Objective of Project

The objective of the project is to develop Thermoelectric cooling System . Thermoelectric cooling uses the Peltier effect to create a heat flux between the junction of two different types of materials. This effect is commonly used in camping and portable coolers.

INTRODUCTION

What is refrigeration?

Refrigeration is a process in which work is done to move heat from one location to another. Refrigeration has many applications including but not limited to; household refrigerators, industrial freezers, cryogenics, air conditioning, and heat pumps.

Cold is the absence of heat, hence in order to decrease a temperature, one "removes heat", rather than "adding cold." In order to satisfy the Second Law of Thermodynamics, some form of work must be performed to accomplish this. The work is traditionally done by mechanical work but can also be done by magnetism, laser or other means.

Historical applications

Ice harvesting

The use of ice to refrigerate and thus preserve food goes back to prehistoric times. Through the ages, the seasonal harvesting of snow and ice was a regular practice of most of the ancient cultures: Chinese, Hebrews, Greeks, Romans, Persians. Ice and snow were stored in caves or dugouts lined with straw or other insulating materials. The Persians stored ice in pits called yakhchals. Rationing of the ice allowed the preservation of foods over the warm periods. This practice worked well down through the centuries, with icehouses remaining in use into the twentieth century.

In the 16th century, the discovery of chemical refrigeration was one of the first steps toward artificial means of refrigeration. Sodium nitrate or potassium nitrate, when added to water, lowered the water temperature and created a sort of refrigeration bath for cooling substances. In Italy, such a solution was used to chill wine and cakes.

During the first half of the 19th century, ice harvesting became big business in America. New Englander Frederic Tudor, who became known as the "Ice King", worked on developing better insulation products for the long distance shipment of ice, especially to the tropics.

First refrigeration systems

The first known method of artificial refrigeration was demonstrated by William Cullen at the University of Glasgow in Scotland in 1756. Cullen used a pump to create a partial vacuum over a container of diethyl ether, which then boiled, absorbing heat from the surrounding air. The experiment even created a small amount of ice, but had no practical application at that time.

In 1758, Benjamin Franklin and John Hadley, professor of chemistry at Cambridge University, conducted an experiment to explore the principle of evaporation as a means to rapidly cool an object. Franklin and Hadley confirmed that evaporation of highly volatile liquids such as alcohol and ether, could be used to drive down the temperature of an object past the freezing point of water. They conducted their experiment with the bulb of a mercury thermometer as their object and with a bellows used to "quicken" the evaporation; they lowered the temperature of the thermometer bulb down to 7 °F (−14 °C) while the ambient temperature was 65 °F (18 °C). Franklin noted that soon after they passed the freezing point of water (32 °F) a thin film of ice formed on the surface of the thermometer's bulb and that the ice mass was about a quarter inch

thick when they stopped the experiment upon reaching 7 °F (−14 °C). Franklin concluded, "From this experiment, one may see the possibility of freezing a man to death on a warm summer's day".

In 1805, American inventor Oliver Evans designed but never built a refrigeration system based on the vapor-compression refrigeration cycle rather than chemical solutions or volatile liquids such as ethyl ether.

In 1820, the British scientist Michael Faraday liquefied ammonia and other gases by using high pressures and low temperatures.

An American living in Great Britain, Jacob Perkins, obtained the first patent for a vapor-compression refrigeration system in 1834. Perkins built a prototype system and it actually worked, although it did not succeed commercially.

In 1842, an American physician, John Gorrie, designed the first system for refrigerating water to produce ice. He also conceived the idea of using his refrigeration system to cool the air for comfort in homes and hospitals (i.e., air-conditioning). His system compressed air, then partially cooled the hot compressed air with water before allowing it to expand while doing part of the work required to drive the air compressor. That isentropic expansion cooled the air to a temperature low enough to freeze water and produce ice, or to flow "through a pipe for effecting refrigeration otherwise" as stated in his patent granted by the U.S. Patent Office in 1851. Gorrie built a working prototype, but his system was a commercial failure.

Alexander Twining began experimenting with vapor-compression refrigeration in 1848 and obtained patents in 1850 and 1853. He is credited with having initiated commercial refrigeration in the United States by 1856.

Dunedin, the first commercially successful refrigerated ship.

Meanwhile in Australia, James Harrison began operation of a mechanical ice-making machine in 1851 on the banks of the Barwon River at Rocky Point in Geelong, Victoria. His first commercial ice-making machine followed in 1854 and his patent for an ether liquid-vapour compression refrigeration system was granted in 1855. Harrison introduced commercial vapor-compression refrigeration to breweries and meat packing houses, and by 1861 a dozen of his systems were in operation.

Australian, Argentine, and American concerns experimented with refrigerated shipping in the mid 1870s, the first commercial success coming when William Soltau Davidson fitted a compression refrigeration unit to the New Zealand vessel Dunedin in 1882, leading to a meat and dairy boom in Australasia and South America. J & E Hall of Dartford, England outfitted the 'SS Selembria' with a vapor compression system bring 30,000 carcasses of mutton from the Falkland Islands in 1886.

The first gas absorption refrigeration system using gaseous ammonia dissolved in water (referred to as "aqua ammonia") was developed by Ferdinand Carré of France in 1859 and patented in 1860. Due to the toxicity of ammonia, such systems were not developed for use in homes, but were used to manufacture ice for sale. In the United States, the consumer public at that time still used the ice box with ice brought in from commercial suppliers, many of whom were still harvesting ice and storing it in an icehouse.

Thaddeus Lowe, an American balloonist from the Civil War, had experimented over the years with the properties of gases. One of his mainstay enterprises was the high-volume production of hydrogen gas. He also held several patents on ice making machines. His "Compression Ice Machine" would revolutionize the cold storage industry. In 1869 he and other investors purchased an old steamship onto which they loaded one of Lowe's refrigeration units and began shipping fresh fruit from New York to the Gulf Coast area, and fresh meat from Galveston, Texas back to New York. Because of Lowe's lack of knowledge about shipping, the business was a costly failure, and it was difficult for the public to get used to the idea of being able to consume meat that had been so long out of the packing house.

Domestic mechanical refrigerators became available in the United States around 1911.

NEED OF REFRIGERATION

1. **Widespread commercial use**

Loading blocks of factory-made ice from a truck to an "ice depot" boat in the fishing harbor of Zhuhai, China

By the 1870s breweries had become the largest users of commercial refrigeration units, though some still relied on harvested ice. Though the ice-harvesting industry had grown immensely by the turn of the 20th century, pollution and sewage had begun to creep into natural ice making it a problem in the metropolitan suburbs. Eventually breweries began to complain of tainted ice. This

raised demand for more modern and consumer-ready refrigeration and ice-making machines. In 1895, German engineer Carl von Linde set up a large-scale process for the production of liquid air and eventually liquid oxygen for use in safe household refrigerators.

Refrigerated railroad cars were introduced in the US in the 1840s for the short-run transportation of dairy products. In 1867 J.B. Sutherland of Detroit, Michigan patented the refrigerator car designed with ice tanks at either end of the car and ventilator flaps near the floor which would create a gravity draft of cold air through the car.

By 1900 the meat packing houses of Chicago had adopted ammonia-cycle commercial refrigeration. By 1914 almost every location used artificial refrigeration. The big meat packers, Armour, Swift, and Wilson, had purchased the most expensive units which they installed on train cars and in branch houses and storage facilities in the more remote distribution areas.

It was not until the middle of the 20th century that refrigeration units were designed for installation on tractor-trailer rigs (trucks or lorries). Refrigerated vehicles are used to transport perishable goods, such as frozen foods, fruit and vegetables, and temperature-sensitive chemicals. Most modern refrigerators keep the temperature between -40 and +20 °C and have a maximum payload of around 24 000 kg. gross weight (in Europe).

2. Home and consumer use

With the invention of synthetic refrigerants based mostly on a chlorofluorocarbon (CFC) chemical, safer refrigerators were possible for home and consumer use. Freon is a trademark of the Dupont Corporation and refers to these CFC, and later hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC), refrigerants developed in the late 1920s. These refrigerants were considered at the time to be less harmful than the commonly used refrigerants of the time, including methyl formate, ammonia, methyl chloride, and sulfur dioxide. The intent was to provide refrigeration equipment for home use without danger: these CFC refrigerants answered that need. However, in the 1970s the compounds were found to be reacting with atmospheric ozone, an important protection against solar ultraviolet radiation, and their use as a refrigerant worldwide was curtailed in the Montreal Protocol of 1987.

Methods of refrigeration

Methods of refrigeration can be classified as non-cyclic, cyclic and thermoelectric.

Non-cyclic refrigeration

In non-cyclic refrigeration, cooling is accomplished by melting ice or by subliming dry ice (frozen carbon dioxide). These methods are used for small-scale refrigeration such as in laboratories and workshops, or in portable coolers.

Ice owes its effectiveness as a cooling agent to its constant melting point of 0 °C (32 °F). In order to melt, ice must absorb 333.55 kJ/kg (approx. 144 Btu/lb) of heat. Foodstuffs maintained at this temperature or slightly above have an increased storage life.

Solid carbon dioxide has no liquid phase at normal atmospheric pressure, so sublimes directly from the solid to vapor phase at a temperature of -78.5 °C (-109.3 °F), and is therefore effective for maintaining products at low temperatures during the period of sublimation. Systems such as this where the refrigerant evaporates and is vented into the atmosphere are known as "total loss refrigeration".

Cyclic refrigeration

This consists of a refrigeration cycle, where heat is removed from a low-temperature space or source and rejected to a high-temperature sink with the help of external work, and its inverse, the thermodynamic power cycle. In the power cycle, heat is supplied from a high-temperature source to the engine, part of the heat being used to produce work and the rest being rejected to a low-temperature sink. This satisfies the second law of thermodynamics.

A refrigeration cycle describes the changes that take place in the refrigerant as it alternately absorbs and rejects heat as it circulates through a refrigerator. It is also applied to HVACR work, when describing the "process" of refrigerant flow through an HVACR unit, whether it is a packaged or split system.

Heat naturally flows from hot to cold. Work is applied to cool a living space or storage volume by pumping heat from a lower temperature heat source into a higher temperature heat sink. Insulation is used to reduce the work and energy required to achieve and maintain a lower temperature in the cooled space. The operating principle of the refrigeration cycle was described mathematically by Sadi Carnot in 1824 as a heat engine.

The most common types of refrigeration systems use the reverse-Rankine vapor-compression refrigeration cycle although absorption heat pumps are used in a minority of applications.

