A Review on Thermoelectric Cooler

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Abstract

Energy disaster and environment pollution are the two major problems of 21 century. Thermoelectric devices are one of key solutions to these problems. These devices attract the researchers because of its solid state nature that converting the heat given off from vehicles, electrical instruments, etc. into the electricity. This paper contains the previous research on thermoelectric cooler and recent advance on it.

Keywords: Thermoelectric Module, Thermoelectric Generator, Thermoelectric Cooler, Figure of Merit, Modelling

I. INTRODUCTION

Excessive use of the fossil fuel has led to the serious atmospheric and environmental problems like global warming, green house emission, ozone layer depletion, acid rain climate change. To avoid such disaster, reducing the consumption of the conventional sources and using the renewable sources or technologies. Thermoelectric devices are one of the technologies to fulfil our goal. These are the solid state devices converting the heat given off from vehicles, electrical instrument, etc. into the electricity. The merit of thermoelectric (TE) is gas free emission, no moving part, no damage, no chemical reaction, maintenance free and long life span. This conversion can be reverse (converting the electricity into the thermal energy) depending upon the cooling and heating requirement. These devices have limited application because of its low energy conversion efficiency and high material cost. Researcher tries to discover out the better technology to increasing conversion efficiency of TE devices [1]. These module can also use with the solar energy as its input. The two most prominent solar energy technologies are photovoltaic (PV) and concentrated solar power (CSP). CSP systems can provide electricity as well as thermal power. Because of solar energy it has attracted the attention of the researchers.

When the voltage is applied to the thermocouple of different material, temperature gradient is developed. At the atomic scale, an applied these difference causes charged carriers in the substance to move from the hot side to the cold side. This effect was known as PELTIER effect. Today we are able to see that it works in astronautic devices and automotive engine system [2]. Thermoelectric cooler (TEC) has been frequently used for the cooling of devices such as sensor, infrared CPU, point reference in thermocouple thermometry, and refrigerators [3].

II. THERMOELECTRIC MODULE

The basic unit of a TEM is thermocouple. As shown in fig. 1(a), a thermocouple consists of a p-type and an n-type semiconductor pellet joined by metal interconnects. These pellets of TE device are connected electrically in series and thermally in parallel and sandwiched between the two ceramic plates, as seen in fig. 1(b). On the other hand, whether the contribution of the metal interconnects is ignored, there is no loss of generality in analysing a single couple[4]. The quality of a thermoelectric cooler depends on the parameters such as the electric current applied at the n-type and p-type couple, the temperature of the hot and cold side, the thermal and electrical conductivities of the thermal elements, the thermal resistance of the heat sink on the hot side of thermoelectric cooler. The electrical contact resistance between the cold side and the surface of the device is shown in fig. 2 [5].
III. PREVIOUS WORKS ON THERMOELECTRIC COOLER

A. Transient Modelling and Dynamic Characteristics of Thermoelectric Cooler:

Dynamic characteristics are very important for design and operation of thermoelectric coolers (TECs). This paper created a three-dimensional transient TEC model based on the coupling of electric conduction and heat transfer within semiconductors. The model considers all thermoelectric effects, including Joule heating, Fourier’s heat conduction, Thomson effect, Peltier effect, and others. For most semiconductor materials, Seebeck coefficient, electric conductivity, and thermal conductivity are strongly dependent on temperature. Therefore, the present transient model is used to compare dynamic temperature variations at the hot and cold ends with variable and constant material properties. Small, medium, and large useful currents with various cooling loads are used as operating conditions. The results show that, for small currents, the constant property model can predict accurately the dynamic characteristics, and nevertheless, with the increase in current, the temperature-dependent properties have remarkable effects on the dynamic temperature variations, particularly for high cooling loads. When the current is higher than a specific value, the heat transferred by Fourier’s heat conduction from the hot end will exceed the heat absorbed at the cold end by Peltier effect, thus, the temperatures at the junction increase continuously and the TEC cannot reach the steady-state.[6]

