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Thermoelectric Refrigeration System

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Abstract: Thermoelectric cooling, is a solid-state method of heat transfer through dissimilar semiconductor materials. It is also called "the Peltier Effect" after the French watchmaker who discovered the phenomenon in the early 19th century. Like their conventional refrigeration counterparts, thermoelectric cooling systems obey the basic laws of thermodynamics. However, the actual system for cooling is different. In a conventional refrigeration system, the main working parts are the evaporator, condenser, and compressor. The evaporator surface is where the liquid refrigerant boils, changes to vapor, and absorbs heat energy. The compressor circulates the refrigerant and applies enough pressure to increase the temperature of the refrigerant above ambient level. The condenser helps discharge the absorbed heat into surrounding room air.techThe three main working parts in a thermoelectric refrigeration system are a cold junction, a heat sink, and a DC power source.Two dissimilar conductors replace the refrigerant in both liquid and vapor form. The cold sink (evaporator surface) becomes cold through absorption of energy by the electrons as they pass from one semiconductor to another, instead of energy absorption by the refrigerant as it changes from liquid to vapor. The DC power source pumps the electrons from one semiconductor to another, and the heat sink (condenser) discharges the accumulated heat energy from the system.Therefore, the thermoelectric cooling system refrigerates without refrigerant and without the use of mechanical devices, except perhaps in the auxiliary sense.
Keyword: Peltier, Thermodynamic, Evaporator, Semiconductor Electron, Sink, Compressor.

I. INTRODUCTION

In the past the possibility of thermoelectric refrigeration has been considered, but all attempts to produce a practical refrigerator have failed owing to lack of suitable thermocouple materials.

In this paper it is proposed that semiconductors should be used and the factors governing their selection are discussed. It is concluded that the semiconductors should be chosen with high mean atomic weights and that they should be prepared with thermoelectric powers lying between 200 and 300 µVC-1.

Preliminary experiments have led to the production of a thermocouple consisting of bismuth telluride, Bi2Te3, and bismuth, capable of maintaining 26 C of cooling.

This technology is far less commonly applied to refrigeration than vapor-compression refrigeration is. The primary advantages of a Peltier cooler compared to a vapor-compression refrigerator are its lack of moving parts or circulating liquid, very long life, invulnerability to leaks, small size, and flexible shape. Its main disadvantages are high cost and poor power efficiency. Many researchers and companies are trying to develop Peltier coolers that are cheap and efficien.

II. MATERIAL REVIEW

The Fermi energy is below the conduction band causing the state density to be asymmetric around the Fermi energy. Therefore, the average electron energy of the conduction band is higher than the Fermi energy, making the system conducive for charge motion into a lower energy state.

By contrast, the Fermi energy lies in the conduction band in metals.

This makes the state density symmetric about the Fermi energy so that the average conduction electron energy is close to the Fermi energy, reducing the forces pushing for charge transport.

Therefore, semiconductors are ideal thermoelectric materials.[6] Due to the small Seebeck coefficient metals have a very limited performance and the main materials of

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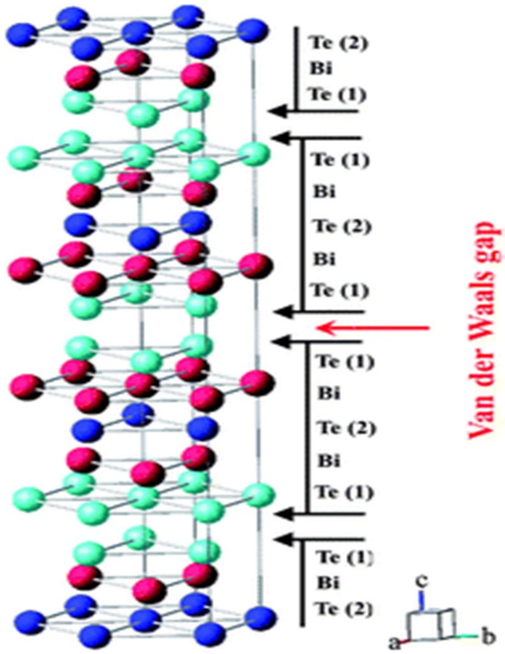

Fig1. Bi2Te3

III. THERMOELECTRIC COOLING

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junction of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other, with consumption of electrical energy, depending on the direction of the current. Such an instrument is also called a Peltier device, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC). It can be used either for heating or for cooling,[1] although in practice the main application is cooling. It can also be used as a temperature controller that either heats or cools.