Cyclic refrigeration can be classified as:

1. Vapor cycle, and
2. Gas cycle

Vapor cycle refrigeration can further be classified as:

1. Vapor-compression refrigeration
2. Vapor-absorption refrigeration

1. **Vapor-compression cycle**

The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Figure 1 provides a schematic diagram of the components of a typical vapor-compression refrigeration system.
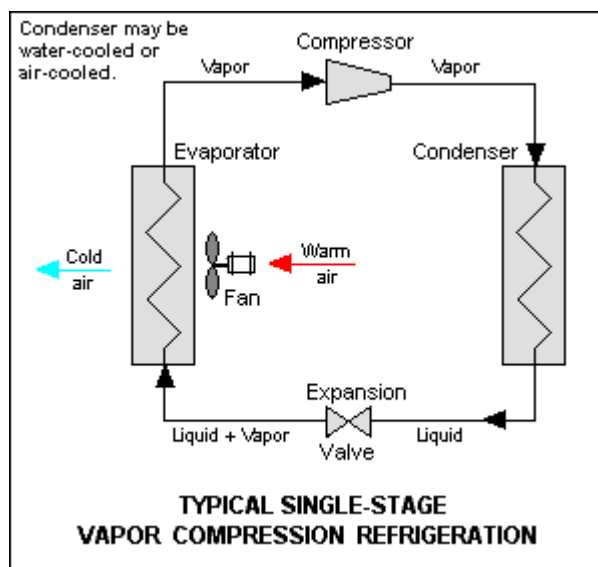
Figure 1: Vapor compression refrigeration

The thermodynamics of the cycle can be analyzed on a diagram as shown in Figure 2. In this cycle, a circulating refrigerant such as Freon enters the compressor as a vapor. From point 1 to point 2, the vapor is compressed at constant entropy and exits the compressor as a vapor at a higher temperature, but still below the vapor pressure at that temperature. From point 2 to point 3 and on to point 4, the vapor travels through the condenser which cools the vapor until it starts condensing, and then condenses the vapor into a liquid by removing additional heat at constant pressure and temperature. Between points 4 and 5, the liquid refrigerant goes through the expansion valve (also called a throttle valve) where its pressure abruptly decreases, causing flash evaporation and auto-refrigeration of, typically, less than half of the liquid.
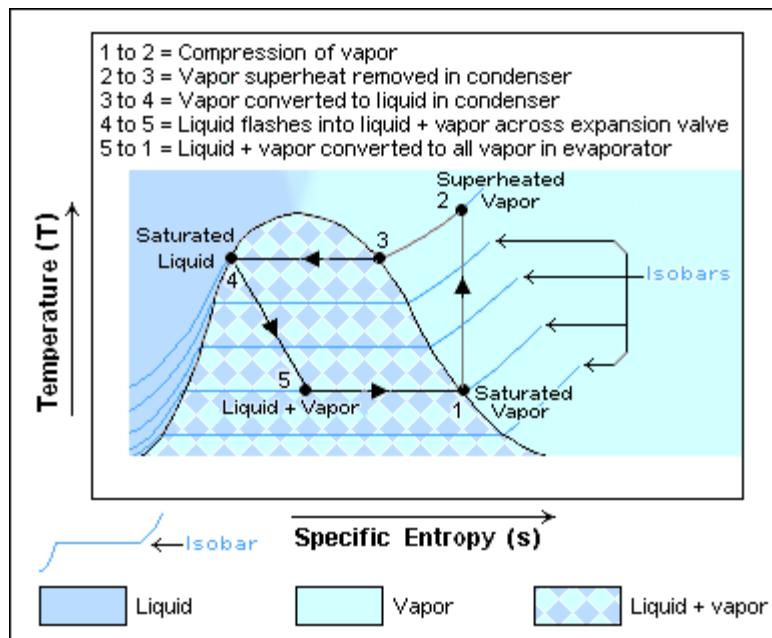

Figure 2: Temperature–Entropy diagram

That results in a mixture of liquid and vapor at a lower temperature and pressure as shown at point 5. The cold liquid-vapor mixture then travels through the evaporator coil or tubes and is completely vaporized by cooling the warm air (from the space being refrigerated) being blown by a fan across the evaporator coil or tubes. The resulting refrigerant vapor returns to the compressor inlet at point 1 to complete the thermodynamic cycle.

The above discussion is based on the ideal vapor-compression refrigeration cycle, and does not take into account real-world effects like frictional pressure drop in the system, slight thermodynamic irreversibility during the compression of the refrigerant vapor, or non-ideal gas behavior (if any).

2. Vapor absorption cycle

In the early years of the twentieth century, the vapor absorption cycle using water-ammonia systems was popular and widely used. After the development of the vapor compression cycle, the vapor absorption cycle lost much of its importance because of its low coefficient of performance (about one fifth of that of the vapor compression cycle). Today, the vapor absorption cycle is

used mainly where fuel for heating is available but electricity is not, such as in recreational vehicles that carry LP gas. It's also used in industrial environments where plentiful waste heat overcomes its inefficiency.

The absorption cycle is similar to the compression cycle, except for the method of raising the pressure of the refrigerant vapor. In the absorption system, the compressor is replaced by an absorber which dissolves the refrigerant in a suitable liquid, a liquid pump which raises the pressure and a generator which, on heat addition, drives off the refrigerant vapor from the high-pressure liquid. Some work is required by the liquid pump but, for a given quantity of refrigerant, it is much smaller than needed by the compressor in the vapor compression cycle. In an absorption refrigerator, a suitable combination of refrigerant and absorbent is used. The most common combinations are ammonia (refrigerant) and water (absorbent), and water (refrigerant) and lithium bromide (absorbent).

Gas cycle

When the working fluid is a gas that is compressed and expanded but doesn't change phase, the refrigeration cycle is called a gas cycle. Air is most often this working fluid. As there is no condensation and evaporation intended in a gas cycle, components corresponding to the condenser and evaporator in a vapor compression cycle are the hot and cold gas-to-gas heat exchangers in gas cycles.

The gas cycle is less efficient than the vapor compression cycle because the gas cycle works on the reverse Brayton cycle instead of the reverse Rankine cycle. As such the working fluid does not receive and reject heat at constant temperature. In the gas cycle, the refrigeration effect is equal to the product of the specific heat of the gas and the rise in temperature of the gas in the low temperature side. Therefore, for the same cooling load, a gas refrigeration cycle will require a large mass flow rate and would be bulky.

Because of their lower efficiency and larger bulk, air cycle coolers are not often used nowadays in terrestrial cooling devices. The air cycle machine is very common, however, on gas turbine-powered jet aircraft because compressed air is readily available from the engines' compressor sections. These jet aircraft's cooling and ventilation units also serve the purpose of pressurizing the aircraft.

Thermoelectric refrigeration

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junction of two different types of materials. This effect is commonly used in camping and portable coolers and for cooling electronic components and small instruments.

Magnetic refrigeration

Magnetic refrigeration, or adiabatic demagnetization, is a cooling technology based on the magnetocaloric effect, an intrinsic property of magnetic solids. The refrigerant is often a paramagnetic salt, such as cerium magnesium nitrate. The active magnetic dipoles in this case are those of the electron shells of the paramagnetic atoms.

A strong magnetic field is applied to the refrigerant, forcing its various magnetic dipoles to align and putting these degrees of freedom of the refrigerant into a state of lowered entropy. A heat sink then absorbs the heat released by the refrigerant due to its loss of entropy. Thermal contact with the heat sink is then broken so that the system is insulated, and the magnetic field is switched off. This increases the heat capacity of the refrigerant, thus decreasing its temperature below the temperature of the heat sink.

Because few materials exhibit the required properties at room temperature, applications have so far been limited to cryogenics and research.

Other methods

Other methods of refrigeration include the air cycle machine used in aircraft; the vortex tube used for spot cooling, when compressed air is available; and thermoacoustic refrigeration using sound waves in a pressurized gas to drive heat transfer and heat exchange. Many Stirling cycle heat engines can be run backwards to act as a refrigerator, and therefore these engines have a niche use in cryogenics.

Thermoelectric effect

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates a voltage when there is a different temperature on each side. Conversely when a voltage is applied to it, it creates a temperature difference (known as the Peltier effect). At atomic scale (specifically, charge carriers), an applied temperature gradient causes charged carriers in the material, whether they are electrons or electron holes, to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated; hence, the thermally induced current.

This effect can be used to generate electricity, to measure temperature, to cool objects, or to heat them or cook them. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices make very convenient temperature controllers.

Traditionally, the term thermoelectric effect or thermoelectricity encompasses three separately identified effects, the Seebeck effect, the Peltier effect, and the Thomson effect. In many textbooks, thermoelectric effect may also be called the Peltier–Seebeck effect. This separation derives from the independent discoveries of French physicist Jean Charles Athanase Peltier and Estonian-German physicist Thomas Johann Seebeck. Joule heating, the heat that is generated whenever a voltage is applied across a resistive material, is somewhat related, though it is not generally termed a thermoelectric effect (and it is usually regarded as being a loss mechanism due to non-ideality in thermoelectric devices). The Peltier–Seebeck and Thomson effects can in principle be thermodynamically reversible, whereas Joule heating is not.

Seebeck effect

The Seebeck effect is the conversion of temperature differences directly into electricity.

Seebeck discovered that a compass needle would be deflected when a closed loop was formed of two metals joined in two places with a temperature difference between the junctions. This is because the metals respond differently to the temperature difference, which creates a current loop, which produces a magnetic field. Seebeck, however, at this time did not recognize there was an electric current involved, so he called the phenomenon the thermomagnetic effect, thinking that the two metals became magnetically polarized by the temperature gradient. The Danish physicist Hans Christian Ørsted played a vital role in explaining and conceiving the term "thermoelectricity".

The effect is that a voltage, the thermoelectric EMF, is created in the presence of a temperature difference between two different metals or semiconductors. This causes a continuous current in the conductors if they form a complete loop. The voltage created is of the order of several microvolts per kelvin difference. One such combination, copper-constantan, has a Seebeck coefficient of 41 microvolts per kelvin at room temperature.