Recently, we proposed a new three-dimensional TEC steady state model which is different from previous models in which only the heat conduction equation with Joule heat and/or Thomson heat as internal heat sources is solved. Our model introduced the coupling of heat and electrical conduction, and considered all the phenomenon occurred in the TEC. The model was used to find out the behaviour of TEC with the temperature dependent material properties. The predictions showed that the variable properties and the heat losses have significant effects on the cooling power and the coefficient of performance (COP) of the TEC. The temperature distributions of the three-dimensional within semiconductors were observed and it became more notable at high temperature differences and large currents. The purpose of this effort reaches the following targets: (1) extending our previous steady state model to a transient model; (2) employing the developed transient model to investigate the dynamic characteristics of TECs under
different operating conditions. The dynamic behaviours for TECs with temperature-dependent properties are studied and compared with those constant properties [7]. This work develops a complete three-dimensional transient TEC model, which helps in heat transfer and electric conduction within the semiconductors, and the developed TEC model in this paper has not been found in the literatures. The developed model is used to investigate the dynamic characteristics of TECs.

B. Computational Study of Transverse Peltier Coolers for Low Temperature Application:
Reverse thermoelectric effect can be produced artificially by stacking the layers of a thermoelectric material with another material that at an angle may or may not be a thermoelectric material. In this exploratory computational study, a new meta-material, consist of tilted alternating layers of an n-type thermoelectric alloy and a metal is investigated to gain an understanding of how much cooling can be created by this effect and the conditions under which maximum cooling is attainable. The governing equations of energy and electric current with the inclusion of thermoelectric effects are explained on an unstructured mesh using the finite-volume method to simulate a transverse Peltier cooler under various operating conditions. First, the code is authenticated against experimental data for a n-Bi2Te3–Pb meta-material, and subsequently explored. It is found that maximum decreasing in temperature (DT) produce at intermediate applied currents. Optimum values of the geometric design parameters such as device aspect ratio and tilt angle are also established through parametric studies. Finally, it is shown that the (DT) can be amplified by constricting the phonon (heat) transport cross-section while making the electron (current) transport cross section unchanged a method that cannot be employed in conventional thermoelectric devices where phonons and electrons follow the same path. This makes transverse Peltier coolers particularly attractive for generating large ΔT without multi-stage cascading. [8] In the near future, cryogenic Peltier coolers are expected to supplant conventional vapour-cycle cooling systems used to cool far-infrared, X-ray, and γ-ray sensors flown in space and weight sensitive platforms such as UAVS And situational awareness satellites. For such applications, the relevant temperature range is 150–10K, i.e., Ultra-low temperature. The theoretical performance of a conventional thermoelectric (TE) device is expressed by the non-dimensional figure of merit, $ZT = \frac{\Sigma^2 \sigma t}{k}$, where $T$ is the temperature, and $\Sigma$, $\sigma$, and $k$ are the electrical conductivity, SEEbeck coefficient and the thermal conductivity respectively, of the thermoelectric material being used. A conventional Peltier cooler yields a maximum temperature depression of $\delta t_{max} = (ZT/T/2$ provided have similar ZT values. Otherwise, the $\Delta T$ is significantly reduced.[9] both n-type and p-type materials of the TE alloy are available, and A computational analysis based feasibility study was conducted to explain the working mechanism of a transverse Peltier cooler constructed out of a meta-material. This meta-material is comprised of alternating tilted layers of n-Bi2Te3 and Pb. From an engineering standpoint, this finding is promising since it opens up the opportunity to develop large DT devices for cryogenic applications without multi-stage cascading [8].

C. An Analysis on a Two-Stage Cascade Thermoelectric Cooler for Electronics Cooling Applications:
This paper offers a comprehensive analysis of a novel two-stage cascade thermoelectric cooler (TTEC). The novel TTEC may be simply designed by joining short-legged thermoelectric couples in cascade, which has advantages of no requirement of interstate electrical insulating materials, easy fabricated and compact structure, and using only one operating power. An analytical model considering the distribution of the total input current between the two stages of the TTEC is created and the performance characteristics are examined in detail. Especially, the allocation ratio of the leg length of thermoelectric couple which maximizes the TTEC COP at a specified condition are explain. The analysis results indicate that such a cascade TTEC can significantly improve the operating temperature gradient and be in theory better than a single-stage thermoelectric cooler under most circumstances. It is also shown that the allocation ratio of thermoelectric couple leg length plays an vital role in determining TTEC thermal performance. Overall, the presented TTEC may use in the future to electronics cooling applications the objective of the present study is to demonstrate a possible two-stage cascade thermoelectric cooler (TTEC) for electronic devices cooling applications which has no interstate electrical insulating materials and need only one power to operate.[10]