IV. PELTIER EFFECT

The Peltier effect is the presence of heating or cooling at an electrified junction of two different conductors and is named after French physicist Jean Charles Athanase Peltier, who discovered it in 1834.

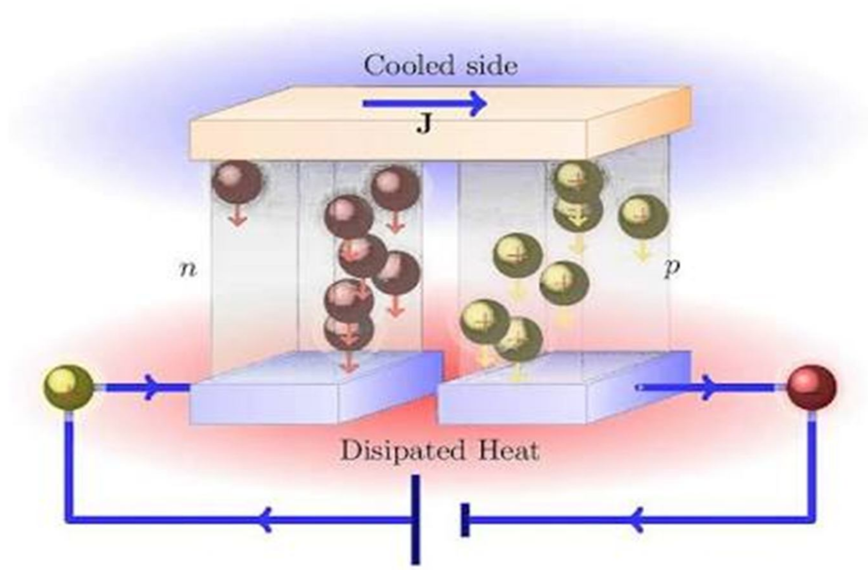

Fig 2. The seebeck circuit configured

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Peltier effect, the cooling of one junction and the heating of the other when electric current is maintained in a circuit of material consisting of two dissimilar conductors; the effect is even stronger in circuits containing dissimilar semiconductors. In a circuit consisting of a battery joined by two pieces of copper wire to a length of bismuth wire, a temperature rise occurs at the junction where the current passes from copper to bismuth, and a temperature drop occurs at the junction where the current passes from bismuth to copper. When a DC voltage source is connected between the electrodes, the negatively-charged side becomes cooler while the positively-charged side becomes warmer. The negative electrode is placed in contact with the component, device or medium to be cooled, while the positive electrode is connected to a heatsink that radiates or dissipates thermal energy into the external environment.

V. PARAMETERS OF THERMOELECTRIC MODULE

A simple and easy-to-use device for measuring thermoelectric module (TEM) properties is presented. The characterization system provides continuous direct measurement of TEM hot and cold side temperatures, electric current flow, and terminal voltage. Seebeck voltage is measured using the Harman method. These measurements are then used to obtain dynamic values of TEM fundamental parameters: electrical resistance, thermal conductance and Seebeck coefficient, from which the TEM figure-of-merit can be calculated. Test conditions, i.e., current flowing through the module can be varied by the user. The thermal circuit used by the characterization system includes an auxiliary TEM that enables to emulate a controlled ambient temperature, which increments the repeatability and versatility of each test. Additionally, the dynamic response can be varied by interchanging the thermal load. Repeatability tests show a dispersion between direct measurements of less than 50mK for temperature measurements and less than 4mV for voltage measurements.

1) Cold Side Temperature

The problem with using thermal electrons to carry heat is the fact that, due to the high work function of metals, which are the only practical emitters, the lowest cooling temperate is around 600 °C - clearly not useful except in the most unusual applications. Thermotunnel cooling avoids this problem by making the gap narrow enough that electrons can tunnel across the gap, carrying the heat with them. The problem with this approach has been getting two surfaces near enough that they can tunnel over a large area, yet not touch at any point, which would short the device out preventing it from doing any useful cooling. it is expressed by Tc.

2) Hot Side Temperature

Thermoelectric coolers (TEC or Peltier) create a temperature differential on each side. One side gets hot and the other side gets cool. Therefore, they can be used to either warm something up or cool something down, depending on which side you use. You can also take advantage of a temperature differential to generate electricity. The thermal tape listed below works very well to attach heat sinks to the hot side. It is expressed by Th.