In the circuit:
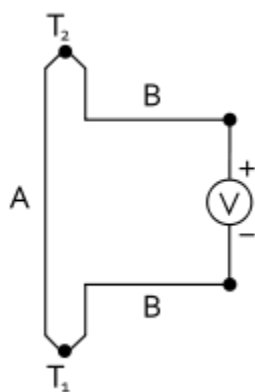
(which can be in several different configurations and be governed by the same equations), the voltage developed can be derived from:

$$V = \int_{T_1}^{T_2} (S_B(T) - S_A(T))\, dT.$$

S_A and S_B are the Seebeck coefficients (also called thermoelectric power or thermopower) of the metals A and B as a function of temperature, and T_1 and T_2 are the temperatures of the two junctions. The Seebeck coefficients are non-linear as a function of temperature, and depend on the conductors' absolute temperature, material, and molecular structure. If the Seebeck coefficients are effectively constant for the measured temperature range, the above formula can be approximated as:

$$V = (S_B - S_A) \cdot (T_2 - T_1).$$

The Seebeck effect is commonly used in a device called a thermocouple (because it is made from a coupling or junction of materials, usually metals) to measure a temperature difference directly or to measure an absolute temperature by setting one end to a known temperature. A metal of unknown composition can be classified by its thermoelectric effect if a metallic probe of known composition, kept at a constant temperature, is held in contact with it. Industrial quality control instruments use this Seebeck effect to identify metal alloys. This is known as thermoelectric alloy sorting.

Several thermocouples connected in series are called a thermopile, which is sometimes constructed in order to increase the output voltage since the voltage induced over each individual couple is small.

This is also the principle at work behind thermal diodes and thermoelectric generators (such as radioisotope thermoelectric generators or RTGs) which are used for creating power from heat differentials.

The Seebeck effect is due to two effects: charge carrier diffusion and phonon drag (described below). If both connections are held at the same temperature, but one connection is periodically opened and closed, an AC voltage is measured, which is also temperature dependent. This application of the Kelvin probe is sometimes used to argue that the underlying physics only needs one junction. And this effect is still visible if the wires only come close, but do not touch, thus no diffusion is needed.

Thermopower

The thermopower, thermoelectric power, or Seebeck coefficient of a material measures the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material. The thermopower has units of (V/K), though in practice it is more common to use microvolts per kelvin. Values in the hundreds of μV/K, negative or positive, are typical of good thermoelectric materials. The term thermopower is a misnomer since it measures the voltage or electric field induced in response to a temperature difference, not the electric power. An applied temperature difference causes charged carriers in the material, whether they are electrons or holes, to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated. Mobile charged carriers migrating to the cold side leave behind their oppositely charged and immobile nuclei at the hot side thus giving rise to a thermoelectric voltage (thermoelectric refers to the fact that the voltage is created by a temperature difference). Since a separation of

charges also creates an electric potential, the buildup of charged carriers onto the cold side eventually ceases at some maximum value since there exists an equal amount of charged carriers drifting back to the hot side as a result of the electric field at equilibrium. Only an increase in the temperature difference can resume a buildup of more charge carriers on the cold side and thus lead to an increase in the thermoelectric voltage. Incidentally the thermopower also measures the entropy per charge carrier in the material. To be more specific, the partial molar electronic entropy is said to equal the absolute thermoelectric power multiplied by the negative of Faraday's constant.

The thermopower of a material, represented by S (or sometimes by α), depends on the material's temperature and crystal structure. Typically metals have small thermopowers because most have half-filled bands. Electrons (negative charges) and holes (positive charges) both contribute to the induced thermoelectric voltage thus canceling each other's contribution to that voltage and making it small. In contrast, semiconductors can be doped with excess electrons or holes, and thus can have large positive or negative values of the thermopower depending on the charge of the excess carriers. The sign of the thermopower can determine which charged carriers dominate the electric transport in both metals and semiconductors.

If the temperature difference ΔT between the two ends of a material is small, then the thermopower of a material is defined (approximately) as:

$$S = \frac{\Delta V}{\Delta T}$$

and a thermoelectric voltage ΔV is seen at the terminals.

This can also be written in relation to the electric field E and the temperature gradient ∇T, by the approximate equation:

$$S = \frac{E}{\nabla T}.$$

In practice one rarely measures the absolute thermopower of the material of interest. This is because electrodes attached to a voltmeter must be placed onto the material in order to measure the thermoelectric voltage. The temperature gradient then also typically induces a thermoelectric voltage across one leg of the measurement electrodes. Therefore the measured thermopower includes a contribution from the thermopower of the material of interest and the material of the measurement electrodes.

The measured thermopower is then a contribution from both and can be written as:

$$S_{AB} = S_B - S_A = \frac{\Delta V_B}{\Delta T} - \frac{\Delta V_A}{\Delta T}.$$

Superconductors have zero thermopower since the charged carriers produce no entropy. This allows a direct measurement of the absolute thermopower of the material of interest, since it is

the thermopower of the entire thermocouple as well. In addition, a measurement of the Thomson coefficient, μ, of a material can also yield the thermopower through the relation:

$$S = \int \frac{\mu}{T} dT.$$

The thermopower is an important material parameter that determines the efficiency of a thermoelectric material. A larger induced thermoelectric voltage for a given temperature gradient will lead to a larger efficiency. Ideally one would want very large thermopower values since only a small amount of heat is then necessary to create a large voltage. This voltage can then be used to provide power.

Charge-carrier diffusion

Charge carriers in the materials (electrons in metals, electrons and holes in semiconductors, ions in ionic conductors) will diffuse when one end of a conductor is at a different temperature to the other. Hot carriers diffuse from the hot end to the cold end, since there is a lower density of hot carriers at the cold end of the conductor. Cold carriers diffuse from the cold end to the hot end for the same reason.If the conductor were left to reach thermodynamic equilibrium, this process would result in heat being distributed evenly throughout the conductor .The movement of heat (in the form of hot charge carriers) from one end to the other is called a heat current. As charge carriers are moving, it is also an electric current.In a system where both ends are kept at a constant temperature difference (a constant heat current from one end to the other), there is a constant diffusion of carriers. If the rate of diffusion of hot and cold carriers in opposite directions were equal, there would be no net change in charge. However, the diffusing charges are scattered by impurities, imperfections, and lattice vibrations (phonons). If the scattering is energy dependent, the hot and cold carriers will diffuse at different rates. This creates a higher density of carriers at one end of the material, and the distance between the positive and negative charges produces a potential difference; an electrostatic voltage.This electric field, however, opposes the uneven scattering of carriers, and an equilibrium is reached where the net number of carriers diffusing in one direction is canceled by the net number of carriers moving in the opposite direction from the electrostatic field. This means the thermopower of a material depends greatly on impurities, imperfections, and structural changes (which often vary themselves with temperature and electric field), and the thermopower of a material is a collection of many different effects.

Early thermocouples were metallic, but many more recently developed thermoelectric devices are made from alternating p-type and n-type semiconductor elements connected by metallic interconnects as pictured in the figures below. Semiconductor junctions are especially common in power generation devices, while metallic junctions are more common in temperature measurement. Charge flows through the n-type element, crosses a metallic interconnect, and passes into the p-type element. If a power source is provided, the thermoelectric device may act as a cooler, as in the figure to the left below. This is the Peltier effect, described below. Electrons in the n-type element will move opposite the direction of current and holes in the p-type element will move in the direction of current, both removing heat from one side of the device. If a heat source is provided, the thermoelectric device may function as a power generator, as in the figure to the right below. The heat source will drive electrons in the n-type element toward the cooler region, thus creating a current through the circuit. Holes in the p-type element will then flow in the direction of the current. The current can then be used to power a load, thus converting the thermal energy into electrical energy.
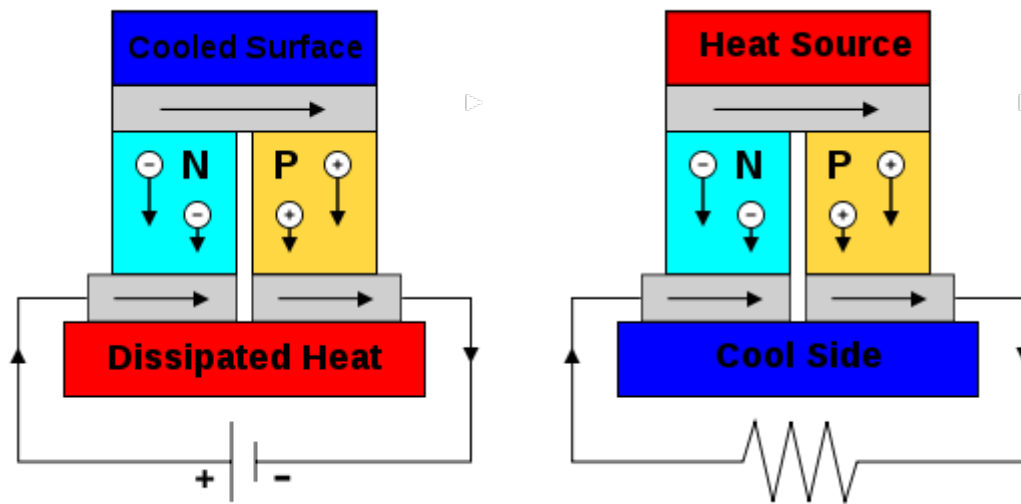
Phonon drag

Phonons are not always in local thermal equilibrium; they move against the thermal gradient. They lose momentum by interacting with electrons (or other carriers) and imperfections in the crystal. If the phonon-electron interaction is predominant, the phonons will tend to push the electrons to one end of the material, losing momentum in the process. This contributes to the already present thermoelectric field. This contribution is most important in the temperature region where phonon-electron scattering is predominant. This happens for

$$T \approx \frac{1}{5}\theta_{\mathrm{D}}$$

where θ_{D} is the Debye temperature. At lower temperatures there are fewer phonons available for drag, and at higher temperatures they tend to lose momentum in phonon-phonon scattering instead of phonon-electron scattering.

This region of the thermopower-versus-temperature function is highly variable under a magnetic field.

Spin Seebeck Effect and Magnetic Batteries

Physicists have recently discovered that heating one side of a magnetized nickel-iron rod causes electrons to rearrange themselves according to their spins. This so-called "spin Seebeck effect" could lead to batteries that generate magnetic currents, rather than electric currents. A source of magnetic currents could be especially useful for the development of spintronics devices, which use magnetic currents in order to reduce overheating in computer chips, since, unlike electric currents, steady magnetic currents do not generate heat.

Peltier effect

The Peltier effect bears the name of Jean-Charles Peltier, a French physicist who in 1834 discovered the calorific effect of an electric current at the junction of two different metals. When a current is made to flow through the circuit, heat is evolved at the upper junction (at T_2), and absorbed at the lower junction (at T_1). The Peltier heat absorbed by the lower junction per unit time, $\dot{Q}$ is equal to

$$\dot{Q} = \Pi_{AB} I = (\Pi_B - \Pi_A) I$$

where π is the Peltier coefficient Π_{AB} of the entire thermocouple, and Π_A and Π_B are the coefficients of each material. p-type silicon typically has a positive Peltier coefficient (though not above ~550 K), and n-type silicon is typically negative.

