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A DESIGN METHOD OF THERMOELECTRIC COOLER

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Abstract

Although the principle of thermoelectricity dates back to the discovery of the Peltier effect in 1834, there was little practical application of the phenomenon until the middle 1950s. Prior to then, the poor thermoelectric properties of known materials made them unsuitable for use in a practical refrigerating device.. Thermoelectric coolers also offer the advantages of being compact, quiet, free of moving parts, and their amount of cooling can be controlled by the current supplied. Unfortunately, compared to vapour compression refrigeration, they are limited in the heat flux that they can be accommodated and exhibit a lower (COP). Thermoelectric coolers also called thermoelectric modules or Peltier coolers. They are semiconductor based electronic components that function as small heat pumps. On applying a low DC voltage to the thermoelectric module, heat moves through the module from one side to the other. One face of the module is therefore cooled, while the other face simultaneously heats up. This phenomenon can also be reversed by changing the polarity of the applied DC voltage causing the heat to flow in the opposite direction. Thermoelectric coolers can be used for applications that require heat removal ranging from milli-watts up to several thousand watts. Therefore they are used for the most demanding industries such as medical, laboratory, aerospace, semiconductor, telecom, industrial, and consumer. Uses range from simple food and beverage coolers for an afternoon picnic to extremely sophisticated temperature control systems in missiles and space vehicles. A thermoelectric cooler provide a solution that is smaller, weighs less, and is more reliable than a comparatively small .

keywords: *Peltier effect, semiconductor, refrigeration, thermoelectricity, heat flux etc.*

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1.INTRODUCTION

Thermoelectric coolers offer the potential to enhance the cooling of electronic module packages, to reduce chip operating temperatures or to allow higher module powers. Thermoelectric coolers also offer the advantages of being compact, quiet, free of moving parts, and their amount of cooling can be controlled by the current supplied. Unfortunately, compared to vapour compression refrigeration, they are limited in the heat flux that they can be accommodated and exhibit a lower coefficient of performance (COP). These two limitations have generally limited thermoelectric cooling to be used in broad expect .

In recent years there has been increased interest in the application of thermoelectric to electronic cooling, followed by efforts to improve their performance through the development of new bulk materials and thin film micro cooler when a voltage or DC current is applied to two dissimilar conductors, a circuit can be created that allows for continuous heat transport between the conductor's junctions. The Seebeck Effect- is the reverse of the Peltier Effect. By applying heat to two different conductors a current can be generated. The materials used for this purpose are generally semiconductors. They are the optimum choice to sandwich between two metal conductors because of the ability to control the semiconductors charge carriers as well as increase the heat pumping ability. The most commonly used semiconductor for electronics cooling applications is Bi2Te3 because of its relatively high figure of merit. However, the performance of this material is still relatively low and alternate materials are being studied with possibly better performance. Alternative materials include.

1.1 PRINCIPLE OF OPERATION

Peltier Effect- when a voltage or DC current is applied to two dissimilar conductors, a circuit can be created that allows for continuous heat transport between the conductor's junctions. The Seebeck Effect- is the reverse of the Peltier Effect. By applying heat to two different conductors a current can be generated. The Seebeck Coefficient is given by:

dT / dx

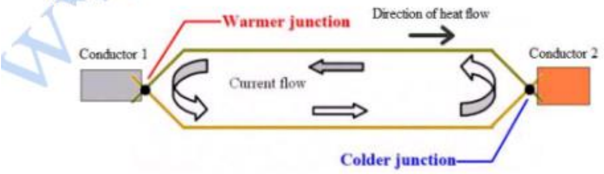

Fig 1:- Principle of operation

The current is transported through the charge carriers (opposite to the electron flow). Heat transfer occurs in the direction of charge carrier movement. Applying a current (e-carriers) transports heat from the warmer junction to the cooler junction.

2. CONSTRUCTION

A typical Thermoelectric Module consists of the following components:

2.1Thermoelectric Material: The materials used for this purpose are generally semiconductors. They are the optimum choice to sandwich between two metal conductors because of the ability to control the semiconductors charge carriers as well as increase the heat pumping ability. The most commonly used semiconductor for electronics cooling applications is Bi2Te3 because of its relatively high figure of merit. However, the performance of this material is still relatively low and alternate materials are being studied with possibly better performance .Alternative materials include: Alternating thin film layers of Sb2Te3 and Bi2Te3, Lead telluride and its alloys, SiGe (Silicon Germanium), Materials based on nanotechnology.