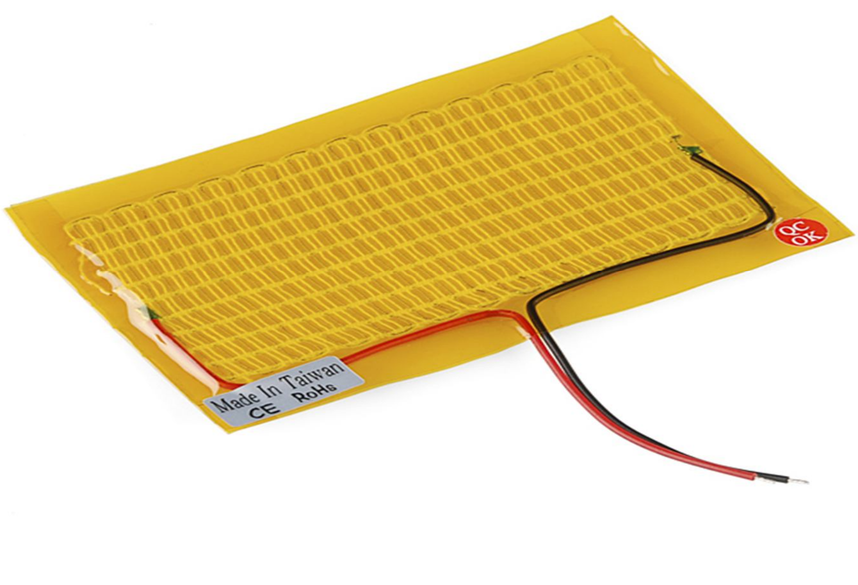

Fig 3. Heating pad

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3) Temperature Difference

The two temperature Tc & Th and the difference between △T is a very important factor. △T has to be accurately determine if the cooling system is to expressed as operating desired. The following equation -

$$\Delta T = Th - Tc$$

4) Cooling Load

The most difficult and important factor to be accurately determine a TEC is a amount of heat to be removed or observed (Qc) by the cold side of the TEC. In this project Qc was calculated by finding the product of mass flow rate of air, specific heat of air and temperature difference. Then the temperature difference in the system between inlet temperature and outlet temperature of the cooling system. The mathematical equation for Qc is shown below

$$Qc = \dot{m}Cp\Delta T$$

5) Heat Sink

A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, thereby allowing regulation of the device's temperature at optimal levels.

Fig 4. Heat sink

VI. NOMENCLATURE

A – Heat Exchanger area (m^2)
COP – Coefficient of performance
DC – Direct current
h – Heat transfer coefficient
I – Current
K – Conduction heat transfer coefficient
P – Input power
Q – Rate of heat transfer
R – Total electrical resistance
T – Absolute temperature
V – Voltage
W – Heat sink
L – Heat source
C – Cold junction side
H – Hot junction side
X – Device – design parameter

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VII. WORKING PRINCIPAL

The effect creates a temperature difference by transferring heat between two electrical junctions. A voltage is applied across joined conductors to create an electric current. When the current flows through the junctions of the two conductors, heat is removed at one junction and cooling occurs. Heat is deposited at the other junction. The main application of the Peltier effect is cooling. However the Peltier effect can also be used for heating or control of temperature. In every case, a DC voltage is required.

Thermoelectric coolers from II-IV Marlow act as a solid-state heat pump. Each features an array of alternating n- and p- type semiconductors. The semiconductors of different type have complementary Peltier coefficients. The array of elements is soldered between two ceramic plates, electrically in series and thermally in parallel. Solid solutions of bismuth telluride, antimony telluride, and bismuth selenide are the preferred materials for Peltier effect devices because they provide the best performance from 180 to 400 K and can be made both n-type and p-type.

The cooling effect of any unit using thermoelectric coolers is proportional to the number of coolers used. Typically multiple thermoelectric coolers are connected side by side and then placed between two metal plates. . II-VI Marlow features three different types of thermoelectric coolers including: Thermocyclers, Single Stage, and Multi-Stage.