The Peltier coefficients represent how much heat current is carried per unit charge through a given material. Since charge current must be continuous across a junction, the associated heat flow will develop a discontinuity if Π_A and Π_B are different. This causes a non-zero divergence at the junction and so heat must accumulate or deplete there, depending on the sign of the current. Another way to understand how this effect could cool a junction is to note that when electrons flow from a region of high density to a region of low density, this "expansion" causes cooling (as with an ideal gas).

The carriers are attempting to return to the electron equilibrium that existed before the current was applied by absorbing energy at one connector and releasing it at the other. The individual couples can be connected in series to enhance the effect.

An interesting consequence of this effect is that the direction of heat transfer is controlled by the polarity of the current; reversing the polarity will change the direction of transfer and thus the sign of the heat absorbed/evolved.

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. Peltier cooling is also called thermo-electric cooling (TEC).

Thomson effect

The Thomson effect was predicted and subsequently experimentally observed by William Thomson (Lord Kelvin) in 1851. It describes the heating or cooling of a current-carrying conductor with a temperature gradient.

Any current-carrying conductor (except for a superconductor), with a temperature difference between two points, will either absorb or emit heat, depending on the material.

If a current density J is passed through a homogeneous conductor, heat production per unit volume is:

$$q = \rho J^2 - \mu J \frac{dT}{dx}$$

where

ρ is the resistivity of the material

dT/dx is the temperature gradient along the wire

μ is the Thomson coefficient.

The first term $\rho\, J^2$ is simply the Joule heating, which is not reversible.

The second term is the Thomson heat, which changes sign when J changes direction.

In metals such as zinc and copper, which have a hotter end at a higher potential and a cooler end at a lower potential, when current moves from the hotter end to the colder end, it is moving from a high to a low potential, so there is an evolution of heat. This is called the positive Thomson effect.

In metals such as cobalt, nickel, and iron, which have a cooler end at a higher potential and a hotter end at a lower potential, when current moves from the hotter end to the colder end, it is moving from a low to a high potential, there is an absorption of heat. This is called the negative Thomson effect.

The Thomson coefficient is unique among the three main thermoelectric coefficients because it is the only thermoelectric coefficient directly measurable for individual materials. The Peltier and Seebeck coefficients can only be determined for pairs of materials. Thus, there is no direct experimental method to determine an absolute Seebeck coefficient (i.e. thermopower) or absolute Peltier coefficient for an individual material. However, as mentioned elsewhere in this article there are two equations, the Thomson relations, also known as the Kelvin relations (see below), relating the three thermoelectric coefficients. Therefore, only one can be considered unique.

If the Thomson coefficient of a material is measured over a wide temperature range, including temperatures close to zero, one can then integrate the Thomson coefficient over the temperature range using the Kelvin relations to determine the absolute (i.e. single-material) values for the Peltier and Seebeck coefficients. In principle, this need only be done for one material, since all other values can be determined by measuring pairwise Seebeck coefficients in thermocouples containing the reference material and then adding back the absolute thermoelecric power (thermopower) of the reference material.

It is commonly asserted that lead has a zero Thomson effect. While it is true that the thermoelectric coefficients of lead are small, they are in general non-zero. The Thomson coefficient of lead has been measured over a wide temperature range and has been integrated to calculate the absolute thermoelectric power (thermopower) of lead as a function of temperature.

Unlike lead, the thermoelectric coefficients of all known superconductors are zero.

The Thomson relationships

The Seebeck effect is actually a combination of the Peltier and Thomson effects. In fact, in 1854 Thomson found two relationships, now called the Thomson or Kelvin relationships, between the corresponding coefficients. The absolute temperature T, the Peltier coefficient Π and Seebeck coefficient S are related by the second Thomson relation

$$\Pi = S \cdot T$$

which predicted the Thomson effect before it was actually formalized. These are related to the Thomson coefficient μ by the first Thomson relation

$$\mu = TdS/dT.$$

Thomson's theoretical treatment of thermoelectricity is remarkable in the fact that it is probably the first attempt to develop a reasonable theory of irreversible thermodynamics (non-equilibrium thermodynamics). This occurred at about the time that Clausius, Thomson, and others were introducing and refining the concept of entropy.

Figure of merit

The figure of merit for thermoelectric devices is defined as

$$Z = \frac{\sigma S^2}{\kappa},$$

where σ is the electrical conductivity, κ is the thermal conductivity, and S is the Seebeck coefficient or thermopower (conventionally in μV/K). This is more commonly expressed as the dimensionless figure of merit ZT by multiplying it with the average temperature $((T_2 + T_1) / 2)$. Greater values of ZT indicate greater thermodynamic efficiency, subject to certain provisions, particularly the requirement that the two materials of the couple have similar Z values. ZT is therefore a very convenient figure for comparing the potential efficiency of devices using different materials. Values of ZT=1 are considered good, and values of at least the 3–4 range are considered to be essential for thermoelectrics to compete with mechanical generation and refrigeration in efficiency. To date, the best reported ZT values have been in the 2–3 range. Much research in thermoelectric materials has focused on increasing the Seebeck coefficient and reducing the thermal conductivity, especially by manipulating the nanostructure of the materials.

Device efficiency

The efficiency of a thermoelectric device for electricity generation is given by η, defined as

$$\eta = \frac{\text{energy provided to the load}}{\text{heat energy absorbed at hot junction}}$$

, and

$$\eta_{max} = \frac{T_H - T_C}{T_H} \frac{\sqrt{1 + Z\bar{T}} - 1}{\sqrt{1 + Z\bar{T}} + \frac{T_C}{T_H}}$$

where T_H is the temperature at the hot junction and T_C is the temperature at the surface being cooled. $Z\bar{T}$ is the modified dimensionless figure of merit which now takes into consideration the thermoelectric capacity of both thermoelectric materials being used in the power generating device, and is defined as

$$ZT = \frac{(S_p - S_n)^2 \bar{T}}{[(\rho_n \kappa_n)^{1/2} + (\rho_p \kappa_p)^{1/2}]^2}$$

where ρ is the electrical resistivity, $\bar{T}$ is the average temperature between the hot and cold surfaces, and the subscripts n and p denote properties related to the n- and p-type semiconducting thermoelectric materials, respectively. It is worthwhile to note that the efficiency of a thermoelectric device is limited by the Carnot efficiency (hence the T_H and T_C terms in Φ_{max}), since thermoelectric devices are still inherently heat engines.

The COP of current commercial thermoelectric refrigerators ranges from 0.3 to 0.6, only about one-sixth the value of traditional vapor-compression refrigerators.

Uses

Thermocouples and thermopiles are commonly used to measure temperatures. They use the Seebeck effect. More precisely, they do not directly measure temperature, they measure temperature differences between the probe and the voltmeter at the other end of the wires. The temperature of the voltmeter, usually the same as room temperature, can be measured separately using "cold junction compensation" techniques.

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 side against the temperature gradient (from cold to hot), with consumption of electrical energy. Such an instrument is also called a Peltier device, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC). Because heating can be achieved more easily and economically by

many other methods, Peltier devices are mostly used for cooling. However, when a single device is to be used for both heating and cooling, a Peltier device may be desirable. Simply connecting it to a DC voltage will cause one side to cool, while the other side warms. The effectiveness of the pump at moving the heat away from the cold side is dependent upon the amount of current provided and how well the heat can be removed from the hot side.

A Peltier cooler is the opposite of a thermoelectric generator. In a Peltier cooler, electric power is used to generate a temperature difference between the two sides of the device; while in a thermoelectric generator, a temperature difference between the two sides is used to generate electric power. The operation of both is closely related (both are manifestations of the thermoelectric effect), and therefore the devices are generally constructed from similar materials using similar designs.
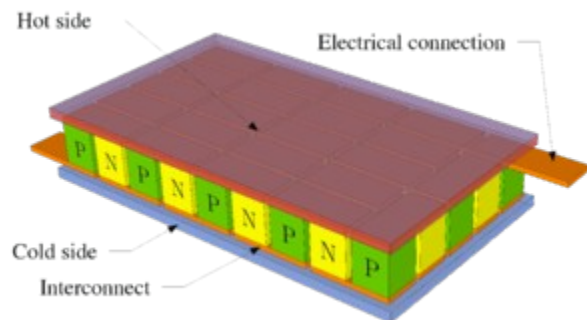
Peltier element schematic: Thermoelectric legs are thermally in parallel and electrically in series.

Peltier element (16x16 mm)

Thermoelectric junctions are generally only around 5–10% as efficient as the ideal refrigerator (Carnot cycle), compared with 40–60% achieved by conventional compression cycle systems (reverse Rankine systems using compression/expansion). Due to the relatively low efficiency, thermoelectric cooling is generally only used in environments where the solid state nature (no moving parts, maintenance-free) outweighs pure efficiency.

Peltier (thermoelectric) cooler performance is a function of ambient temperature, hot and cold side heat exchanger (heat sink) performance, thermal load, Peltier module (thermopile) geometry, and Peltier electrical parameters.

Uses

Peltier devices are commonly used in camping and portable coolers and for cooling electronic components and small instruments. Some electronic equipment intended for military use in the field is thermoelectrically cooled. The cooling effect of Peltier heat pumps can also be used to extract water from the air in dehumidifiers.

Peltier elements are a common component in thermal cyclers, used for the synthesis of DNA by polymerase chain reaction (PCR), a common molecular biological technique which requires the rapid heating and cooling of the reaction mixture for denaturation, primer annealing and enzymatic synthesis cycles.

The effect is used in satellites and spacecraft to counter the effect of direct sunlight on one side of a craft by dissipating the heat over the cold shaded side, whereupon the heat is dissipated by thermal radiation into space.

Photon detectors such as CCDs in astronomical telescopes or very high-end digital cameras are often cooled down with Peltier elements. This reduces dark counts due to thermal noise. A dark count is the event that a pixel gives a signal although it has not received a photon but rather mistook a thermal fluctuation for one. On digital photos taken at low light these occur as speckles (or "pixel noise").

Thermoelectric coolers can be used to cool computer components to keep temperatures within design limits without the noise of a fan, or to maintain stable functioning when overclocking. 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. A Peltier cooler with a heat sink or waterblock can cool a chip to well below ambient temperature.