Application of multistage or cascaded TECs has been widely investigated developed a cascade TEC model with respect of interstate thermal resistance. They found that the losses at interstate thermal resistance can dominate over other types of losses and the optimization on the interstate substrate authenticate to receive considerable increase in TEC efficiency [11,12]. A two-stage cascade TEC is presented and the corresponding analytical model is developed. The presented TTEC has a more compact structure and may be simply fabricated. Similar to conventional pyramid-styled two-stage TEC, the presented TTEC can also provide a relatively high temperature difference. For the case of leg length division, on the other hand, a smaller l provides a relatively lower Tm and then results in greater operating temperature difference and cooling capacity.

D. A Numerical Study on the Performance of Miniature Thermoelectric Cooler Affected By Thomson Effect:
Miniature thermoelectric cooler (TEC) is considered as a promising device to achieve effective cooling in small scale equipments electronics devices and microprocessors. To understand the performances of miniature TEC, we analysed three different thermoelectric cooling modules through a three-dimensional numerical simulation. Particular attention is given to the influence of scaling and Thomson effect on the cooling performance. The temperature differences of 0 and 10 K between the top and the bottom copper interconnectors are taken. In addition, three different modules of TEC, consisting of 40, 20 and 8 pairs of TEC, are studied where a single TEC length decreases from 500 to 100 lm with the situation of fixed ratio of cross-sectional area to length. It can be seen that when the number of pairs of TEC in a module is raised from 8 to 40, the cooling power of the module raises drastically,
revealing that the miniature TEC is a desirable device to attain thermoelectric cooling with high performance. The obtained results also suggest that the cooling power of a thermoelectric module with Thomson effect can be improved by a factor of 5–7%, and the higher the number of pairs of TEC, better the improvement of the Thomson effect on the cooling power.[13]

E. Development of an Energy-Saving Module via Combination of Solar Cells and Thermoelectric Coolers for Green Building Applications:

In this paper a solar-driven thermoelectric cooling module with a waste heat regeneration unit designed for green building applications is investigated. The waste heat regeneration unit consisting of two parallel copper plates and a water channel with staggered fins is connected between the solar cells and the thermoelectric cooler. The useless solar energy from the heat dissipated from the thermoelectric cooler and solar cells can both be removed by the cooling water such that the performance of the cooling module is raised. Moreover, it makes engineering sense to take advantage of the hot water produced by the waste heat regeneration unit during the daytime. Experiments are conducted to investigating the cooling efficiency of the module. Results indicate that the performance of the combined module is enhance by increasing the flow rate of the cooling water flowing into the heat regeneration water channel due to the reductions of the hot side temperature and the solar cell temperature of the thermoelectric coolers. The combined module is tested in the applications of a model house. It is found that the present approach is able to produce a difference of 16.2 °C between the ambient temperature and the air temperature in the model house [14].

Advantage of this technology is that the waste heat rejected by the solar cell and the thermoelectric cooler is utilized for water heating. Therefore, both demands, the air-conditioning and the water heating is to be satisfied without consuming any electricity provided from the external source.


Global warming and Energy crisis have become more and more serious problem with the social development. Since buildings account for a significant amount of the total energy consumption and carbon emissions, it is very necessary and urgent to decrease building energy consumption. About 30% of energy consumption in China 40% in USA and 20–40% in developed countries is consumed in buildings [15,16]. Minimizing the need for energy use in buildings through energy-efficient measures and consuming renewable energy are the basic strategies. Zero energy buildings, which only consume solar energy and other renewable energies, have been considered as one of the solution and have drawn more and more attention in recent years. Solar thermoelectric cooling technologies can be driven directly by a photovoltaic (PV) and cause no harm to the environment, which fully fulfil the need of ZEBS. This paper reviews solar thermoelectric cooling technologies and proposes a technical ways of solar thermoelectric cooling technologies for use in zero energy buildings. It can be seen that solar thermoelectric cooling systems can reducing the energy demands, increase energy effectiveness and reduce fossil energy consumption in buildings. With the thermoelectric and PV industry’s development along with the advent of new materials, the solar thermoelectric cooling technologies for use in zero energy buildings are promising [17].

