Critical Review of Effect of Current, Voltage and Figure of Merit on Performance of TEC

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Abstract— Thermoelectric materials show the thermoelectric effect in a strong or convenient form. The thermoelectric effect refers to phenomena by which electric potential creates a temperature difference. These phenomena are known more specifically as Peltier effect (converting current to temperature). A commonly used thermoelectric material in such applications is bismuth telluride (Bi_2Te_3). Developing thermoelectric materials with superior performance means tailoring interrelated thermo- electric physical parameters – electrical conductivities, Seeback coefficients, and thermal conductivities – for a crystalline system. In this paper, basic knowledge of thermoelectric materials and an overview of parameters (current and voltage) that affect the figure of merit (ZT) and Coefficient of Performance (COP) are provided.

Index Terms- Peltier effect, Seeback coefficient, Current, Voltage, Figure of Merit, Coefficient of Performance

I. INTRODUCTION

Thermoelectricity is the direct conversion of temperature gradient to electrical potential difference. The phenomenon is described by three effects. The Seebeck effect -discovered by Thomas Seeback- in 1821 is the conversion of temperature difference into electrical voltage. The Peltier effect -discovered by Jean Peltier in 1934- is the conversion of voltage into temperature gradient. And the Thomson effect – discovered by William Thomson in 1851- is the heat flow in a conductor with terminals held at different temperatures, due to current flow.[1]

A practical thermoelectric cooler consists of two or more elements of semiconductor material that are connected electrically in series and thermally in parallel. These thermoelectric elements and their electrical interconnects typically are mounted between two ceramic substrates. The substrates serve to hold the overall structure together mechanically and to insulate the individual elements electrically from one another and from external mounting surfaces. Both N-type and P-type Bismuth Telluride thermoelectric materials are used in a thermoelectric cooler. This arrangement causes heat to move through the cooler in one direction only while the electrical current moves back and forth alternately between the top and bottom substrates through each N and P element. N-type material is doped so that it will have an excess of electrons (more electrons than needed to complete a perfect molecular lattice structure) and P-type material is doped so that it will have a deficiency of electrons (fewer electrons than are necessary to complete a perfect lattice structure). The extra electrons in the N material and the “holes” resulting from the deficiency of electrons in the P material are the carriers which move the heat energy through the thermoelectric material. Figure.1 shows a typical thermoelectric cooler with heat being moved as a result of an applied electrical current (I). Most thermoelectric cooling modules are fabricated with an equal number of N-type and P-type elements where one N and P element pair form a thermoelectric “couple.” The module illustrated in Figure 2 has two pairs of N and P elements and is termed a “two-couple module”. [2]

The crystal structure of Bi_2Te_3 contains sheets separated by gaps in which there is no covalent bonding (figure2). These gaps are one of the factors that give this material a low thermal conductivity. However, the potential for chemical modifications and so improvements in the figure of merit, in a structure containing only two elements is limited.[2]

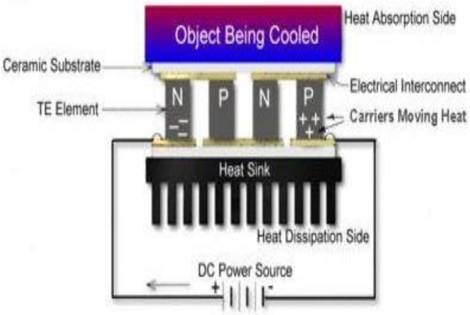

Fig.1 Schematic Diagram of Thermoelectric Cooler (TEC)[2]

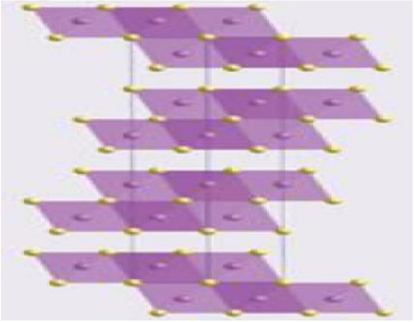

Fig. 2 Structure of TEC [2]

Major Parameters Affecting Performance of TEC:

1. Figure of Merit
2. Input Current
3. Design of Heat Sink

II. THERMOELECTRIC FIGURE OF MERIT

The performance of a thermoelectric device is indicated by the figure of merit (FOM) ZT, it is a dimensionless quantity, which is given by:

□□ = (□□2× □) / (□l + □e) ………..(1)

Where G, S, □□ and T are electrical conductivity, lattice thermal conductivity, electronic thermal conductivity, and absolute average temperature.