A USB powered beverage cooler

Peltier devices are used in USB drink coolers/chillers, one of the latest addition to USB gadgets/toys. These devices are powered directly from the USB port and are said to keep drinks chilled, some can even keep drinks warm. The effectiveness of these devices, however, is highly questionable. The available power from a USB socket is very limited (maximum of 500 mA at 5 VDC for most situations, although high-power ports providing 1 amp or more do exist) so cooling or heating will be minimal (5-10% of 2.5 W).

Thermoelectric materials

Thermoelectric materials show the thermoelectric effect in a strong and/or convenient form. The thermoelectric effect refers to phenomena in which a temperature difference creates an electric potential or electric potential creates a temperature difference: Specifically, the Seebeck effect (temperature->current), Peltier effect (current->temperature), and Thomson effect (conductor heating/cooling). While all materials have a nonzero thermoelectric effect, in most materials it is too small to be useful. However, low cost materials that have a sufficiently strong thermoelectric effect (and other required properties) could be used for applications including power generation, refrigeration and a variety of other applications.

A commonly used thermoelectric material in such applications is Bismuth telluride (Bi_2Te_3).

Applications

Power generation

Approximately 90% of the world's electricity is generated by heat energy, typically operating at 30-40% efficiency, losing roughly 15 terawatts of power in the form of heat to the environment. Thermoelectric devices could convert this waste heat into useful electricity. Thermoelectric efficiency depends on the figure of merit, ZT. There is no theoretical upper limit to ZT, although no known thermoelectrics have a ZT>1. 2010 devices serve application niches where efficiency is less important than reliability, light weight, and small size.

Internal combustion engines capture 20-25% of the energy released during fuel combustion. Increasing the conversion rate can increase mileage and provide more electricity for on-board controls and creature comforts (stability controls, telematics, navigation systems, electronic braking, etc.) It may be possible to shift energy draw from the engine (in certain cases) to the electrical load in the car, e.g. electrical power steering or electrical coolant pump operation.

Cogeneration power plants use the heat produced during electricity generation for alternative purposes. Thermoelectrics may find applications in such systems or in solar thermal energy generation.

Refrigeration

Peltier effect devices could reduce the emission of ozone-depleting refrigerants into the atmosphere. Hydrochlorofluorocarbons (HCFCs) and now-obsolete chlorofluorocarbons (CFCs) deplete the ozone layer. CFCs were replaced by HCFCs, however, the latter also impact the ozone and are being phased out. International legislation caps HCFC production and prohibits production after 2020 in developed countries and 2030 in developing countries. Thermoelectric refrigeration units could reduce the use of such harmful chemicals and reduce noise levels because they do not require compressors.) Common (vapor compression) refrigerators remain more efficient than peltier refrigerators, but they are larger and require more maintenance. A ZT>3 (about 20-30% Carnot efficiency) is required to replace traditional coolers.

Materials selection criteria

Figure of merit

The primary criterion for thermoelectric device viability is the figure of merit given by:

$$Z = \frac{\sigma S^2}{\lambda}$$

,

which depends on the Seebeck coefficient, S, thermal conductivity, λ, and electrical conductivity, σ. The product (ZT) of Z and the use temperature, T, serves as a dimensionless parameter to evaluate the performance of a thermoelectric material.

Phonon-Glass, electron-crystal behavior

Notably, in the above equation, thermal conductivity and electrical conductivity intertwine. G. A. Slack proposed that in order to optimize the figure of merit, phonons, which are responsible for thermal conductivity must experience the material as they would in a glass (experiencing a high degree of phonon scattering—lowering thermal conductivity) while electrons must experience it as a crystal (experiencing very little scattering—maintaining electrical conductivity). The figure of merit can be improved through the independent adjustment of these properties.

Semiconductors

Semiconductors are ideal thermoelectric devices because of their band structure and electronic properties at high temperatures. Device efficiency is proportional to ZT, so ideal materials have a large Z value at high temperatures. Since temperature is easily adjustable, electrical conductivity is crucial. Specifically, maximizing electrical conductivity at high temperatures and minimizing thermal conductivity optimizes ZT.

Thermal conductivity

$\kappa = \kappa_{electron} + \kappa_{phonon}$

According to the Wiedemann–Franz law, the higher the electrical conductivity, the higher $\kappa_{electron}$ becomes. Therefore, it is necessary to minimize κ_{phonon}. In semiconductors, $\kappa_{electron} < \kappa_{phonon}$, so it is easier to decouple κ and σ in a semiconductor through engineering κ_{phonon}.

Electrical conductivity

Metals are typically good electrical conductors, but the higher the temperature, the lower the conductivity, given by the equation for electrical conductivity:

$\sigma_{metal} = ne^2\tau/m$

- n is carrier density
- e is electron charge
- τ is electron lifetime
- m is mass

As temperature increases, τ decreases, thereby decreasing σ_{metal}. By contrast, electrical conductivity in semiconductors correlates positively with temperature.

$\sigma_{semiconductor} = ne\mu$

- n is carrier density
- e is electron charge
- μ is carrier mobility

Carrier mobility increases with increasing temperature, thereby increasing $\sigma_{semiconductor}$.

State density

The band structure of semiconductors offers better thermoelectric effects than the band structure of metals.

The Fermi energy is below the conduction band causing the state density to be asymmetric around the Fermi energy. Therefore, the average electron energy 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.

Materials of interest

Strategies to improve thermoelectrics include both advanced bulk materials and the use of low-dimensional systems. Such approaches to reduce lattice thermal conductivity fall under three general material types:

1. Alloys: create point defects, vacancies, or rattling structures (heavy-ion species with large vibrational amplitudes contained within partially filled structural sites) to scatter phonons within the unit cell crystal.

2. Complex crystals: separate the phonon-glass from the electron crystal using approaches similar to those for superconductors. The region responsible for electron transport would be an electron-crystal of a high-mobility semiconductor, while the phonon-glass would be ideal to house disordered structures and dopants without disrupting the electron-crystal (analogous to the charge reservoir in high-Tc superconductors.

3. Multiphase nanocomposites: scatter phonons at the interfaces of nanostructured materials, be they mixed composites or thin film superlattices.

Materials under consideration for thermoelectric device applications include:

Bismuth chalcogenides

Materials such as [Bi_2Te_3](#) and Bi_2Se_3 comprise some of the best performing room temperature thermoelectrics with a temperature-independent thermoelectric effect, ZT, between 0.8 and 1.0. Nanostructuring these materials to produce a layered superlattice structure of alternating Bi_2Te_3 and Bi_2Se_3 layers produces a device within which there is good electrical conductivity but perpendicular to which thermal conductivity is poor. The result is an enhanced ZT (approximately 2.4 at room temperature for p-type). Note that this high value has not entirely been independently confirmed.

Skutterudite thermoelectrics

Recently, skutterudite materials have sparked the interest of researchers in search of new thermoelectric. These structures are of the form $(Co,Ni,Fe)(P,Sb,As)_3$ and are cubic with space group Im3. Unfilled, these materials contain voids into which low-coordination ions (usually rare earth elements) can be inserted in order to alter thermal conductivity by producing sources for lattice phonon scattering and decrease thermal conductivity due to the lattice without reducing electrical conductivity. Such qualities make these materials exhibit PGEC behavior.

Oxide thermoelectrics

Due to the natural superlattice formed by the layered structure in homologous compounds (such as those of the form $(SrTiO_3)_n(SrO)_m$—the Ruddleson-Popper phase), oxides have potential for high-temperature thermoelectric devices. These materials exhibit low thermal conductivity perpendicular to these layers while maintaining electrical conductivity within the layers. The figure of merit in oxides is still relatively low (~0.34 at 1,000K),but the enhanced thermal stability, as compared to conventional high-ZT bismuth compounds, makes the oxides superior in high-temperature applications.

Nanomaterials

In addition to the nanostructured Bi_2/Bi_2Se_3 superlattice thin films that have shown a great deal of promise, other nanomaterials show potential in improving thermoelectric materials. One example involving PbTe/PbSeTe quantum dot superlattices provides an enhanced ZT (approximately 1.5 at room temperature) that was higher than the bulk ZT value for either PbTe or PbSeTe (approximately 0.5). Individual silicon nanowires can act as efficient thermoelectric materials, with ZT values approaching 1.0 for their structures, even though bulk silicon is a poor thermoelectric material (approximately 0.01 at room temperature) because of its high thermal conductivity.

THERMOELECTRIC COOLER BASICS

Introduction

Although thermoelectric (TE) phenomena was discovered more than 150 years ago, thermoelectric devices (TE coolers) have only been applied commercially during recent decades. For some time, commercial TECs have been developing in parallel with two mainstream directions of technical progress – electronics and photonics, particularly optoelectronics and laser techniques. Lately, a dramatic increase in the application of TE solutions in optoelectronic devices has been observed, such as diode lasers, superluminescent diodes (SLD), various photodetectors, diode pumped solid state lasers (DPSS), charge-coupled devices (CCDs), focal plane arrays (FPA) and others.

The progress in applications is provided by advantages of TE coolers – they are solid state, have no moving parts and are miniature, highly reliable and flexible in design to meet particular requirements.

History

The effect of heating or cooling at the junctions of two different conductors exposed to the current was named in a honor of the French watchmaker Jean Peltier (1785–1845) who discovered it in 1834. It was found that if a current passes through the contacts of two dissimilar

conductors in a circuit, a temperature differential appears between them. This briefly described phenomenon is the basis of thermoelectricity and is applied actively in the so-called thermoelectric cooling modules.

