A Re-Review of Thermoeletric Module

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ABSTRACT

In 21st century there are major two problem energy shortage and environmental defects. Thermoelectric cooler is the best solution for those two problems. This review is explaining about basic concept of thermoelectric and thermoelectric generator, including the structure optimization which significantly affects the thermoelectric generator, the low temperature recovery, the heat resource and itsapplication area. Then it reports the recent application of the thermoelectric cooler including the thermoelectricmodel and its application area. It ends with the discussion of the further research direction.

Keywords*: Cooling system, Peltier effect, Thermoelectric cooler.*

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1. INTRODUCTION

Extensive fossil fuel consumption by human activities has led toserious atmospheric and environmental problems. Consequently,global warming, greenhouse gas emission, climate change, ozonelayer depletion and acid rain terminologies have started to appearfrequently in the literature. To abate the impact of the above disasters,the thermoelectric (TE) energy converters is proposed as oneof the possible technologies for this aim, which currently gains themost popularity owing to its capability in converting the heat givenoff from vehicles, electrical instruments, etc., into the electricity[1].

In 1823, a German scientist Thomas Seeback discovered that, in a closed circuit made up of two dissimilar metals an electric current is generated continuously provided that both the junctions of the metals were maintained at different temperatures. After some years in 1834, a French watchmaker,Jean Charles Athanase Peltier (1785-1845) discovered thermoelectric cooling effect which is also known as Peltier effect. Who discovered that when an electric current is passed through junction who is made up of two dissimilar metals, then one side of the junction becomes hot while the other end of the junction becomes cold. By changing the polarities of electric current supplied the hot side becomes cold while the cold side becomes hot. After four years in 1838, Emil Lenz made clear about the true nature of Peltier effect by placing a bismuth-antimony junction to freeze the water by passing of an electric current through the junction.He also observed that the ice could be melt if the current was reversed. In 1950’s, Bismuth-Telluride replaced bismuth-antimony and began to be used as the primary material in the thermoelectric cooling.

Thermoelectric (TE) property was discovered earlier about two centuries but (Thermoelectric cooler) TEC was commercialized in recent years. The applications of TE ranges from small sized devices like refrigerators and electronic devices to big sized devices like Avionic instrumentation illumination control and thermal imaging cameras. Recently there is a tremendous increase in the applications of TE coolers in water chillers, medical chillers, semiconductor chillers, food and beverage chillers, etc.[16].

2. WORKING PRINCIPLE

TEC works on the principle of Peltier effect, when a DC is supplied from a 12V battery to TEC module then, heat is absorbed at one junction and dissipated at the other junction. Depending on the direction of applied DC power source and the relative Seeback coefficient of the two materials, the direction of the heat flow is regulated. TEC can be used either for heating or for cooling, while the main application is cooling. TEC module is a solid-state active heat pump which contains number of p- and n- type semi-conductor which are coupled in series and sandwiched between two thermally conductive and electrically insulated ceramic substrate. The main advantages of a TEC compared to a vapor-compression refrigerator are its lack of moving parts or circulating refrigerants, flexible shape, invulnerability to potential leaks and its smaller size. The "hot" side is attached to a water cooled heat sink so that it remains at ambient temperature, while the “cold” side goes below room temperature. Multiple coolers can be cascaded together for lower temperature for some applications.

There are various thermoelectric materials which include Lead Telluride (Pb-Te), Silicon Germanium (Si-Ge), Bismuth-Antimony (Bi-Sb) and Bismuth Telluride (Bi-Te) alloys that may be used according to the situations. Conventional R&AC system uses refrigerant to carry the heat from refrigerated space while TEC uses electrons rather than refrigerant as a carrier of heat. TEC is the emerging green R&AC technology which can be used to couple with Solar PV cell generated DC power, which makes them complete environmental friendly [16].