G. Characterization of a Thermoelectric Cooler Based Thermal Management System under Different Operating Conditions:

The behaviour of a thermoelectric cooler (TEC) based thermal management system for an electronic packaging design that operates under the ambient condition and system loads are examined using a standard model for the TEC. By the Experiments, it was found that the model predictions were in good with the experimental results. An operating module is developed to describe the TEC based thermal management system for peak and off peak operating conditions. Study of parameter were performed to analyse the influence of the number of TEC module(s) in the system, geometric factor of the thermal elements and the thermal resistances of cold to hot side on the system performance. The results showed that there is a trade-off between the extent of off peak heat fluxes and ambient temperatures when the system can be operated at maximum capacity and the low power penalty region of the system [18] TECs also have advantage in thermal management uses at elevated ambient temperatures due to the reduced driving temperature potential for heat transfer under these conditions. The maximum output capacity at these conditions can be found using models for the TECs [19,20]. A thermal management system using a thermal resistance network model incorporating TEC modules was used to examine the behaviour of TEC based thermal management systems at off peak conditions. The case of a thermal management system for a sealed computer working at a range of heat loads and ambient temperatures Or (T_{design}–T_∞) was considered. Experiments were performed to find out the typical properties of the components and to validate the model predictions [18].

H. Distributed Control of Thermoelectric Coolers:

Thermoelectric refrigeration has been studied for use in electronics cooling applications. Because of its low efficiency, a significant amount of additional heat is produced that must be removed from the device by other means. However, even well designed passive heat removal systems are faced with physical limitations and cannot dissipate all the additional energy. Therefore, thermoelectric coolers often are not a viable alternative to chip cooling. In distributed control the individual devices operate based on their local condition and that of their nearest neighbours. With this approach a more number of sensors and actuators can be bundled with minimal compute power and communication. In the case of electronics cooling, a thermoelectric cooler can be constructed as many separate coolers, each with its own thermocouple and control system. With this
architecture, only those regions that generate heat will be cooled thermoelectrically reducing the force on the heat removal system and increasing the viability of thermoelectric coolers. Through analytic TEC heat models, the present work seeks to estimate the possibility of using distributed controlled thermoelectric coolers for cooling of microelectronics applications. Results indicate that TEC coolers can provide a two-fold increase in efficiency when distributed control is used for non-uniformly heated chips [22].

The results indicate that a distributed controlled thermoelectric cooler could provide better performance in realistic situations when heating is localized compared to standard devices, which are all on or all off. Further, the results indicate that as the heating load becomes more localized, the performance increases. Even though the analysis indicates that standard TEC coolers can provide enhanced performance, the gains are modest and distributed controlled TECs can provide much better overall performance.

IV. Current research on thermoelectric coolers

Material Researches of Thermoelectric:
The TE materials can be classified into 3 categories: polymers, semiconductors and ceramics and. Recently, certain polymers, i.e. Ethylenedioxythiophene, carbon fibre polymer-matrix structural composites, shown to have the interesting thermoelectric material properties [23].