Cooling occurs when a current passes through one or more pairs of elements from n- to p-type; there is a decrease in temperature at the junction ("cold side"), resulting in the absorption of heat from the environment. The heat is carried along the elements by electron transport and released on the opposite ("hot") side as the electrons move from a high- to low-energy state.

The Peltier heat absorption is given by Q = P (Peltier Coefficient) I (current) t (time). A single stage thermoelectric cooler can produce a maximum temperature difference of about 70 degrees Celsius. However, II-VI Marlow’s Triton ICE Thermoelectric Cooler will chill electronics as much as 2 degrees Celsius below current market offerings.

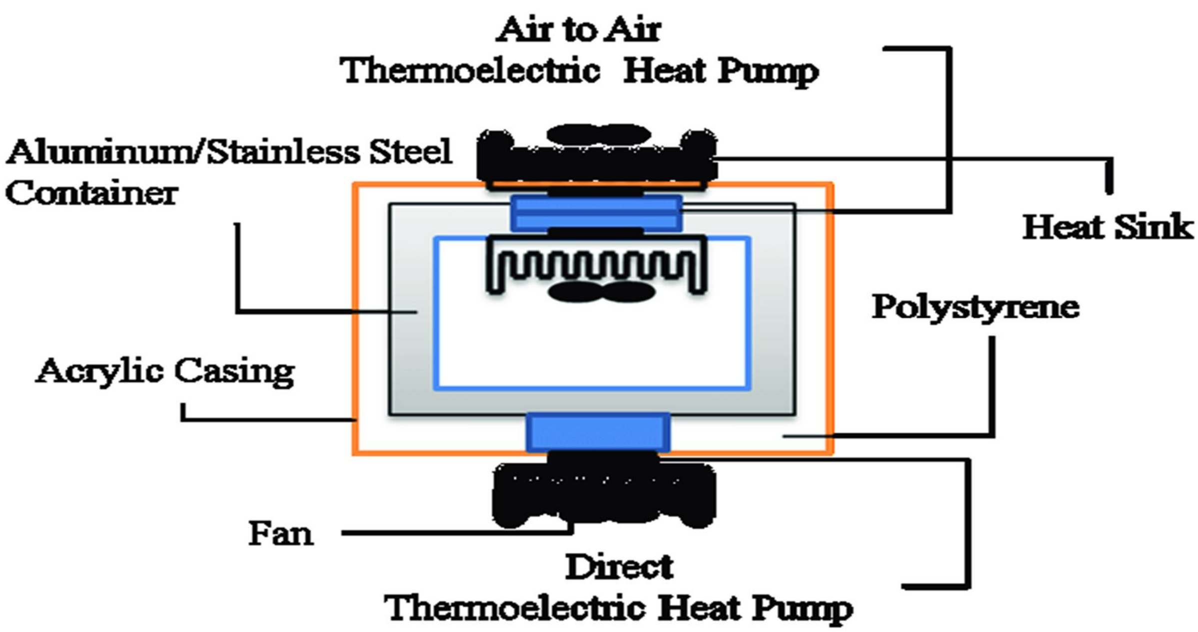

Fig 5. Working model of thermoelectric cooling

VIII. IMPROVEMENT OF COP

Solid-state refrigeration offers potential advantages over traditional cooling systems, but few devices offer high specific cooling power with a high coefficient of performance (COP) and the ability to be applied directly to surfaces. We developed a cooling device with a high intrinsic thermodynamic efficiency using a flexible electrocaloric (EC) polymer film and an electrostatic actuation mechanism. Reversible electrostatic forces reduce parasitic power consumption and allow efficient heat transfer through good thermal contacts with the heat source or heat sink. The EC device produced a specific cooling power of 2.8 watts per gram and a COP of 13. The new cooling device is more efficient and compact than existing surface-conformable solid-state cooling technologies, opening a path to using the technology for a variety of practical applications.