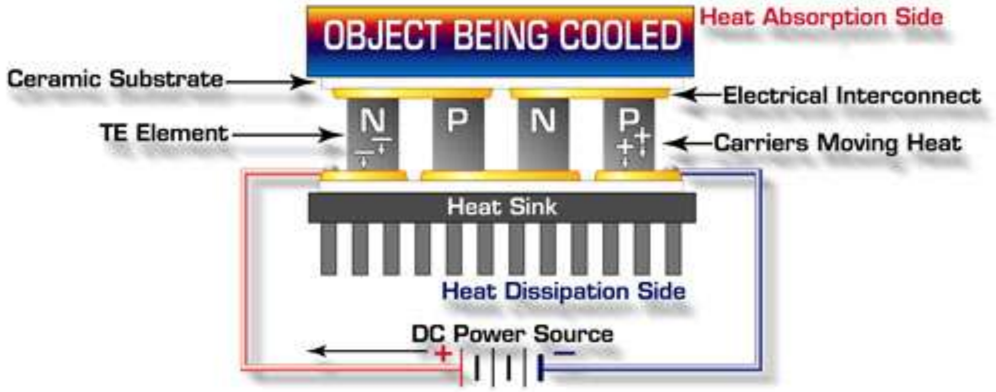

Fig-1: Working principle of TEC module [16].

Seebeck effect was found in 1821 which disclosed that two joint dissimilar metals have the different temperatures (DT) at the joints, and the corresponding current and electromotive force existing in the joint circuit are called the thermo-current and thermo-electromotive force. Increasing the voltage difference (ΔV) enlarges the temperature difference between two joints (ΔT). The proportional constant related to the intrinsic property of the material is known as the Seebeck coefficient. This coefficient is relatively low for materials like metals at approximately 0μV/K, while it would be much larger at around ±200 μV/K for thesemiconductor[1].

$$\alpha = \Delta V/\Delta T \qquad (1)$$

Peltier effect, which was discovered in 1834, is the phenomena that when there is the current in the circuit, the joint of different conductors absorbs or rejects the heat depending on the direction of the current. This phenomenon is largely due to the difference of the Fermi energies between two materials. The capacity of the heat absorption or rejection is largely related to the property of the twodissimilar conductors and the temperature of the joint. When defining the heat absorbed in per area of the joint per second, a dimensionless parameter, ZT, is usually used to determine the Peltier performance of a thermoelectric material.

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3. MATERIAL RESEARCHES OF THERMOELECTRIC

The TE materials can be classified into 3 catalogues: semiconductors,ceramics and polymers. Recently, certain polymers, i.e. ethylenedioxythiophene,carbon fiber polymer-matrix structuralcomposites, have also been shown to exhibit interesting thermoelectric material properties[1].

3.1. Semiconductor

Semiconductor materials are promising for the construction ofthermocouples because they have large Seebeck coefficients inexcess of 100 µV/◦C, and one proper way to reduce j withoutaffecting a and s in bulk materials, thereby increasing ZT, is touse semiconductors for its high atomic weight, such as $Bi_2Te_3$and its alloys with Sb, Sn, and Pb. A high atomic weight reducesthe speed of sound in the material and thereby decreases the thermalconductivity. A solid state or semiconductor electronics component,for example, can perform well and reliably for manyyears when it is operating at or near the ambient temperature.The best-ZT materials are found to be heavily doped, small bandgapsemiconductors. The intermetallic compounds such as Mg_2X(X = Si, Ge, Sn) (the figure of merit, ZT, for Mg_2Si is 0.86 at 862 K. And their solid solutions are semiconductors having theantifluorite structure and have been proposed to be good candidatesfor high-performance thermoelectric materials, because oftheir superior features such as its large Seebeck coefficient, lowelectrical resistivity, and low thermal conductivity.The highest ZT for Bi_2Te_3 and its dopant has been reported to be2.4 in p type Bi_2Te_3/Sb_2Te_3 super lattices at 300 K by growing phononblocking electron transmitting hetero-structures by the lowtemperature metal organic chemical vapour deposition (MOCVD) technique. Pei et al. have found that the transport propertiesof PbTe alloyed with MnTe result in a ZT as high as 1.6 at 700 Kwhich can be explained by alloy scattering and multiple bandmodel, as shown in Fig. 3.As mentioned before, lowering the thermal conductivity canenhance the ZT. Pei et al. have founded that Ca-doped BiCuSeOcan intrinsically low thermal conductivity thus boost the ZT- 0.9at 923 K for $Bi_{0.925}Ca_{0.075}CuSeO$. Rhyee et al. have discoveredthat the binary crystalline n-type material, In4Se3_r have the ZTvalue of 1.48 at 705 K, which is the result of the high Seebeck coefficientand the low thermal conductivity in the plane of the chargedensity wave.