In contrast to the Joule heating, which is proportional to the square of the current:

$$(Q=RI^2),$$

the Peltier heat (Q_p) varies as a linear function of the current and changes its sign with it:

$$Q_p = P \cdot q$$

where q is the charge that passes through the junction (q=I·t); P is the Peltier coefficient, whose value depends on the contacting materials' nature and the contact temperature. The common way of presenting the Peltier coefficient is the following:

$$P = \alpha \cdot T$$

Here, α - alpha is the Seebeck coefficient defined by both contacting materials, properties and their temperature. T is the junction temperature in Kelvins.
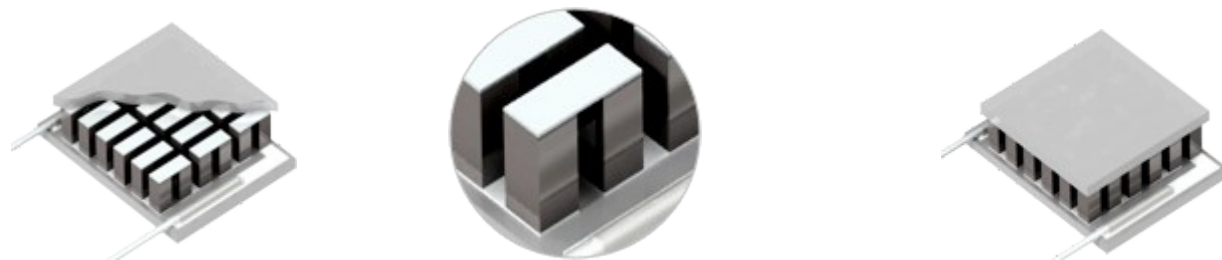
Thermoelectric Module Construction

A TE module is a device composed of thermoelectric couples (N and P-type semiconductor legs) that are connected electrically in series, in parallel thermally and, fixed by soldering, sandwiched between two ceramic plates. The latter form the hot and cold thermoelectric cooler (TEC) sides. The configuration of thermoelectric coolers is shown in Figures .
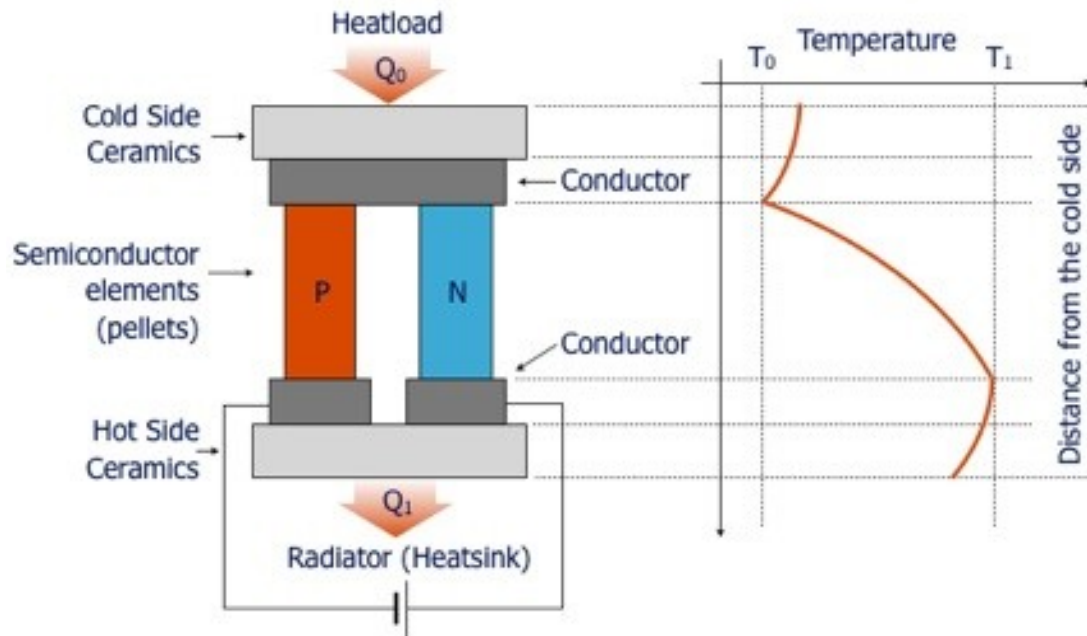
Commonly, a TE module consists of the following parts:

1. Regular matrix of TE elements – Pellets. Usually, such semiconductors as bismuth telluride (BiTe), antimony telluride or their solid solutions are used. The semiconductors are the best among the known materials due to a complex optimal TE performance and technological properties. BiTe material is the most typical for TE cooler.

2. Ceramic plates – cold and warm (and intermediate for multi-stage coolers) ceramic layers of a module. The plates provide mechanical integrity of a TE module. They must satisfy strict requirements of electrical insulation from an object to be cooled and the heat sink. The plates must have good thermal conductance to provide heat transfer with minimal resistance. The aluminum oxide (Al2O3) ceramics is used most widely due to the optimal cost/performance ratio and developed processing technique. Other ceramics types, such as aluminum nitride (AlN) and beryllium oxide (BeO), are also used. They have much better thermal conductance – five to seven times more than Al2O3 – but both are more expensive. In addition, BeO technology is poisonous.

3. Electric conductors provide serial electric contacting of pellets with each other and contacts to leading wires. For most of the miniature TE coolers, the conductors are made as thin films (multilayer structure containing copper (Cu) as a conductor) deposited onto ceramic plates. For large size, high-power coolers, they are made from Cu tabs to reduce the resistance.

4. Solders provide assembling of the TE module. The most standard solders used include Lead-Tin (Pb-Sn), Antimony-Tin (Sn-Sb) and Gold-Tin (Au-Sn) alloys. The solders must provide good assembling of the TE module. The melting point of a solder is the one of limiting factors for TE Cooler reflow processes and operating temperature. Leading wires are connected to the ending conductors and deliver power from a direct current (DC) electrical source.

A single-stage module consists of one matrix of pellets and a pair of cold and warm sides (see Figure 1). *A multi-stage module* can be viewed as two (see Figure 2) or more single stages stacked on top of each other. The construction of a multi-stage module is usually of a pyramidal type – each lower stage is bigger than the upper stage. Once the top stage is used for cooling, the lower stage requires greater cooling capacity to pump heat that is dissipated from the upper stage.
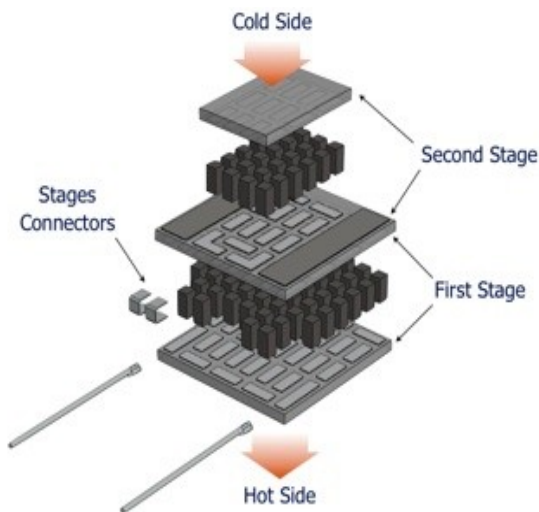

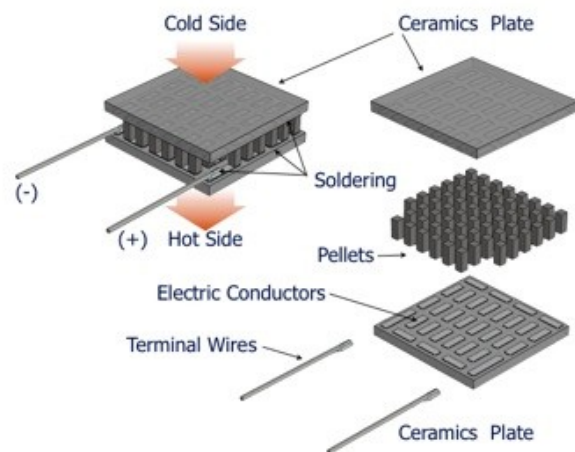**Fig.1** Single-stage Thermoelectric Cooler Construction   **Fig. 2** Two-stage Thermoelectric Cooler Construction

TECAD SOFTWARE

It is not a simple task to select a TE module that fits the need most optimally. It is also frequently necessary
to give some operational characteristics of a TE module for a range of conditions and in the graphic form.
To assist in it, the company RMT has developed the software TECcad.
TECcad is available in two version:
1. **TECcad Lite**
2. **TECcad Pro**

HEAT SINK

A heat sink is a term for a component or assembly that transfers heat generated within a solid material to a fluid medium, such as air or a liquid. Examples of heat sinks are the heat exchangers used in refrigeration and air conditioning systems and the radiator (also a heat exchanger) in a car. Heat sinks also help to cool electronic and optoelectronic devices, such as higher-power lasers and light emitting diodes (LEDs).

A heat sink uses its extended surfaces to increase the surface area in contact with the cooling fluid, the air for example. The term is not meant literally, as a heat sink does not have a "magical ability to absorb heat like a sponge and send it off to a parallel universe". Heat transfer theory helps explain practical aspects of how heat sinks work, and can also help to clear up common

misconceptions and design mistakes. Approach air velocity, choice of material, fin (or other protrusion) design and surface treatment are some of the design factors which influence the thermal resistance, i.e. thermal performance, of a heat sink. One engineering application of heat sinks is in the thermal management of electronics, often computer CPU or graphics processors. For these, heat sink attachment methods and thermal interface materials also influence the eventual junction or die temperature of the processor(s). Theoretical, experimental and numerical methods can be used to determine a heat sink's thermal performance.
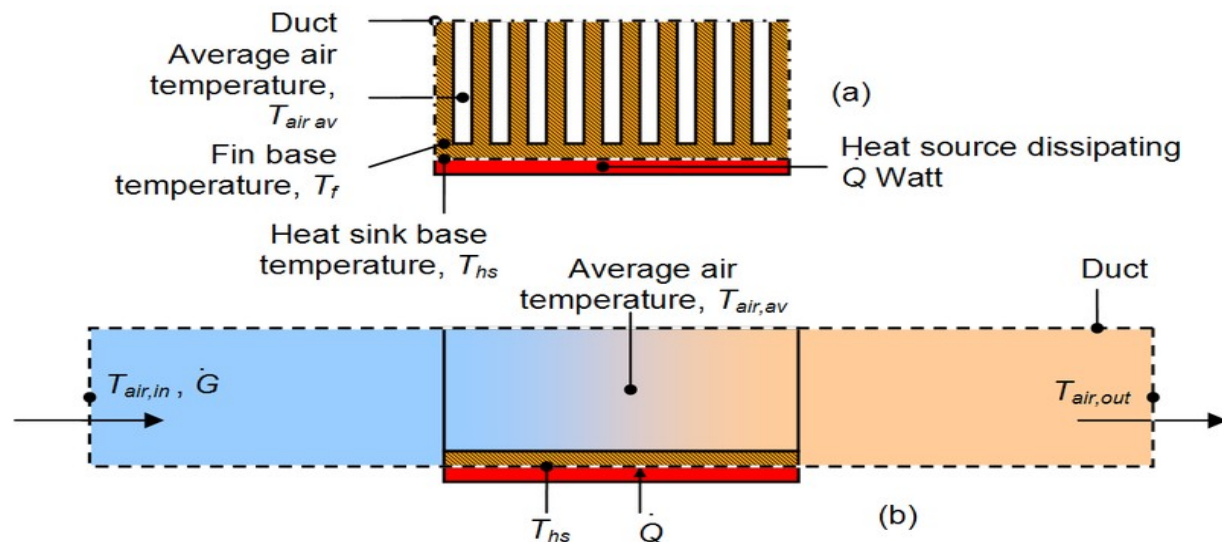
Quality of Mounting a Cooled Object onto a TE module and a TE Module onto a Heat Rejecting System

The efficiency of TE sub-mount as a whole depends on the quality of mounting an object to be cooled onto a TE module and a TE module onto heat rejecting elements. Based on RMT's and other manufacturers' (for example, the company Melcor) data the highest extent of TE modules failure is due to an improper process of installation of objects on the module and the module on the appropriate header. It is necessary to take into account, that at installation some problems are solved, namely:

_ Strong mechanical design, steady at mechanical influence of various kinds while in service (vibration, impacts);
_ Good thermal contact, which is important both foran object located on the TE module cold side and for effective heat rejecting system.
There are three widely applied methods that can be used for mounting::
1) Mechanical mounting,
2) Soldering
3) Adhesive bonding.

