Improvement In The COP Of Thermoelectric Cooler

Jatin Patel, Matik Patel, Jigar Patel, Himanshu Modi

Abstract: This paper described the study for heat transfer through thermoelectric cooler (TEC) by use of multistage thermoelectric module. To satisfy the heat dissipation of modern electronic element, thermal designers have to increase fin area and fan speed to improve its cooling capacity. However, the increase of fin area is restricted by the space. Besides, the increase of fan speed would induce noise, which damages human health. So air cooling by fan is hardly to meet the requirement of modern electronic component. Recently, thermoelectric cooler (TEC) is applied to electronic cooling with the advantages of small size, quietness and reliability. A typical thermoelectric cooler consists of p-type and n-type semiconductor pellets connected electrically in series and sandwiched between two ceramic substrates. Whenever direct current passes through the circuit, it causes temperature differential between TEC sides. As a result, one face of TEC, which is called cold side, will be cooled while its opposite face, which is called hot side, is simultaneously heated. The main problem over the use of TEC is the limited COP and its thermal performance. But these can be eliminated by use of multistage thermoelectric cooler.

Keywords: Thermoelectric cooler, TEC, thermoelectric cooling, heat sink, peltier effect

1 INTRODUCTION

Thermoelectric cooling, also called "The Peltier Cooling" is a solid-state method of heat transfer through dissimilar semiconductor materials. Coefficient of performance for thermoelectric cooling system are discussed here with single stage thermoelectric module and multi-stage thermoelectric module. TECs inherently have many advantages over the alternate types of refrigeration. TECs are solid-state, so they have no moving parts. Because they have no moving parts, their reliability greatly exceeds any other refrigeration technology currently being considered. Also, TECs are compact and quiet. TECs have no operating fluid or gas that can leak and damage the electronics or the environment TECs are compact, lightweight, and relatively inexpensive. TECs appear to be the most desirable cooling alternative; however, TECs still have the efficiency problem that reduces their applicability. Recent studies about TEC mostly emphasize on improving the COP of TEC and developing mathematical model. Few research studies the thermal performance of a cooling module which involves TEC. Figure 1 shows the entire fabrication of thermoelectric cooling system and according to the requirement optimum changes are carried out on the system to get the best thermal performance. The general measure of efficiency of a TEC is based on the amount of heat that it removes compared to the amount of work that it requires. This value is referred to as coefficient of performance, COP.

$$COP=\frac{Qc}{Win}$$

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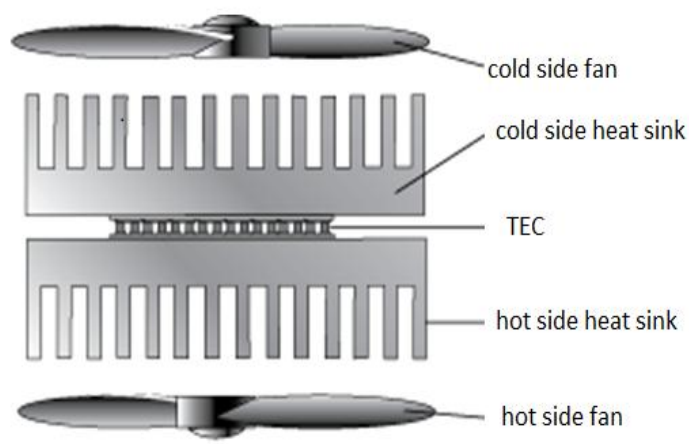

Figure 1: *Configuration of thermoelectric cooler*

The heat extracted from the source is also referred to as the cooling power and its magnitude is of critical importance. The cooler can be operated for maximum COP or for maximum cooling power depending on the electrical current. Recent material improvements have resulted in the improvement in the performance of the thermoelectric module, but it is not at such level that thermoelectric module can be utilize at domestic and industrial level. And our problem with the current material improvements, is may require years to become fully implemented into industry. One alternative approach that can be considered is a method to use a thermoelectric system which COP is high.

2 CONSTRUCTION

The typical thermoelectric module is manufactured using two thin small ceramic plates with a series of P and N doped bismuth-telluride semiconductor material, sandwiched between them. The ceramic material on both sides of the thermoelectric adds rigidity and the necessary electrical insulation. The N type material has an excess of electrons, while the P type material has a .deficit of electrons. One P and one N make up a couple. The thermoelectric couples are electrically in series and thermally in parallel. A thermoelectric module can contain one to several hundred couples. As the electrons move from the P type material to the N type material through an electrical connector, the electrons jump to a higher energy state absorbing thermal energy (cold side). Continuing through the lattice of material, the electrons flow from the N type material to the P type material through an electrical connector, dropping to a lower energy state and releasing energy as heat to the heat sink (hot side). Thermoelectric can be used to heat and to cool, depending on the direction of the current. In an application requiring both heating and cooling, the design should focus on the cooling mode. Using a thermoelectric in the heating mode is very efficient because all the internal heating (Joulian heat) and the load from the cold side is pumped to the hot side. This reduces the power needed to achieve the desired heating. By doing this it absorbs the heat from one side and releases the heat to another side. An array of p-type and n-type semiconductor pellets are connected electrically in series sandwiched between the substrates as shown in the figure 2.