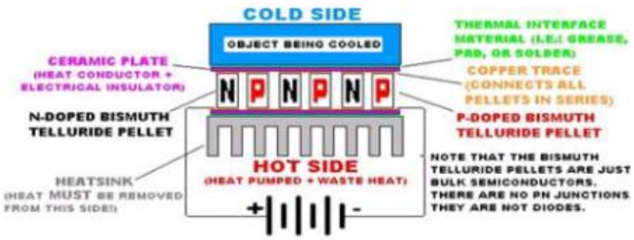

Fig.2: A Typical Thermoelectric Module

2.2 Ceramic Plates: An electrical insulator is provided between the heats generating device and the conductor to prevent an electrical short circuit between the module and the heat. The electrical insulator must have a high thermal conductivity so that the temperature gradient between the source and the conductor is small. Ceramics like alumina are generally used for this purpose.

2.3 TIM (Thermal Interface Material): This principle requires the heat to be transferred from the object being cooled (or heated) to the Peltier module and heat must be transferred from the Peltier module to the heat sink. Realistically, the interface between the Peltier module surfaces to the object being cooled and to the heat sink will not be perfect. There will be peaks and valleys in the surfaces resulting in tiny air pockets which conduct heat poorly. So it is required to place a "thermal interface material" (TIM) between the Peltier module surfaces. These include mainly silicone based greases, elastomeric pads, thermally conductive tapes, thermally conductive adhesives, old fashioned zinc oxide silicone heat sink grease.

2.4 Heat Sink: A heat sink is required for either heating or cooling a thermal load. They are employed either to collect heat (in heating mode) or dissipate collected heat into another medium (e.g., air, water, etc.). Without such provisions, the TE device will be vulnerable to overheating. Once TE device reaches the reflow temperature of the solder employed, the unit will be destroyed. When the heat sink is exchanging heat with air a fan is usually required to minimize the size of the sink required.

2.5 Uses of two type of Material (P and N type):

A simple thermoelectric device can be made with a single semiconductor pellet, but it can't pump an appreciable amount of heat through it. In order to give a TE device greater heat pumping capacity multiple pellets are used together. The initial attempt would be to simply connect them in parallel both electrically and thermally. While this is possible, it is not suitable for a practical device. The drawback is that the typical TE semiconductor pellet is rated for only a very small voltage as small as tens of mill volts so it can draw a substantial amount of current. For example, a single pellet in an ordinary TE device might draw five amps or more with only 60 mV applied, if connected in parallel in a typical 254 pellet configuration, the device would draw over 1270 amps with the application of that 60 mV (assuming that the power supply could deliver that much current). The only realistic solution is to connect the semiconductors in series and doing so in a way that keeps them thermally in parallel (i.e., pumping together in the same direction). Here we might think to simply zigzag the electrical connections from pellet to pellet to achieve a series circuit. This is theoretically workable however; the interconnections between pellets will create thermal shorting that significantly compromises the performance of the device. Fortunately, there is another option which gives us the desired electrical and thermal configuration while better optimizing the thermoelectric effect. By arranging N and P-type pellets in a 'couple' (see Figure 3) and forming a junction between them with a plated copper tab, it is possible to configure a series circuit which can keep all of the heat moving in the same direction.

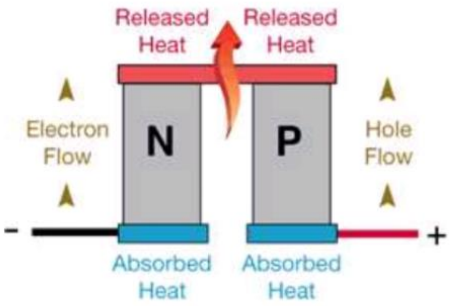

Fig-3: N and P type pellet

As shown in the illustration, with the free (bottom) end of the P-type pellet connected to the positive voltage potential and the free (bottom) end of the N-type pellet.