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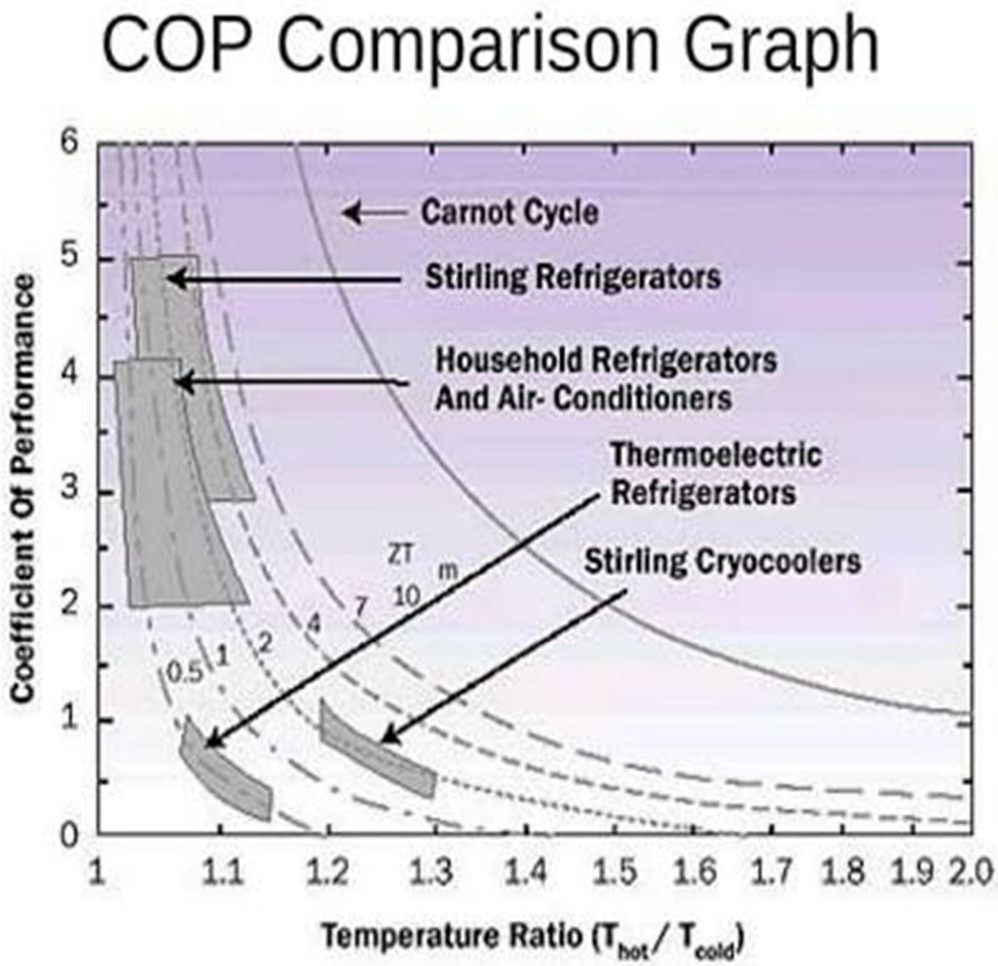

Fig 6. compression of COP

IX. ADVANTAGE OF THERMOELECTRIC REFRIGERATION

Some of the more significant features of thermoelectric modules include:

1) *No Moving Part:* A TE module works electrically without any moving parts so they are virtually maintenance free.
2) *Small Size And Weight:* The overall thermoelectric cooling system is much smaller and lighter than a comparable mechanical system. In addition, a variety of standard and special sizes and configurations are available to meet strict application requirements.
3) *Ability to cool below Ambient:* Unlike a conventional heat sink whose temperature necessarily must rise above ambient, a TE cooler attached to that same heat sink has the ability to reduce the temperature below the ambient value.
4) *Precise Temperature Controll:* With an appropriate closed-loop temperature control circuit, TE coolers can control temperatures to better than +/- 0.1°C.
5) *High Reliability:* Thermoelectric modules exhibit very high reliability due to their solid state construction. Although reliability is somewhat application dependent, the life of typical TE coolers is greater than 200,000 hours. Thermoelectric modules exhibit very high reliability due to their solid state construction. Although reliability is somewhat application dependent, the life of typical TE coolers is greater than 200,000 hours.
6) *Electrically "Quit" Operation:* Unlike a mechanical refrigeration system, TE modules generate virtually no electrical noise and can be used in conjunction with sensitive electronic sensors. They are also acoustically silent.
7) *Operation In Any Orientation:* TEs can be used in any orientation and in zero gravity environments. Thus they are popular in many aerospace applications.
8) *Convenient Power Supply:* TE modules operate directly from a DC power source. Modules having a wide range of input voltages and currents are available. Pulse Width Modulation (PWM) may be used in many applications

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9) *Spot cooling:* With a TE cooler it is possible to cool one specific component or area only, thereby often making it unnecessary to cool an entire package or enclosure.