J. de Booret. Al.[5] have investigate that material magnesium alloy have different characteristics than can help in thermoelectric module. In this section we want to give an overview over the elements that have been successfully employed to p-dope Mg_2X. The optimizationof the carrier concentration is a fundamental prerequisitefor good thermoelectric properties and one of the fundamentaloptimization parameters for any thermoelectric material. For P-typeMg_2X the issue is of particular importance: first, the experimentalrealization of samples with sufficient number of chargecarriers has been proven to be difficult, often leading to sampleswith too low p and hence un-optimized thermoelectric properties, Secondly, the choice of the dopant might influence thematerial properties more than for the n-type material. For the n-typematerial the most popular dopants Sb and Bi seem to obey therigid band picture, i.e., addition of dopants shifts the chemicalpotential of the electrons and enhances the number of chargecarriers but the band structure itself remains unaffected. Disregardingsmall differences in carrier mobility and lattice thermalconductivity the choice of the dopant does not significantly influencethe thermoelectric properties. This has been confirmedexperimentally for Sb and Bi for n-type Mg_2X where zT> 1:2 hasbeen found for both dopants. For the p-type it has been argued repeatedlythat the rigid band model is not applicable for all dopants. In thiscase the choice of dopant is naturally of utmost importance for theoptimization of the thermoelectric material.

3.2. Ceramics

TE materials in practical applications are always based on alloy materials, such as SiGe and Bi_2Te_3. In comparison with TE alloys, metal oxides have advantages in better chemical stability, oxidation resistance, less toxic and low cost, so their use enables the fabrication of more durable devices. Ceramic is an important thermoelectric material for thermoelectric energy conversion to retrieve high-temperature waste heat from incinerators or combustion engines. However, oxides had not been considered to be candidates as TE materials due to their low carrier mobility, until the high performance TE oxide of $Na_xCo_2O_4$appeared [1]. Now cobalt-based oxides, such as $Ca_3Co_4O_9$, $NaCo_2O_4$, have been fabricated as p-type legs in TE modulus. As a counterpart, n-type $SrTiO_3$,ZnO and $CaMnO_3$ ceramics have also been studied. Among them, $CaMnO_3$ can be synthesized in ambient atmospheric conditionand shows excellent TE properties, which make the $CaMnO_3$ a prospectivecandidate as n-type oxide TE material. Comparedwith their p-type counterparts, most n-type oxide TE materialsare inferior due to their high thermal conductivities. Up tonow, several n-type oxide materials such as $SrTiO_3$, $CaMnO_3$ andZnO have been reported having good thermoelectric properties. Cadmium oxide (CdO) is an n-type semiconductor that iswidely used as a transparent conductive material [13]. NonstoichiometricCdO usually exhibits very good electrical conductivity dueto the native defects of oxygen vacancies and Cd interstitials, andits resistivity can be further decreased by appropriate doping withhigh-valence elements, such as rare-earth elements. The conductiontype of SnO_2 is n-type. Moreover, it is known that the dopingof Sb_2O_5 in SnO_2 can increase the electrical conductivity. Thecarrier mobility of SnO2 is known to be as large as oxide material. Wang et al have studied the high-temperature thermoelectricproperties of $Cd_{1-x}Pr_xO$ceramics. The results show thatthe dimensionless figure-of-merit ZT of the 0.1% Pr-doped CdOsample reaches 0.38 at about 1000 K. Zhu et al have studiedthe TE properties of CaMnO3 ceramics doped by Lanthanides andother rare-earth elements the results show that the optimizeddopants were found and the highest ZT of 0.20 can be achievedwith the substitution of either Dy or Yb. A suitable dual-dopingresults in a remarkable increase of figure of merit. The highestZT = 0.21 at 973 K is obtained for $Ca_{0.96}Dy_{0.02}Bi_{0.02}MnO_3$[1].

3.3. Polymers

The widely investigated, developed and used inorganic thermoelectricmaterials involve issues such as toxicity, a shortage of naturalresources, and complicated manufacturing processes withhigh cost. Thus it is of great importance to develop or find newtypes of materials to further improve their properties. The conductive polymer composites family containing insulating polymermatrices and conducting fillers have been studied for itsadvantages of mechanical flexibility, low-cost synthesis, solutionprocessability, inexpensive, lightweight, and more environmentallyfriendly alternatives to common thermoelectric devices. Wang et al have investigated the thermoelectric behaviour ofsegregated conductive polymer composites with hybrid fillers ofcarbon nanotube and bismuth telluride

Table 1
The value of ZT of the Bi–Te based material [1][9].