1) Semiconductor:
Semiconductor materials are capable for the construction of thermocouples because they have large SEEBECK coefficients in excess of 100 lv/C, and one proper way to reduce j without affecting a and s in bulk materials, thereby increasing ZT, is to use semiconductors for its high atomic weight, such as Bi₂Te₃ and its alloys with Pb, Sb, and Sn. Due to the high molecular weight, speed of sound reduces in the material and thereby decreases the thermal conductivity. The best-ZT materials are heavily doped, small band gap semiconductors. The intermetallic compounds such as Mg₂X(X = Si, Ge, Sn) (the figure of merit, ZT, for Mg₂Si is 0.86 at 862 K) [24]. And their solid solutions are semiconductors passes the antifluorite structure and have been proposed to be Good applicants for high-performance thermoelectric materials, because of their superior characteristics such as large SEEBECK coefficient, low electrical resistivity, and low thermal conductivity. The highest ZT for Bi₂Te₃ and its dopant has been reported to be2.4 in p type Bi₂Te₃/Sb₂Te₃ As mentioned earlier, lowering the thermal conductivity can improve the ZT. Pei et al. Have found that Ca-doped biceuso can intrinsically low thermal conductivity thus enhance the ZT _ 0.9at 923 K for Bi0.925Ca0.075cuseo [25]. The ZT of 2.6 ± 0.3 at 923 K, for SnSe single crystals measured along the b axis of the room-temperature orthorhombic unit cell. The reason for that is possibly the intrinsically very low lattice thermal conductivity in SnSe along the b axis [26].

2) Ceramics:
TE materials in practical applications are always depend on alloy materials, such as SiGe and Bi₂Te₃. In comparison with TE alloys, metal oxides have advantage of better chemical stability, oxidation resistance, less toxic and low cost, so their use makes the fabrication of more durable devices [27]. Ceramic is an important Thermoelectric material for thermoelectric energy conversion to recover high-temperature waste heat from incinerators or combustion engines Now cobalt-based oxides, such as Ca₃CoO₉, naco₂or, have been fabricated as p-type legs in TE modulus. As a counterpart, n-type Sr₂O₃, zno and cassio3 ceramics have also been studied. Among them, cassio3 can be synthesized in ambient atmospheric condition and shows excellent TE properties, which make the cassio3 a prospective candidate as n-type oxide TE material Cadmium oxide (cdo) is an n-type semiconductor is widely used as a transparent conductor material. Moreover, it is known that the electrical conductivity can increase by doping of Sb205 in SnO2. Wang et al [28] have investigated the effect of ytterbium doping on the thermoelectric Properties of LaO.1Sr0.9tio3 ceramics at the temperature range between 300 and 1000 K. The results show that the highest figure of merit of 0.20 is obtained at 963 K[28]. Tsunobota et al [29] have investigated thermoelectric properties of laaco3 ceramics with B₂O₃–CUO addition. The results show that material has maximum value of ZT = 0.073 at 373 K, which was about 1.5 times higher than that of pure laaco3 sintered at 1473 K. Which indicates that the addition of B₂O₃–CUO could concurrently lower the sintering temperature and improve the thermoelectric properties of laaco3ceramics.

3) Polymers:
The widely investigated, developed and used inorganic thermoelectric materials involve issues such as toxicity, a shortage of natural resources, and difficult manufacturing processes with high cost. Thus it is of great importance to develop or find new types of materials with improving their properties. The conductive polymers is combinations of family containing insulating polymer matrices and conducting fillers have been studied for its advantages of mechanical flexibility, low-cost synthesis, solution process ability, inexpensive, lightweight, and more environmentally friendly alternatives to common thermoelectric devices. Wang et al Have the thermoelectric behaviour of segregated conductive polymer composites with hybrid fillers of bismuth telluride and carbon nanotube and. The results show that the segregated composite containing 2.6 vol% cnts and 5.1 vol%

Bi₂Te₃ exhibit the thermoelectric figure of merit ZT = 3 _ 10_5 at room temperature Wang et al. have investigated thermoelectric properties of polythiophene/multiwalled carbon nanotube composites. The results show that the highest ZT of 8.71 _ 10_4 at 393 K was found in the composite with80 wt.% multiwall carbon nanotube. However, recently there is great advance in the ZT of polymers the disadvantages for semiconductors are that it cannot stand the high temperature and lack of flexibility. Thus polymers and ceramics are good supplementary [30,31,32].
V. CONCLUSION

This paper is focused mainly on thermoelectric cooler and different technologies which are used on thermoelectric cooler. It includes how thermoelectricity is better than other solar based technology to make electricity. But there is a drawback of thermoelectric cooler of its low efficiency or low figure of merit. In this review, different methods are presented to obtain a higher satisfactory efficiency. There is easy solution to gain this higher efficiency with the help of material changing properties includes how thermoelectricity is better than other solar based technology to make electricity. But there is a drawback of

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