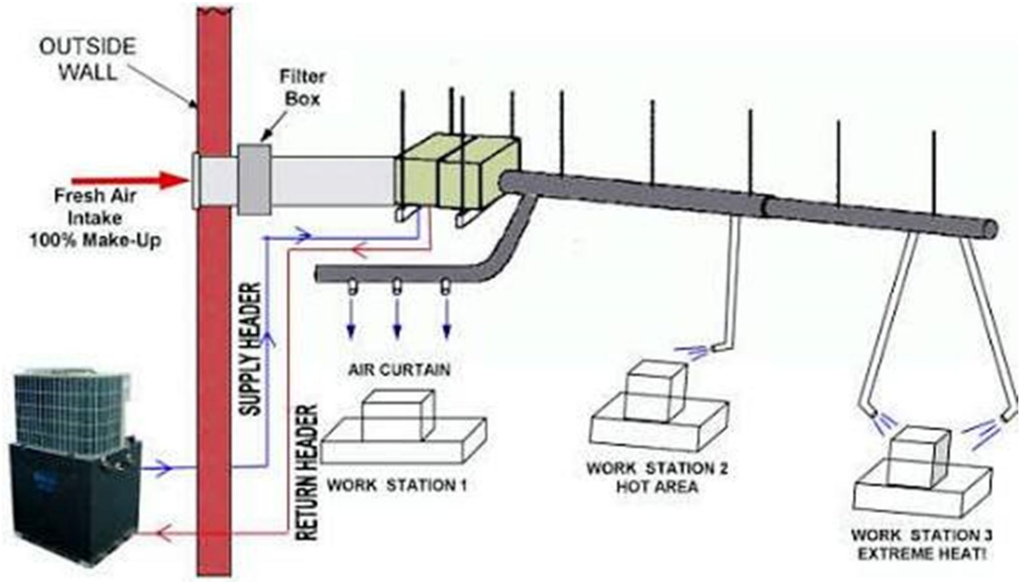

Fig 7.Spot cooling system

10) *Ability To Generate Electrical Power:* When used "in reverse" by applying a temperature differential across the faces of a TE cooler, it is possible to generate a small amount of DC power.
11) *Environmentally Friendly:* Conventional refrigeration systems can not be fabricated without using chlorofluorocarbons or other chemicals that may be harmful to the environment. Thermoelectric devices do not use or generate gases of any kind.

X. DISADVANTAGES OF THERMOELECTRIC REFRIGERATION

A. Advantageous only for unit smaller capacity.
B. More power needed to run the system.
C. Low COP.

XI. APPLICATION

1) Avionics
2) Black box cooling
3) CCD (Charged Couple Devices)
4) CID (Charge Induced Devices)
5) Cold chambers
6) Cold plates
7) Compact heat exchangers
8) Constant temperature baths
9) Dehumidifiers
10) Dew point hygrometers
11) Electronics package cooling
12) Electrophoresis cell coolers
13) Environmental anal
14) Heat density measurement
15) Ice point references
16) Immersion coolers
17) Integrated circuit cooling
18) Inertial guidance systems

19) Infrared calibration sources and black body references
20) Infrared detectors
21) Infrared seeking missiles
22) Laser collimators
23) Laser diode coolers
24) Long lasting cooling devices
25) Low noise amplifiers
26) Microprocessor cooling
27) Microtome stage coolers
28) NEMA enclosures
29) Night vision equipment
30) Osmometers
31) Parametric amplifiers
32) Photomultiplier tube housing
33) Power generators (small)
34) Precision device cooling (lasers and microprocessors)
35) Refrigerators and on-board refrigeration systems (aircraft, automobile, boat, hotel, insulin, portable/picnic, pharmaceutical, RV)
36) Restaurant portion dispenser
37) Self-scanned arrays systems
38) Semiconductor wafer probes
39) Stir coolers
40) Thermal viewers and weapons sights
41) Thermal cycling devices (DNA and blood analyzers)
42) Thermostat calibrating baths
43) Tissue preparation and storage
44) Vidicon tube coolers
45) Wafer thermal characterization
46) Water and beverage coolers
47) Wet process temperature controller
48) Wine cabinets

XII. CONCLUSION

Thermoelectric coolers can be used to cool computer components to keep temperatures within design limits or to maintain stable functioning when overclocking. A Peltier cooler with a heat sink or waterblock can cool a chip to well below ambient temperature.
In fiber-optic applications, where the wavelength of a laser or a component is highly dependent on temperature, Peltier coolers are used along with a thermistor in a feedback loop to maintain a constant temperature and thereby stabilize the wavelength of the device.Some electronic equipment intended for military use in the field is thermoelectrically cooled.