Authors	Published year	Material	ZT	Temperature (K)
Jong Gil Park	2016	P-$Bi_{0.5}Sb_{1.5}Te_3$ N-Bi_2Te_3	0.86 0.52	325 473
Wei Zhu	2015	P-$Bi_{0.5}Sb_{1.5}Te_3$/ N-$Bi_2Te_{2.7}Se_{0.3}$	2.2	915
Ming Tan [24]	2014	$Bi_2Se_{0.5}Te_{2.5}$	1.28	Roomtemperature
Y.H. Yeo [25]	2014	$(Bi,Sb)_2Te_3$	1.41	Room temperature
Ming Ma [26]	2014	$Bi_2Te_{2.7}Se_{0.3}$	1.27	Room temperature
Z. Chen [27]	2014	$Bi_{0.4}Sb_{1.6}Te_3$	1.26	Room temperature
Xi'an Fan [28]	2014	p-type $(Bi,Sb)_2Te_3$ Thermoelectric material	1.17	323
Ming Tan [29]	2014	$Bi_2 (Te,Se)_3$	1.01	Room temperature
ZhijunXu [30]	2012	P-type $(Bi_{0.26}Sb_{0.74})_2Te_3$ + 3%Te ingots	1.12	Room temperature
J. Seo et al. [38]	1997	Bi_2Te_3	1.62	693
Jun-HoSeo et al. [39]	1996	$Bi_2Te_{2.85}Se_{0.15}$	1.86	93
Venkatasubramanian et al. [5]	2001	p type Bi_2Te_3/Sb_2Te_3	2.4	300

4. TE APPLICATION

The thermoelectric effect can convert heat to electricity, etc.vice versa. Thus the TE applications are mainly based on thosetwo aspects by either converting heat to electricity (TEG) [13] or convertingelectricity to heat (TEC).

4.1. TEG

TEG can directly converse the heat to the electricity with solidstate which makes it adaptable in many areas from the space nuclearauxiliary power (SNAP) program applied for space and the militaryuse to the building and the automobile daily commonly used stuffs.And the heat sources for TEG are also various from solar, biomassand the earth. It should be point out that the temperature rangesfor TEG recently are relative low. The higher the temperature is,the less competitive the TEG is. It is true that the conversion efficiencyof the TEG is rather small because of the material properties.However, the efficiency can be improved by enhancing the intrinsic of the TE material which has been discussed early and optimizingthe structure of the TEG.

Niu et al have investigated the TEG with the parallel-plate heat exchanger.The results show that the hot fluid inlet temperature and flowrate significantly all affect the maximum power output and conversionefficiency. Karabetoglu et al have investigated thecharacterization of a commercially available and the cheapest versionsBi2Te3 based TEG at low temperatures in the temperaturerange of 100–375 K.In the experiment, two parameter Seebeck coefficient and electricalconductivity of a Bi_2Te_3 based TEG are examined. Fig.6 isdimensionless maximum power output vs. mean temperature for$\Delta T = 200$ K. The result shows that 250 K seems a critical meanoperating temperature for the considered Bi_2Te_3 module.The results also give correlations for temperature dependencyof material quantities in the temperature region of 100–375 K. Lesage et al have studied a forty Bismuth Telluride basedmodule TE liquid-to-liquid generator which is optimized for thepeak power output via changing the electrical load resistance