According to Yehea Ismail and Ahmed Al-askalnya[1], For higher ZT, a large Seebeck coefficient and electrical conductivity, and small thermal conductivity are required. Thermal conductivity decreases the FOM, since it leads to undesired thermal exchange between hot and cold sides of a thermoelectric device. The compromise to increase ZT is shown in fig. 3, Increasing the carrier concentration in order to increase electrical conductivity, also gives rise to thermal conductivity, and the Seebeck coefficient starts to decrease with higher thermal conductivity, due to lack of the ability of the material to maintain higher temperature gradient. Bi2Te3 is the most commonly used semiconductor material because of its relatively high FOM ZT=1 at 300°K.

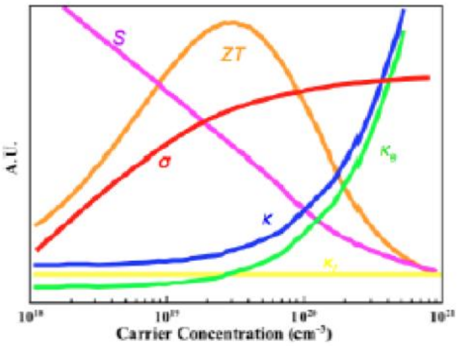

Figure 1: shows the FOM for some p-type semiconductor materials [1].

Fig.3 FOM for P-type SC materials [1]

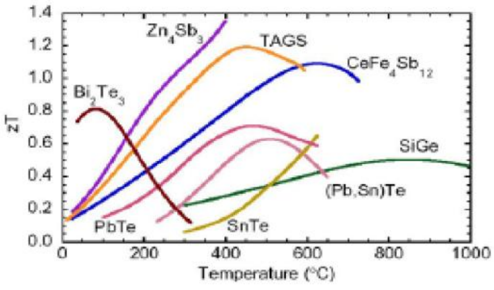

Figure 2: FOM for p-type materials [1].

Fig. 4 FOM for p-type materials [1]

According to Fluerial et al, reported that in 1991 JPL started abroad search to identify and develop advanced materials. Among the materials considered, Skutterudite and Zn4Sb3 based materials appeared particularly promising and several of these materials are being developed. ZT values equal to or greater than one have been obtained for these materials over

different ranges of temperature varying from 375 to 975K. The Figure of Merit (FOM) of different materials are given below as follows in Table-1.[3]

Table.1-Figure of Merit for different materials[3]

MATERIAL	Figure of Merit
Pb - Te	1.2×10^{-3}
Pb - Se	1.2×10^{-3}
Pb – Te_3	1.2×10^{-3}
Bi_2 – Te_3	1.3×10^{-3}
$(BiSb)_2$ - Te_3	3.3×10^{-3}

It can be concluded that A higher Figure of Merit (atleast≥1) is always desirable to increase the effect of cooling, and increasing doping (carrier concentration) of various combinations of P-type and N-type material increase the performance of TEC.

III. THERMOELECTRIC CURRENT

The paper entitled 'Thermal management for a Micro Semiconductor Laser based on Thermoelectric Cooling' by Wei Zhang, LimeiShen, Yaxin Yang, Huanxin Chen [4], shows that diiferent heat sinks draw different Input Current and affect the COP of TEC. The simulation model showed that 3rd Heat Sink drawed the minimum current and Maximum COP (Fig-5). [4]

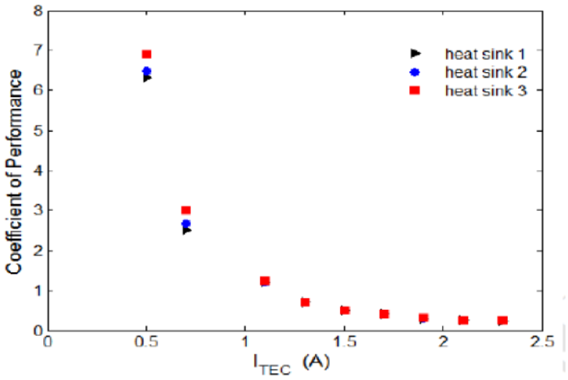

Fig.5 COP Changes with ITEC in different heat sinks [4]

It is more important to use a heat sink which is more economical and TEC of 20×20×2.3 mm should be employed which gives a COP of about 2.5-3 (experimental) at a current of ITEC = 0.7-1.4 A.