The negative side of the voltage, an interesting phenomenon takes place. The positive charge carriers (holes) in the P material are repelled by the positive voltage potential and attracted by the negative pole and the negative charge carriers (electrons) in the N material are similarly repelled by the negative voltage potential and attracted by the positive pole of the voltage supply. In the copper tabs and wiring, electrons are the charge carriers. When these electrons reach the P material, they simply flow through the holes within the crystalline structure of the P-type pellet. Thus the electrons flow continuously from the negative pole of the voltage supply, through the N pellet, through the copper tab junction, through the P pellet, and back to the positive pole of the supply. This happens because two different types of semiconductor material are being used. The charge carriers and heat are flowing in the same direction through the pellets . Using these special properties of the TE 'couple', it is possible to combine many pellets together in rectangular arrays to create practical thermoelectric modules. These devices can not only pump appreciable amounts of heat but with their series electrical connection are suitable for commonly available DC power supplies. Thus the most common TE devices now in use connecting 254 alternating P and N-type pellets and can run from a 12 to 16 VDC supply and draw only 4 to 5 amps (rather than 1270 amps at 60 mV)

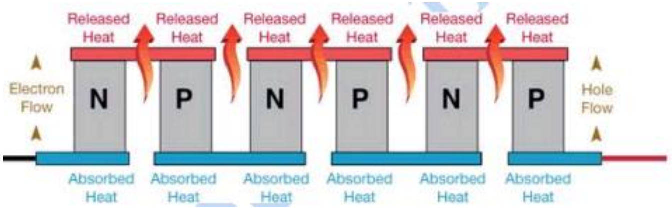

Fig-4: different p and n arranged in series

3. WORKING

Electrons can travel freely in the copper conductors but not so freely in the semiconductor. As the electrons leave the copper tabs and enter the hot side of the p-type, they must fill a hole in order to move through the p-type. When the electrons fill a hole, they drop down to a lower energy level and release heat in the process. Then, as the electrons move from the p-type into the copper conductor on the cold side, the electrons are again taken back to a higher energy level and in the process they absorbs heat. Next, the electrons move freely through the copper tabs until they reach the cold side of the n-type semiconductor. to a higher energy level in order to move through the n-type semiconductor. Heat is absorbed when this occurs. Finally, when the electrons leave the hot side of the n-type, they can move freely in the copper conductors. They drop down to a lower energy level and release heat in the process. Thus the charge carriers, negative electrons and positive holes transfer heat.

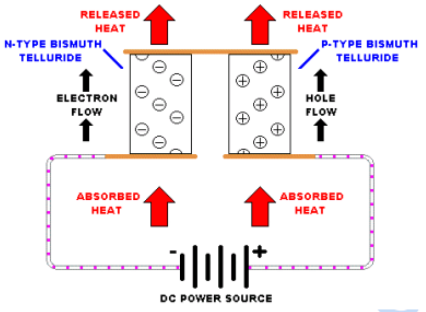

Fig-5: Working of thermoelectric design

3 .2 Condensation: This is the most serious fact that has to be taken in to account while designing a TE device. A common problem with TE cooling is that condensation may occur causing corrosion and eroding the TE's inherent reliability. Condensation occurs when the dew point is reached. The dew point is the temperature to which air must be cooled at constant pressure for the water vapour to start to condense. Condensation occurs because the air loses the ability to carry the water vapour that condenses. As the air's temperature decreases its water vapour carrying capacity decreases. Since TE coolers can cool to low and even below ambient temperatures condensation is a problem. The most common sealant employed is silicon rubber. Research has been performed to determine the most effective sealing agent used to protect the chip from water. Four sealants were used to seal a TE cooling device and the weight gain due to water entering the device measured. The best sealants should have the lowest weight gain.

4. THERMOELECTRIC PERFORMANCE

The performance depends on the following factors:

1. The temperature of the cold and hot sides.
2. Thermal and electrical conductivities of the device's materials.
3. Contact resistance between the TE device and heat source or heat sink.
4 .Thermal resistance of the heat sink. Improving The performance: Various methods have been used to improve the performance of TE coolers which are its major drawback. Examples: thin film coolers or multistage (bulk) coolers.

5. THIN FILM COOLERS

Thin films are material layers of about one micrometer thickness. Alternating layers of Sb2Te3 (antimony telluride) and Bi2Te3 (bismuth telluride) are used to produce thin film TE coolers. An example is shown below where the highest power components are mounted on a diamond substrate which would be the top or cold side substrate of a thin film TE cooler. Power densities were found to be above 100W/cm2. Thin film coolers considerably reduce the size of TE devices because the cooling density of a Peltier cooler is inversely proportional to its length. Smaller size is desirable.