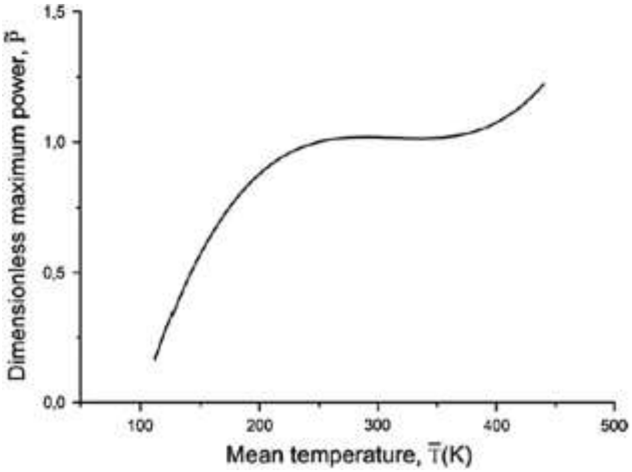


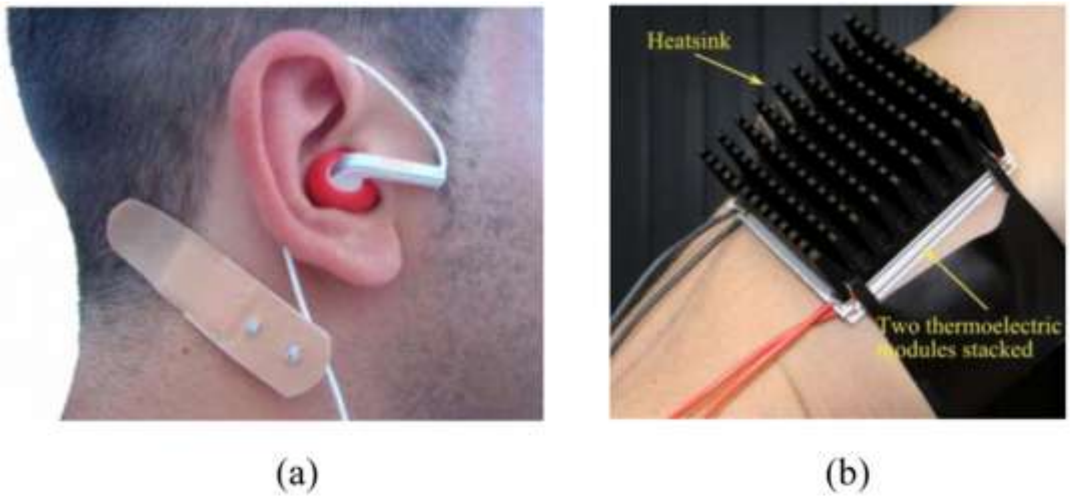
Fig.2. Dimensionless maximum power output vs. mean temperature for $\Delta T = 200$ K [1].

Abu Raihan Mohammad Siddiqueet. al have discuss about wearable power generators are one of the more recent technological advancements in the field of portable electronics. Wearable TEGsuse the temperature difference between any living body and surroundingenvironment to harvest energy and convert it to useful electrical output. The core temperature of a human body varies from 28 °Cto 37 °C with a change in the room temperature from 0 °C to 35 °C. Moreover, the heat flow varies from 50 to 150 Wm-2 duringregular activities of the body. Wearable TEGs can theoreticallygenerate a maximum of 180 µWcm-2 power from skin (considered skintemperature and heat flow are 34 °C and 20mW cm-2, respectively) at 22 °C ambient temperature. Table 2 presents the power generationcapabilities of different parts of the human body.

Table 2
Possible capabilities of harvesting power from human body parts [12].

Body part Power generation	(mW)
Forehead	2.3–27.6
Chest	3.1–36.6
Arm	1.7–20.2
Forearm	1.3–16.1
Abdomen	3.1–36.6
Thigh	2.4–28.8
Foot	2.1–25.2

One growing area of application for TEGS is for powering biomedicaldevices using body heat. Mitcheson et al reported that a TEGwas more suitable than a motion energy harvester for bio-sensors sincethe power density of a TEG harvester was 20μW cm^{-3}, while10μW cm^{-3} for the motion energy harvester used during walking andrunning3. Yang et al investigated the use of TEGs to powerimplantable medical device (IMD). Different thermal conditions of apatient (e.g. environmental and physical) were investigated and theresults indicated that close to the skin surface was the best part of thehuman body to harvest power [14]. In another application study, Ekuakilleet alconcluded that a TEG could be used to provide sufficientenergy for a hearing aid device. An additional powermanagement circuit and battery were used as a backup power source.In the interest of improving the efficiency of a TEG at lower bodytemperatures, Udalagama et alused resonance and voltage set uptechniques to increase the power harvesting capability of the system. ADC-DC boost converter was used as a setup transformer in the powermanagement circuit (also used by Lossec et al. in their powermanagement circuit). A new parameter ZE, which depends on thephysical properties of materials, was used to optimize the power outputof the TEG during poor thermal coupling [14]. An additional heat sinkwas attached to the TEG to increase the productivity of the TEG asshown in Fig. 3(b).Different thermoelectric materials (e.g. bismuth telluride), havebeen investigated by Funahashi et al who used $Ni_{0.9}Mo_{0.1}$ for then-type and $La_{0.035}Sr_{0.965}TiO_3$ for the p-type for fabricating theirprototype generator. An $Y_{0.03}Zr_{0.97}O_2$ insulator was placed betweenthe n-type and the p-type elements. Multilayer co-fired ceramictechnology was used for fabricating the generator. At a 10 °C temperaturedifference, the prototype (see Fig. 3(a)) produced 100 μW which issufficient for powering a radio transmitter [12].