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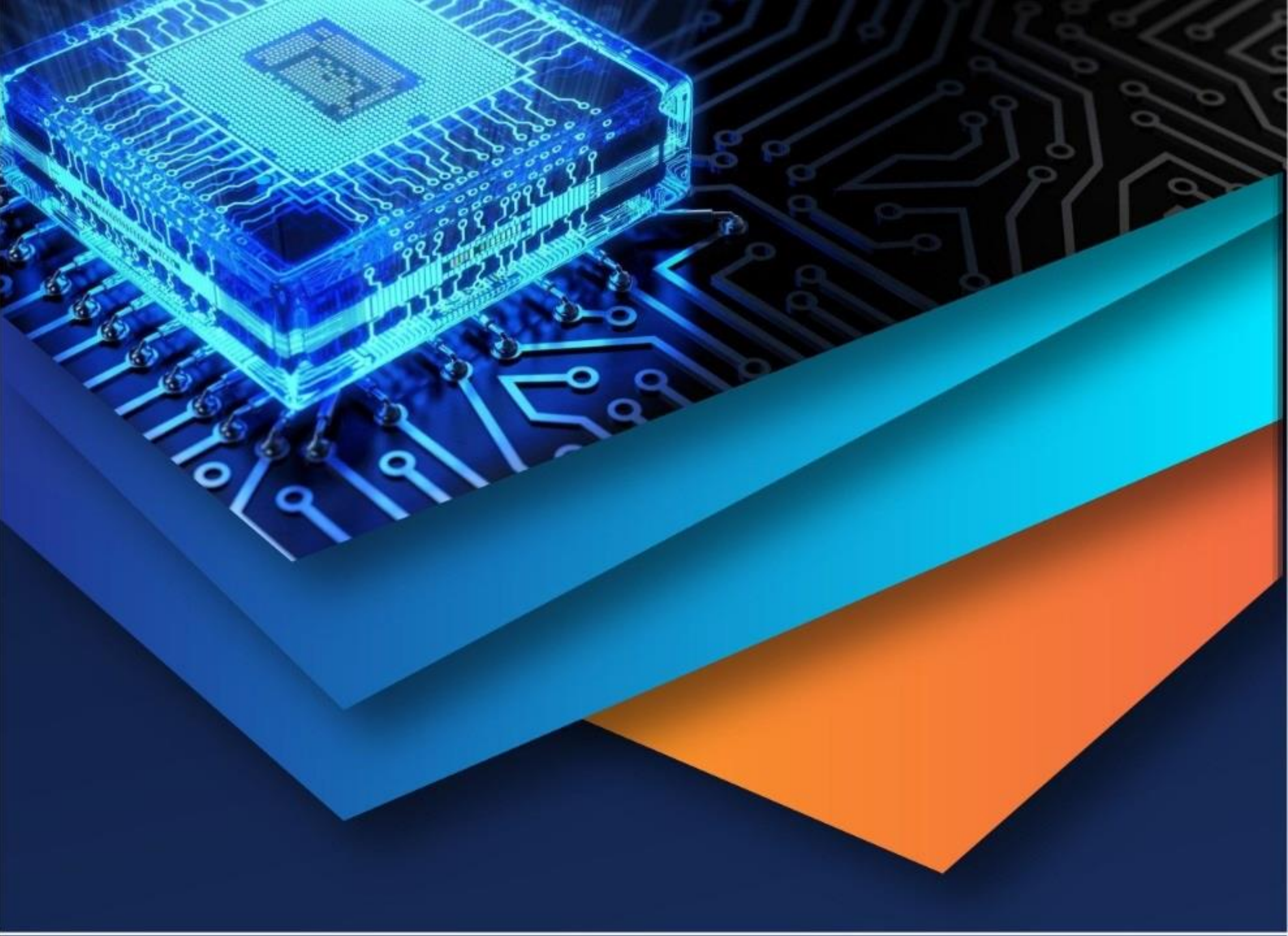

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