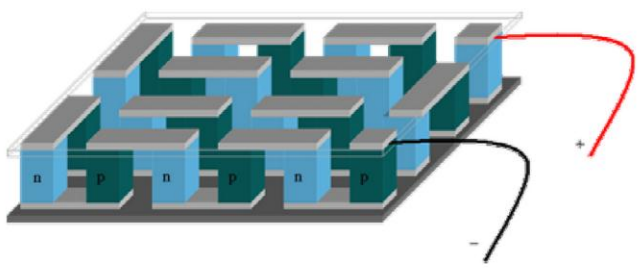

Figure 2: *A transparent top piece of thermoelectric module*

The device is normally attached to the cold side of the TEC module, and a heat sink which is required for enhanced heat dissipation is attached to the hot side. Considering a typical thermoelectric system designed to cool electronic circuit. Recently, this is probably the most common type of TE application. Usually, this is done by employing two heat sink/fan combinations in conjunction with one or more Peltier devices. One of the heat sinks is used for cooling to a temperature below that of the ambient temperature. So in other words, the Peltier module is placed between this “cold side” heat sink and a “hot side” sink. And as direct current passes through the thermoelectric device, it actively pumps heat from the cold side sink to the one on the hot side. The fan on the hot side then circulates ambient air between the sink’s fins to absorb some of the collected heat.

3 NOMENCLATURE

COP	Coefficient of performance
I	Current
K	Thermal conductivity
Q	heating and cooling rate
Q_H	heat rejection
Q_L	heat absorption
R	Electric Resistance
T	Temperature
Tc	cold side temperature
Th	hot side temperature
ΔT	Temperature Difference
TEC	Thermoelectric cooler
P	power consumption
S	seebeck co-efficient

4 EXPERIMENTAL SETUP

This presents the detailed information of instruments, working procedure, operating parameters of thermoelectric cooler.

4.1 TEC Specification

In this study we use TEC1-127-06L a thermoelectric module, which specification are as follow.

Table : Model Number for TER			
Module: Model TEC1-127-06L			
Q_{max}	60 Watts	Dimensions	
I_{max}	6 Amp	Width	40 mm
V_{max}	15.4 V	Length	40 mm
T_{max}	90 °C	Thickness	3.5 mm
Number of Thermocouple	127		

4.2 Design & measurement of temperature

Every specific application where a thermoelectric cooler module or refrigerator is required is characterized by a set of operation parameters, which dictate the necessity and accurate selection of the optional thermoelectric cooler type among a wide range of single and multi-stage thermoelectric cooler modules.

A.Thermoelectric Cooler Module

The thermoelectric cooler module material chosen is Bismuth telluride. The properties of a 127 couple, 6A Bismuth Telluride module TEC1-127-06L are:

Seebeck coefficient (S) = 0.01229 V/k
Module thermal conductance (K) = 0.1815 W/k
Module resistance (R) = 4Ω

B. Thermal Resistance Network

Thermal resistance network is conducted here for analysis. Since TEC generates Joule heat, it makes heat rejection, which is called Q_H, from TEC hot side larger than the heat absorption, which is called Q_L, into TEC cold side. According to literatures, the general forms of heat absorption and heat rejection are presented as bellow. Heat transferred into the cold side when neglected the temperature drop through the TEC is given by,

$$Q_L = [SIT_c - \frac{1}{2} I^2R - k (T_h - T_c)]$$ (-) sign for heat rejection.

While the heat transferred out of the hot side into the heat sink is given by,

$$Q_H = SIT_h + \frac{1}{2} I^2R - k (T_h - T_c)$$

Seebeck coefficient (S) and electrical resistance (R) in Ohms are dependent both on the materials used within the TEC, but also on the geometry of the device, given by the number and dimensions of the individual N and P-type semiconductor elements.

C. Temperature difference

After measuring the temperature by **radiation pyrometer**, final temperature at the surface of module and the heat sink are as follow.

Temperature at hot side T_h = 68˚ C

Temperature at cold side T_c = 17˚ C

So, Temperature difference can be considered as
$\Delta T = (T_h - T_c) = (68-17) = 51˚C$

4.3 COP of Single stage thermoelectric cooler

A non-dimensionless parameter called the Coefficient of Performance is therefore used to measure the performance of a cooling machine. The coefficient of performance (COP) of a thermoelectric module which is the thermal efficiency must be considered for a TE system. COP is the ratio of the thermal output power and the electrical input power of the TEC. COP can be calculated by dividing the amount of heat absorbed at the cold side to the input power.