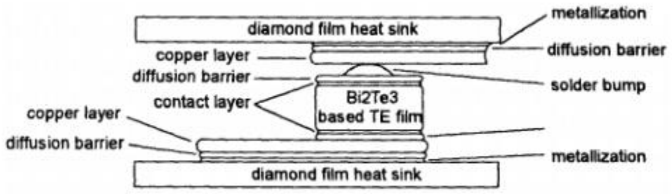

Fig-6: Thin film thermoelectric cooler

6. MULTISTAGE MODULES

When the desired temperature difference between the cold and hot side cannot be obtained with a single stage module, or when the cold side temperature must be lower than a one stage cooler will provide a multistage module may need to be applied. Multistage modules are essentially single stage modules stacked up in a vertical pyramid shaped array. As the number of stages increases, the minimum cold side temperature will decrease. Also, increasing

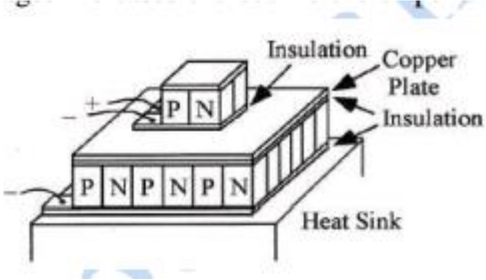

Fig-7: Multistage module

7. PERFORMANCE CURVE

The number of stages increases the coefficient of performance for a given cold side.

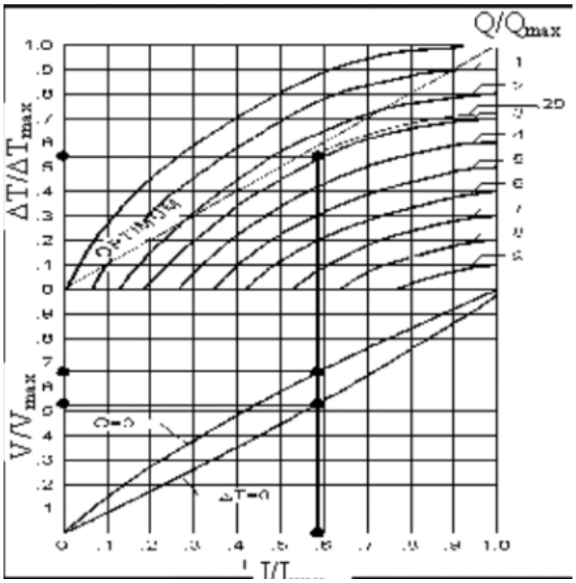

Fig-8: Performance curve

8. ADVANTAGES

1. No moving parts make them very reliable; approximately 105 hrs of operation at 100 degrees Celsius, longer for lower temperature.
2. Ideal when precise temperature control is required.
3. Ability to lower temperature below ambient.
4. Heat transport controlled by current input.
5. Able to operate in any orientation
6. Compact size makes them useful for applications where size or weight is a constraint.
7. Ability to alternate between heating and cooling.
8. Excellent cooling alternative to vapor compression coolers for systems that are sensitive to mechanical vibration.

9. DISADVANTAGES

1. Able to dissipate limited amount of heat flux.
2. Lower coefficient of performance than vapor-compression systems.
3. Relegated to low heat flux applications.

10. APPLICATION

The industries which use TE cooling are Electronics, Medical, Aerospace and telecommunication and their applications are:-

1. Electronic enclosures
2. Laser diodes
3. Laboratory instruments, DNA synthesis, Blood analyzers, Tissue preparation
4. Temperature baths
5. Refrigerators
6. Telecommunications equipment
7. Temperature control in missiles and space systems, CCD/LED/Infrared detector cooling, Night vision equipment
8. Heat transport ranges vary from a few mill watts to several thousand watts, however, since the efficiency of TE devices are low, smaller heat transfer applications are more practical.

11. CONCLUSION

A new dimension has been added to the cooling challenge by the requirement to reduce operating temperatures to achieve enhanced speed. With the continued demand for improved cooling technology to enhance the performance and reliability of CMOS applications, thermoelectric cooling may be considered a potential candidate for cooling enhancement .To use the equations, detailed information in terms of the parameters , ρ, K, and R pertaining to the thermoelectric module under consideration is required. The application of thermoelectric coolers could provide cooling enhancement for a limited range of powers. Unfortunately, in many cases MCM powers may be simply too high for current thermoelectric modules to handle effectively. The current figure of merit, Z, of the available candidate materials, and the coefficient of performance (COP) attainable with existing thermoelectric coolers, need to be increased .Until and unless improvements can be made to enhance heat pumping capability.

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