Each of the listed methods has its own areas of applications, both advantages and short coming. When choosing an optimal way of mounting a TE module and cooled objects it is necessary to be guided by features of the methods.

Mechanical (Compression Method)

Description.
A TE module is placed between two heat exchangers (plates) fixed by screws or bolts. For good thermal conductance the clearances between the plates should be filled by some substances of high thermal conductance. As such a thermal grease or a heat-conducting gasket may be used.

Application.
The method is widely applied for mounting large single-stage TE modules.
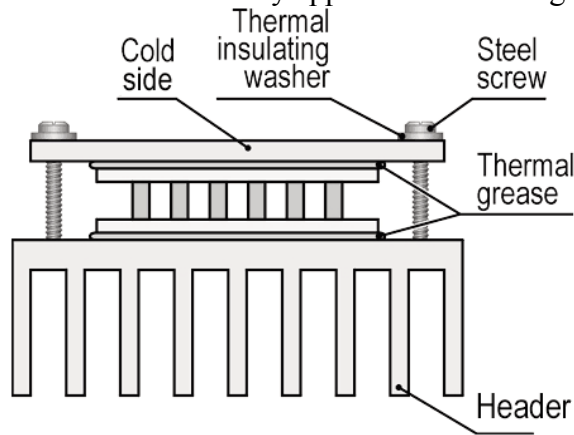
For micromodules this method has a limited application as fixing elements occupy too much space and cause significant thermal losses. Besides for micromodules the compression should be small and accurately normalized.

Advantages

 Advantages of the mechanical method of installation are a possibility to disassemble of the construction and, consequently, maintainability of a design.

Important remarks

 It is necessary to take into account the following:

Preparation of contacting surfaces

The preparation is expressed in terms of requirements for non flatness and roughness of surfaces as well as exception of alien particles and inclusions. The non flatness of contacting surfaces is very important. It concerns ceramic surfaces of a module and metal plates of heat exchangers. Roughnesses or deflections of contacting surfaces at applying pressure
can destroy a TE module.

Thus it is recommended that the non flatness of contacting surfaces be not more than 0.02 mm. The roughness of contacting surfaces is the reason of deterioration of thermal contact between surfaces. The class of roughness not worse than Ra=2.5 is recommended. For the similar reasons it is necessary to eliminate alien particles and inclusions from contacting surfaces. Even in the best case they increase a clearance between contacting surfaces, in the worst case at pressure applied they can cause mechanical destruction.

Normalized Compression

It is necessary to take into account that TE modules are rather fragile products. It can endure a limited compression,
stretching and sheer effort. Therefore it is required to control compression of the module when mechanically installed. It is also necessary to exclude a compression non-uniformity between the bolts.

Quality of heat-conducting gaskets and thermal greases

Quality of thermal contact determines an overall performance of TE module assembly. Taking into account that it is impossible to prepare ideally smooth and even surfaces, heat-conducting substances are necessary between contacting surfaces. The heat-conducting substances are called to compensate the heterogeneity of contacting surfaces and
to increase the area of contact.

Thermal Losses Reduction

In the mechanical way of installation cold and hot sides of the TE module are held down by bolts, which create channels of thermal losses. To reduce such thermal losses it is necessary to apply thermal insulating elements (washers) and make bolts of metals with low thermal conductivity.

Elastic connection

While operating the mechanical connection of this kind, a thermal expansion (compression) is observed due to temperature change. A compression results in easing the clip and deteriorating the thermal contact, accordingly. An expansion increases the pressure on the module. Therefore it is necessary to apply elastic elements. Otherwise, the design mechanical destruction or overheating is probable because of loss of the thermal contact.

Restrictions

Unfortunately, the mechanical method of mounting is not applicable to TE micromodules as the mechanical installation demands an additional space. Moreover, it is impossible to exclude passive heat fluxes through the elements of fixtures (bolts), which is crucial for micromodules efficiency, especial in case of multicascade modules.

Mechanical Mounting Step by Step

A. The following order of mechanical installation using heat conducting greases can be recommended:
- Prepare contacting surfaces. Check the planeness of surfaces, remove alien particles. Clear the surfaces with a lint free soft cloth. Use ethanol.
- Put a thin layer of a heat conducting gease on the contacting surfaces.
- Connect the surfaces. With a small effort grind the surfaces to improve the contact.
- Give the elements a final alignment and set them by a slight clamping effort.
- Connect the surfaces with bolts. It is necessary to provide a uniform pressing without skrews. The maximal
clamping effort should meet the restrictions.

B. The following order of mechanical installation using heat conducting gaskets can be recommended:
- Prepare contacting surfaces. Check the planeness of surfaces, remove alien particles. Clear the surfaces with a lint free soft cloth. Use ethanol.
- Put an all-over thin layer of the thermal grease on each contacting surface.
- Connect the surfaces with the prepared heat conducting gaskets.
- Give the elements a final alignment and set them by a slight clamping effort.
- Connect the surfaces with bolts. It is necessary to provide a uniform pressing without skrews. The maximal clamping effort should meet the restrictions.

SOLDERING

Description

 The module is soldered by a soft solder to a heat-conducting header, and a cooled object is soldered by a similar way on the cold side of the TE module. The thermal contact and echanical durability is provided by the used solder. The soldered surfaces should be prepared:
- Surfaces of the module (the cold and hot sides) should be metallized and have a good solder ability. As this metallization we most frequently recommend either a nickel metallization covered by a tin galvanic layer with additives (for example Sn-Bi or Sn-Co), or a thin gold covering atop of a nickel layer.
- Surfaces soldered to the TE module also should have a good solder ability. Most frequently soldered objects are made of metals or ceramics whose solder ability is also provided with metallizations applied to the module - a tin covering atop of a nickel layer or gilding.

Advantages of the Method

The method of the soldering has a lot of doubtless advantages:
_ Good mechanical durability;
_ Good thermal contact between the surfaces;
_ Suitability for vacuum applications as does not cause outgassing;
_ No need for additional space as in case of mechanical mounting;
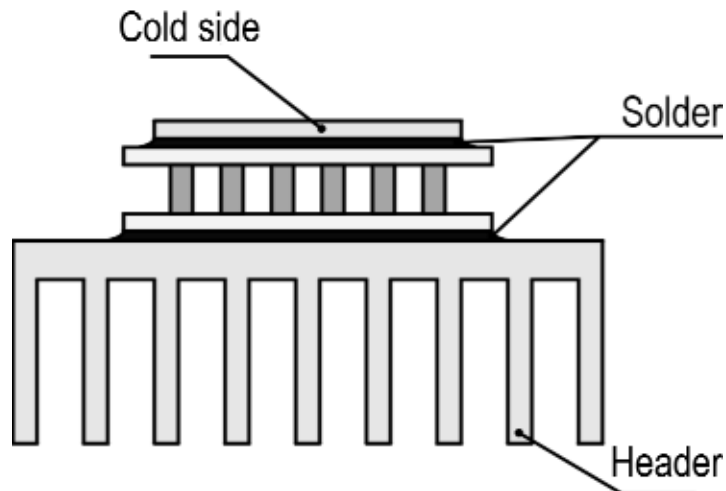_ Possibility of partly disassemblying.

Figure 1.2.1. Soldering method of mounting

Application

It is the main mounting method for single-and multistage micromodules. For large modules it is limited due to a risk of mechanical strain owing to a difference of thermal expansions of contacting surfaces.

Important remarks
 When the soldering method is used, it is necessary to pay attention to the following:

1. **Preparation of Surfaces**

As mentioned above, the solderability of the contactingsurfaces, therefore their metallization is absolutely necessary for the method application.Similarly to the mechanical installation and gluing, the requirement to the planeness and roughness of surfaces, as well as to the particles ingress exception are actual. Excessive roughnesses and heterogeneity results in increasing the soldering seam. It is undesirable as solders' thermal conductivity is frequently much lower than that of contacting details.

2. **Solder Selection**

The first requirement is application of solders with melting temperature below that of the internal solder of the module. Otherwise there is a risk of the module destroyment. Thus, the maximal melting temperature of installation solders is determined by the internal solder.In Table 1.2.1 the melting temperatures of the most frequent solders are given. It should be borne in mind that the most habitual solders containing lead has become forbidden in Electrical and Electronic Equipment (EEE) since the middle of 2006. Therefore the set of solders from the list offered has to be considerably reduced and applicability of other suitable solders is investigated.

3. **How to Solder**

The most simple way is tin-plating the surfaces by a soldering iron with a chosen solder and a suitable flux and further connecting them at the temperature above the solder melting point and then cooling. The given way is based on manual skills. Thus, the quality and appearance of the soldered connections is far from being perfect. A more progressive way is applying soldering pastes. The soldering paste is put on one of the surfaces.Surfaces are touched and the connecting area is heated up to the melting temperature.

4. **Soldering Seam Thickness**

The thickness of a soldering seam is of vital concern. During the soldering it is possible to adjust the solder thickness in a wide range.

5. **Thermal Expansion Agreement.**

The method of soldering is referred to a rigid fixation.In this case it is necessary to bring the coefficients of thermal expansion (CTE) to agreement.

Soldering Mounting Step by Step
We can recommend the following prcedure of installation by the soldering method (with a soldering flux):
- Put a thin all-over layer of the soldering paste on one of the surfaces, commonly on that of the module. The thickness of the layer should be no more than 50-70 microns.
- Connect surfaces and slightly grind them in to improve the contact.
- Bring the surfaces into a final orientation and elements into a necessary position, press and fix for the period of the soldering.
- Place the detail into a furnace or on a heating table.
- Provide a short-term heating up to the solder melting Temperature.