The work done by OpeoluwaOwoyele, Scott Ferguson and Brendan T.O' Connor, [5]presents that Peltier Effect is the transfer of heat from cold side to hot side actuated by direction of current. Thus Current is an important parameter that effect the performance of TEC. Also TEC and Heat sink offers some sort of Thermal Resistance. It is observed that Thermal Resistance of TEC (RTEC) Increases with heat load and Decreases with input current; while thermal resistance of Heat sink (RHS) Increases with input Current and Decreases with heat load. Thus the total Thermal Resistance in affecting the performance of TEC is given by equation,

RTOTAL = RTEC + RHS ………..(2)

The figure.6 shows the plot of Current versus COP of TEC considering Radiation mode of Heat Transfer.[6]

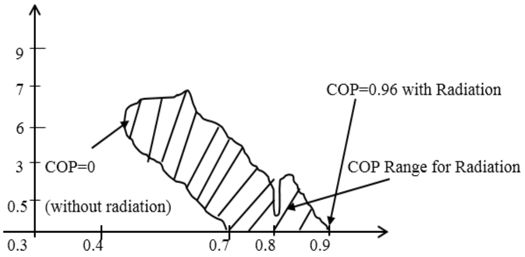

Fig.6 – COP vs Current (radiation Heat transfer mode) [2]

Thus it is concluded that instead of adjusting the current value to optimum, Radiation Mode of Heat Transfer should be employed to increase the value of COP.Thus with Radiation as Heat Tranfer range – Current of 0.5 – 3 A range for 1 TEC and judicious choice of Heat Sink leads to Improvement in COP (≈1 or 3-6) of TEC.

IV. DESIGN OF HEAT SINK

J. Richard Colham et al. has performed experimental analysis on different types of fin material and it was demonstrated that conventional heat sink materials, such as aluminum alloys, with a thermal conductivity of 200 W/mK, provide excellent heat transfer characteristics, however, manufactured composites k= 25 to 100 W/mK consisting of graphite or metal particles contained within a plastic binder can be used with only a minimal loss in thermal performance. When using lower conductivity materials in heat sink applications, fin profiles are typically shorter and wider to accommodate the higher thermal resistance and in some instances there may be a marginal increase in the number of fins required to achieve optimal performance. In addition, the head loss associate with the increased flow blockage of additional fins with a thicker profile can necessitate a need to examine fan performance in these instances.[7]

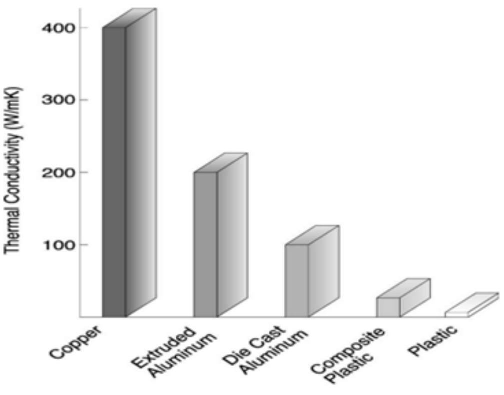

Fig.7 Different materials of heat sink[7]

W. A. KHAN et al. had conducted experiments and different fin geometries having the same perimeter were compared from the point of views of heat transfer, drag force, and dimensionless total entropy generation rate. Optimum dimensionless entropy generation rate exists for each geometry corresponding to Reynolds number, perimeter, axis ratio in case of EPF, and the aspect ratio. The square geometry is found to be the worst choice from the point of view of heat transfer and drag force and hence from the point of view of total entropy generation rate. Whereas, the circular geometry performs better from the point of view of the dimensionless total entropy generation rate for smaller perimeters, larger aspect ratios and lower Reynolds numbers. The RPF gives the best results from the point of view of total entropy generation rate for higher Reynolds numbers, smaller aspect ratios and large perimeters. The elliptical geometry is the next most favorable geometry from the point of view of total entropy generation rate for higher Reynolds numbers and with smaller axis ratios. It offers higher heat transfer coefficients and lower drag force as the axis ratio is decreased and the approach velocity is increased.[8]

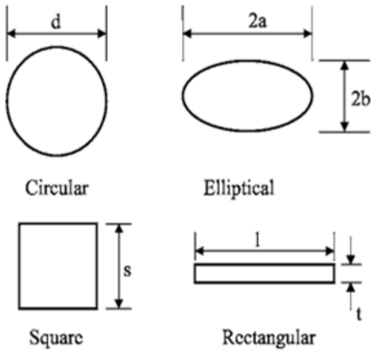

Fig.7 Different fin geometries[8]

It is concluded that fin made up of conventional material gives maximum efficiency and triangular or elliptical geometry of fin is more effective than any other geometry.

V. CONCLUSION

1. COP of a Cooling Effect by TEC is increased greater than 1 (up to maximum 3 – 6) if Figure of Merit of material of TEC is greater than or equal to 1 (by doping carrier concentration).

2. The optimum Current for TEC is in the range 0.4 – 2 A (amperes) for materials of TEC like Bi2Te3,

Pb-Te, Pb-Se, Pb2Te3, (BiSb)2-Te3.

3. Rectangular or elliptical fin is employed for maximum fin efficiency.

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