(a) (b)

Fig.3. A hearing aid powered by a TEG. (b) Fin was attached to the cold surface of the module (two TEG modules were connected in series) to harvest energy from hand [12].

4.2 TEC

TEC, compared to the traditional refrigeration or heat supplying devices, has many advantages such as solid-state, no vibration, simplicity and environmentally friendly. TEC models and its application areas are discussed. It is easy to discover that the main disadvantage of the TEC is its low efficiency, which causes its limitation in commercial application. Thus, the optimization of the TEG models has been done to maximum the COP.

Raghied Mohammed Atta has investigated about newsystemSolar-driven Thermoelectric Dehumidifiers:Anadditional key concern water scarcity is the waterconsumption during energy generation. Solar energy hasthe distinct advantage of low water consumption duringits use-phase, making it ideal for installation inlocations that have a highly variable or scarce freshwatersupply. However, close attention was not paid to solarrefrigeration until the energy crisis in 1970s..Research in a Peltier’s cooling effect integrated withPhotovoltaic (PV) also developed around that time,primarily for the cold chain project of the World HealthOrganization and the international Health Organizationsspecifically for rural areas. Solar cells were used topower small TE operated fridges [15]. Experimentalinvestigation and relevant analysis on a solar cell driven,thermoelectric refrigerator has been conducted.The main components of the solar PV/batterythermoelectric dehumidifying system are the PV cell(including the PV array, the storage battery and thecontroller), the thermoelectric refrigeration system andthe cooled object (e.g., a cooling box). The PV array isinstalled outdoors and the storage battery stores theexcess electricity produced during sunshine periods. Thisstored energy is used for running the system during the

The technique used in the assembly of a TE system is as important as the selection of the properdevice. It is imperative to keep in mind the purpose of theassembly, namely to move heat. All of the mechanicalinterfaces between the objects to be cooled and ambientare also thermal interfaces.Similarly all thermal interfaces tend to inhibit the flowof heat or add thermal resistance. Again, whenconsidering assembly techniques every reasonable effortshould be made to minimize thermal resistance.Mechanical tolerances for heat exchanger surfaces shouldnot exceed 0.001 in/in with a maximum of 0.003" TotalIndicated Reading. If it is necessary to use more than onemodule between common plates, then the height variationbetween modules should not exceed 0.001" (requesttolerance lapped modules when ordering). Most TEassemblies utilize one or more "thermal grease" interfaces.The grease thickness should be held to 0.001 ± 0.0005".When these types of tolerances are to be held, a certainlevel of cleanliness must be maintained. Dirt, grit andgrime should be minimized; this is very important when"grease" joints are utilized due to their affinity for these types of contaminants [15].

5. CONCLUSION

The thermoelectric technology can be used in globally for energy conservation without any pollution. Theresearch reviewed on thermoelectric module of existing work shows potential,theory, material, model, energy resources, construction and applicationsfor electricity generation and cooling. Some appropriateresearch directions were further proposed by authors [1]

- TE potential in current electricity generation and cooling.The TE technology can be applied in many areas, althoughrecently it is still utilized in niche fields such as out-spacemission and distant area. With the increase of the figure ofmerit and advancement in the devices, it can be applied inthe domestic building as air conditioner and the power generator.It can also be applied to the areas where the temperatureof the waste heat is relatively low. In those areas thetraditional generator is low efficient and cost relatively high.Another potential field is self-cooling system, especiallyfairly small device where TEC compared to the traditionalcooler has many unique advantages.
- For the structure of the TEG and TEC, with the optimizationof the TEG devices for wood stove, the output power graduallygrows from 1W per module in 2003 to 9W per module in 2014. Thus the priority for efficiency of TE devices is tooptimize the influence of heat exchange.
- For TEG, the temperature plays a significant role for TEGapplication. The low temperaturerecovery especially converting the waste heat to the electricityis feasible. The efficiency of the low temperature devicesis among 1% and 2%. For TEC, the COP is a significant parameterto evaluate the performance of the cooler. The COP isgenerally among 1 and 2 when the temperature is between313 K and 293 K. And theoretical COP for ZT = 2.4 at the same temperature is 3.97. There is still improvement forthe device to gain better performance [1].
- In recent work from 2015 to 2017 that explaining new thing than can introduce to increase its application and improve its performance.

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