Adhesive Bonding

Description

 A TE module is attached to a header heat sink or an object to be cooled is mounted onto a module by a thermoconductive glue. The thermal contact and mechanical durability strongly depend on a glue used. As a rule these are epoxy glue with different fillers, which are called to provide a good thermal conductivity. For adhesive bonding the TE module surface should be lapped though a metallization is admitted unless it worsens the adhesion quality of the glue supposed. The method of adhesive bonding is widely used both for micromodules (mainly) and for the big modules. Though in the second case its usage is restricted. The method of adhesive bonding is referred to methods of rigid fixing, therefore the thermal expansion agreement of contacting materials (ceramics of the module, heat-removing surface and a material of a cooled object) is necessary.

Application

 The method application is similar to that of soldering: it is mostly applied to single- and multistage micromodules. The application for powerful modules is limited due to possible mechanical strains due to thermal expansion.

Important Remarks

An excessive roughness and heterogeneity of the surface may result in increasing the thickness of the bonding layer that reduces thermal conductance.

1. Bonding Layer Thickness
Whatever the manufacturers of the glues and pastes invent to highten thermal conductivity, its value remains quite lower than the properties of contacting ceramics metal surfaces. Therefore, on the one hand, the bonding seam should be rather thin, which can be managed by clamping. On the other hand, limitless minimizing the seam thickness is the extreme to be avoided. The seam thickness should be enough to provide a sufficient strength and a certain compensation of the coefficient of thermal expansion difference between the bonded surfaces. It is recommended that the bonding thickness should be 10-20 μm.

2. Agreement of Thermal Expansions of Contacting Materials
The method of adhesive bonding is referred to the rigid fixation. In that case it is necessary to take into account agreement of thermal expansion coefficients of the pasted surfaces.
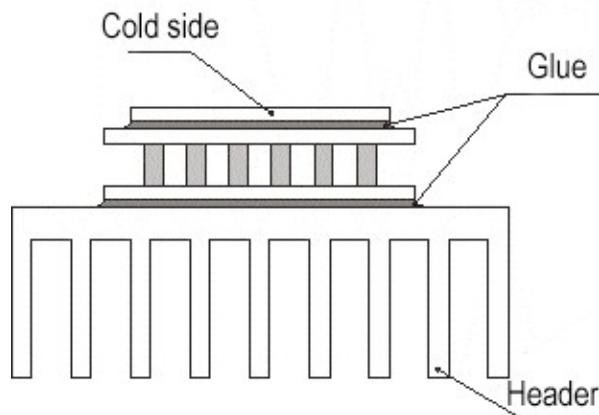

Figure 1.3.1. Adhesive bonding mounting

Adhesive Bonding Mounting Step by Step:

The following procedure s to be recommended:
- Prepare the surfaces thoroughly: remove alien particles, wipe it with a lint free soft cloth. Use ethanol.
- Get ready with a sufficient glue quantity. If the glue is two-component, prepare the composition.
- Put a thin layer of the glue on one of the surfaces to be bonded. The layer thickness should not exceed 50-70 μm.
- Join the surfaces and slightly grind them in for a better contact.
- Bring the surfaces into a final orientation and elements into a necessary position, press and fix for the period of the glue polymerization.
- Carefully remove the redundant glue.
- Soak the detail in a high temperature condition if it is recommended for the glue given.

- After a complete polymerization of the glue remove the tools of temporary fixing.

Advantages of the Method

Adhesive bonding is a reliable and a rather simple method for TE modules mounting:
1. Unlike the mechanical installation it does not demand any additional elements occupying the area.
2. In contrast to the soldering method it does not demand any intensive heating of the mounted surfaces, accurate control of temperatures and a special equipment for high temperature.

Limitations

Adhesive bonding has its own shortcomings and disadvantages:
1. Disassembly of the details mounted by this method is complicated. In some cases it is not acceptable.
2. Gluing is quite a long process (determined by the glue hardening duration, or a cure time), which reduces productivity.
3. In operation it is necessary to take into account temperature restrictions of the used adhesive connection. Usually it is not recommended to heat it up above 150-160 °C. Otherwise the material of the glue can undergo irreversible changes and consequently the connection durability and thermal properties can degrade . There are also restrictions on the lowered temperature that may cause embrittlement of the epoxy structures.
4. It is necessary to limit the use of adhesive connections in vacuum designs due to outgassing intensified by temperature growth.

Thermal Expansion Effect

In any of the mounting methods listed above there is a contact of different materials. In a TE module operational mode there are significant temperature changes of TE module elements caused by the gradient of temperature between the cold and hot sides of the design. The materials of the design have different coefficients of temperature expansion (CTE) resulting in inevitable mechanical strains that may destroy the TE module Mechanical strains arise both in the vertical direction along the heat path and in the plane of the cold and hot sides. It is the difference of CTEs in the plane of the module as its width commonly exceeds its height.It should always be borne in mind in case "rigid" methods of installation are used, such as soldering or adhesive bonding. It concerns a mechanical method to a lesser extent The destruction character is typical enough. As the TE material has the least strength , at excessive mechanical strains TE elements (pellets) may be destroyed. This process initially manifests itself in an increase of the TE module resistance and a corresponding decrease of the Figure-of-Merit (the time constant of the module remains approximately unvaried). It is the result of microcracks occurrence in the TE material. A total mechanical break of pellets follows.

Heat Sink Efficiency

A TE module must not be operated without a sufficient heat rejection from the hot side.
As a rule designing a heat sink can be divided into two phases:

1. Determining a value of the heat sink thermal resistance Rt, as necessary to meet operational requirements;
2. Designing of the heat sink system that has thermal resistance not higher than the obtained value Rt.

We assume that the operational mode of a TE cooling system is known: a full heat to be pumped Q cold and necessary ∆T in the described conditions and at a known ambient temperature Ta are given. Then we can calculate the TE module/TE sub-mount maximum hot side temperature Thotmax to meet the requirements. Let the corresponding heat to be rejected be Q hot. Then the necessary thermal resistance Rt can be calculated. Then an experienced designer-thermo physicist selects or develops a radiator (heat sink) to meet the Rt, makes conclusions on necessary free or induced heat exchange between the heat sink and the ambient, recommending a fan or a liquid exchanger, if needed.

TE Module Power Supply: A TE module is a DC device. An alternating current of any nature can be detrimental to a TE module efficiency.

By thorough study of above given chapters. We have designed the product which can withstand according to our objective which we have mentioned.

OBJECTIVE

The objective of the project is to develop Thermoelectric cooling System . Thermoelectric cooling uses the Peltier effect to create a heat flux between the junction of two different types of materials. This effect is commonly used in camping and portable coolers.

COMPONENTS USED:

1. 12v Peltier
2. 5 Heat Sinks (4 on hot side, 1on cold side)
3. 12v 5 Fans(4 on hot side, 1on cold side)
4. DC power supply
5. Temperature Measuring Device
6. Silver foil
7. Thermal grease
8. Closed Box with foam insulation
9. Screws
10. Copper plate
11. Solidworks Software (For designing different assemblies)

ASSEMBLING PROCEDURE:

All the given components are assembled in systematic manner by following given steps:

1. Firstly , 4 heat sinks are mounted on a copper plate by screwing each heat sink on corner of the copper plate. To make proper heat flow between the heat sinks the thermal grease is applied on the sides of the heat sinks so that there should be no gap between them when they

are mounted on copper plate. And it also helps in heat flow between the heat sinks. As shown in fig.
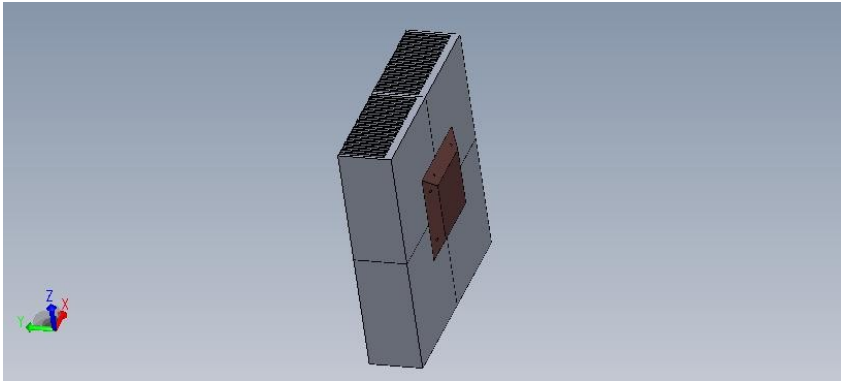
DESIGNED IN SOLIDWORKS

2. After following the 1ˢᵗ step now peltier is mounted by following the steps of Mechanical mounting method or compression method . On Hot side the copper plate with 4 heat sinks mounted on it with 4 fan on top of each heat sink (which are very useful in cooling by throwing hot air out to the atmosphere) is attached whereas on cold side the small heat sink is attached on cold side of module with fan which throws cold air outwards.
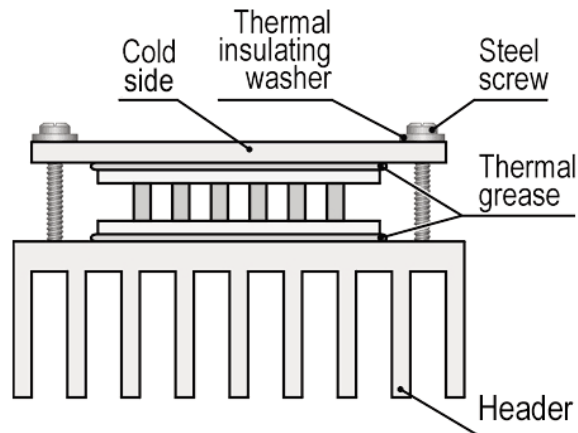
3. Then after assembling the above given components , the assembled piece is attached on one face of the box as such the cold side or cold heat sink should be inside the box whereas hot side is exposed to atmosphere . Inner sides of the box is laminated with silver foil for proper cooling.
4. After following all the above steps all the fans and peltier is attached to the 12 volt power supply unit.
5. Temperature measuring device is installed inside the box so that we can assume the temperature difference b/w atmosphere and box.

WORKING PROCEDURE:

After assembling all the given components in proper manner, the power is switched on than according peltier effect electric power generates a temperature difference between the two sides of the

device (peltier). On hot side heat is absorbed by copper and dissipated to atmosphere after passing through aluminum heat sink whereas on cold side the cold air is dissipated through heat sink and drops the temperature of the box. More the heat dissipated on hot side more will be cooling on cold side.