate to fill the temperature range in the *ZT* spectrum between those based on Bi2Te3 and PbTe is the semiconductor compound ß-Zn4Sb3. This material possesses very low thermal conductivity as well exhibits a maximum figure of merit *ZT* of 1.3 at a temperature of 670K. This material is also less expensive as well stable up to this temperature in a vacuum. Research are also being made to improve the competitiveness of thermoelectric in directions to improve the figure-of-merit. The efforts have focused on increasing the electrical power factor as well as decreasing cost and developing environmental friendly materials. In addition, when the fuel cost is low or essentially free, as in waste heat recovery, then the cost per watt is mainly determined by the power per unit area and the operating period. For example, considering the electrical power factor as the dominant parameter, it has initiated a search for materials with high power factors rather than conversion efficiency. Considerable success has been enjoyed in synthesizing materials, particularly attractive for waste heat recovery. For example, it is reported in that the rare earth compounds YbAl3, although possessing a relatively low figure-of-merit, has a power factor at least double that of any other reported in the literature, which operates over the temperature range of a waste heat source. When compared to YbAl3, MgSn has almost the same performance but costs less than 25% . Another recent direction to improve the competitiveness of thermoelectric materials, other than by improving the figure-of-merit, is by developing novel thermoelectric module shapes. As discussed previously, thermoelectric modules have typically plate-like shapes and fabricated from bulk semiconductors such as Bi2Te3 and PbTe, making them rigid and unsuitable for covering relatively large surfaces that are curved or non-flat (e.g. circular tubes) used in waste heat recovery applications. Also, this conventional configuration is suitable for applications where the flow of heat is perpendicular to the ceramic substrates. When heat flows in outward directions, the attachment of plate-shape modules around a cylindrical heat source is complicated. It becomes difficult, when the diameter of the cylindrical heat source decreases to less than 1 cm. In order to improve thermal contact to heat sources of required geometry, it is desirable to fabricate thermoelectric modules which can conform easily to a surface. Therefore, recent research has been focused on developing such cylindrical based shapes of thermoelectric power generators which are very flexible. For example, Yana et al. proposed and demonstrated the use of cost-effective thermoelectric power generator based on thin film thermoelectric on flexible fiber substrates as shown in Fig. (5). their innovation can be effectively applied in making flexible thermoelectric power generators for waste heat recovery applications.

It was also suggested that utilizing thicker semiconductor films evaporated onto hollow, low thermal conductivitysubstrates represents an opportunity to further increase power extraction efficiency from heat sources having a variety of shapes.

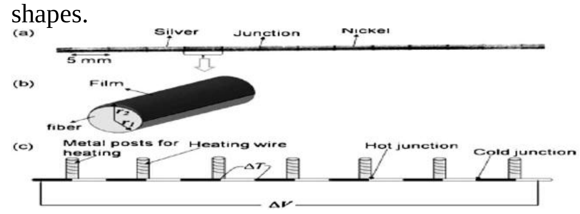

Fig. (5). (a) Schematic diagram of a striped thin film thermoelectric fiber made with thermal evaporation of nickel and silver; (b) schematic of fiber with thin film deposited on one side; and (c) schematic of experimental setup for applying a temperature difference and measuring the induced open circuit voltage Min and Rowe have also recently developed a novel tube-shape thermoelectric module for power generation.

It is fabricated from four ring-shaped thermo elements and its performance in electrical power generation is evaluated by measuring the power output as a function of temperature gradient of the device. Fig. (5) shows a schematic of the novel thermoelectric module developed by. It consists of two coaxial tubes: the inner tube is a thermoelectric assembly with heat source flowing in the center and the outer tube is an ordinary tube to hold the cooling fluid flowing between the inner and outer tubes. It was concluded that a tube-shape thermoelectric module could achieve similar performance to that of a conventional plate-like module, and has an advantage in waste heat recovery applications where heat flows in a radial direction

Recent developments & novel applications.

The scientists have known that in order to improve the performance of a thermoelectric material, they must increase its thermal conductivity. The following table shows Recent Development in thermoelectric materials energy harvesting devices.

Table 1. recent thermoelectric material list

Sr.no.	Materials
1)	PEDOT doped by PSS.
2)	Tetrahedrites made from common Dirt
3)	Skutterudites made from microwave energy
4)	Lead and tellurium
5)	Earth-Abundant which increase ZT In (OSCs)

The proposed energy harvesting device takes advantage of the temperature differences between the hot to cold parts to produce an electrical power and provides a solution for micro-scale electronic systems.

5. CMOS

The standard CMOS processes enables to realize a novel on-chip power supply capable of powering many low-power wireless sensor networks and devices.

Micro-Scale Waste Heat Applications

Growing applications like autonomous micro-systems or wearable electronics urgently look for micro-scale power generators. One possibility is to convert waste heat into electrical power with a micro thermoelectric power generator.

Macro-Scale Waste Heat Applications

Rowe reported that a waste heat-based thermoelectric power generator is used in a domestic central heating system with the modules located between the heat source and the water jacket.

Micro-Nano Systems (Mnss)

It is highly desirable that these MNSs operate without an external electricity source and instead draw the energy they require from the environment in which they are used. This Review covers various approaches for energy harvesting to meet the future demand for self-powered MNSs.

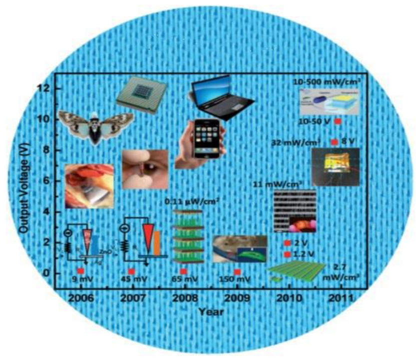

FIG.(6). Micro-/Nano devices exhibit operational advantages, such as small electrical/thermal time constants, enhanced sensitivity/ responsively, and high integrated complexity with respect to their conventional counterparts.

In addition to the above merits, another key characteristic of micro-/Nano devices is the low operation power, with typical values in the range of microwatts to miliwatts. Typical power consumption in MNSs also includes contributions from other operations of the system, such as signal conditioning, information processing/ storage, and data communication.

6. Current & future developments

Recently, an increasing concern of environmental issues of emissions, in particular global warming and the constraints on energy sources has resulted in extensive research into innovative technologies of generating electrical power and thermoelectric power generation has emerged as a promising alternative green technology. In addition, vast quantities of waste heat are discharged into the earth's environment much of it at temperatures which are too low (i.e. low-grade thermal energy) to recover using conventional electrical power generators.

Thermoelectric power generation offers a promising technology in the direct conversion of waste-heat energy, into electrical power. In this paper, a background on the basic concepts of thermoelectric power generation is presented and recent patents of thermoelectric power generation with their important and relevant applications to waste-heat energy are reviewed and discussed. Currently, waste.

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