COP = Q_L/Energy supplied (W)

Heat absorption is calculated as bellow.

$$Q_L = -[SIT_c - \frac{1}{2} I^2R - k(T_h - T_c)]$$
$$= 58.21185$$

From the first law of thermodynamics, the Energy supplied is:

Energy supplied, $W = Q_H - Q_L$
$= SI(T_h - T_c) + I^2R$
$= 103.13395$

The Coefficient of Performance (COP) is obtained by the following empirical equation.

COP = Q_L/Energy supplied

$$= \frac{SITc - \frac{1}{2} I^2R - k(Th - Tc)}{SI(Th - Tc) + I^2R}$$

$$= \frac{58.21185}{103.13395}$$

COP =0.564432

Here it is remarkable that the value of COP is still lower than the expectation. Although the COP of a TE module is lower than that of conventional VCR system, efforts have been made to develop thermoelectric domestic coolers to exploit the advantages associated with this solid-state energy conversion technology. Further improvement in the COP may be possible through using multi stage thermoelectric module, improving module contact resistance, thermal interfaces and heat exchanger. Among these possibilities use of multistage thermoelectric module is the simplest and presently available method. Due to the performance limits of thermoelectric materials, a single-stage thermoelectric cooler can only be operated over a small temperature range. If the temperature ratio between the heat sink and the cooled space is large, a single-stage thermoelectric cooler will lose its effectiveness. Thus, the application of two- or multi-stage combined thermoelectric coolers is an important method of improving the performance of thermoelectric coolers.

4.4 COP of Multi-stage thermoelectric cooler

Multi-stage thermoelectric coolers offer larger temperature differences between heat source and heat sink than single or two stage thermoelectric coolers. Having considered the COP of a heat sink as key parameters in the design of a multi-stage thermoelectric cooler. Multistage TEC system allows use of heat sink with higher thermal resistance which helps in improvement of COP. In this study, a pyramid type multi-stage cooler is analysed, focusing on the importance of overall COP.

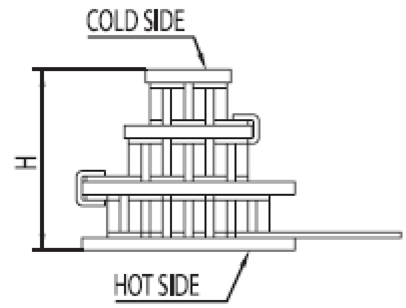

Figure 3:*Schematic sketch of multistage TE module*

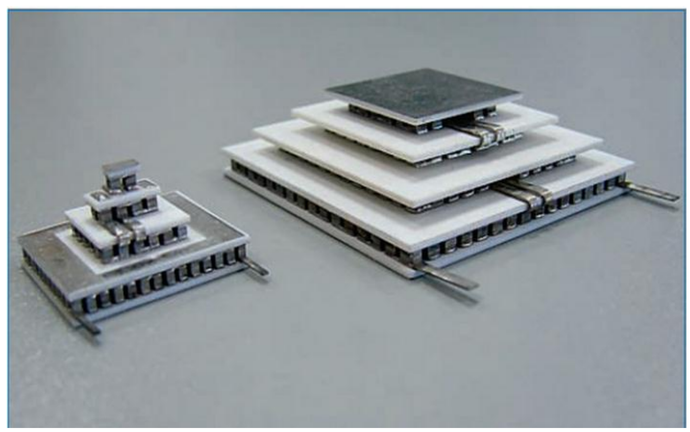

Figure 4: *Multistage thermoelectric module*

For the multi stage thermoelectric cooler, It is possible to achieve the very high temperature difference upto 100-110˚ C. And cold side temperature is around 8-10˚ and hot side temperature is around 110-116˚. Now, in our study consider a 3 stage TE module M2-40-1503-3.

For this module,

Tc=11˚C, Th=118˚C, ΔT=118-11=107˚C

Now, for these value of temperature, use above mention formula of Q_L and W,

Q_L = 68.74455 J

W=56.57515 J

Now COP of the 3 stage TE module M2-40-1503-3.

$$COP=\frac{68.74455}{56.57515}$$

COP=1.2151

From the above calculation it is clear that by using multistage TE module it is possible to achieve the remarkable COP.

5 CONCLUSION

This study experimentally investigates the performance of the single stage and multistage TEC air-cooling module. It is quite easy to achieve the significant temperature difference in the single stage TE module, but, the COP of the single stage module is very less for the domestic use. In the multistage TE module, It is possible to get the require COP as well as better thermal performance. The main limitation of the use of the multistage TE module is the price of this module. The price of multistage module is very high compare to single stage module and that make it very costly. With recent development taking place in field of thermoelectric and nanoscience, different thermoelectric material with high temperature difference and lower price to be explored. This will further help to reduce the overall price of the multistage TEC and improve the thermal performance.

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