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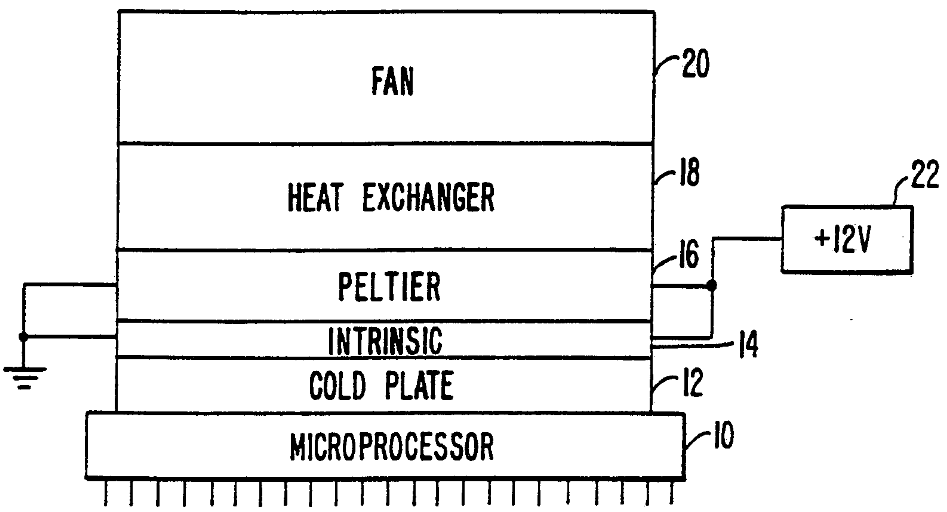


(57) Abstract

The invention uses an intrinsic semiconductor layer (14) which is connected to the cooling device and the apparatus (10) to be cooled. The intrinsic layer (14) has a resistance which varies with temperature. In one embodiment, the cooling device is a thermoelectric or Peltier device (16) and the intrinsic layer (14) is a positive temperature coefficient material mounted between the apparatus (10) and the thermoelectric device (16). The intrinsic layer (14) provides a self-correcting function to the thermoelectric device (16) to maintain the apparatus (10) at the desired temperature. If the thermoelectric device (16) tries to cool the apparatus too much, the intrinsic layer (14) will generate heat to offset this effect, and vice versa if the apparatus (10) gets too hot. A unique heat exchanger (18) design is disclosed with a central core surrounded by radially extending fins.

INTRINSICALLY CONTROLLED COOLING CONTAINER

BACKGROUND

The present invention relates to methods and apparatus for controlling the temperature of a cooling device. In particular, it relates to precisely controlling the temperature of a Peltier or other thermoelectric cooling device.

There exist a number of known designs for thermoelectric cooling devices. One such design relies on the Peltier coefficient of a pair of conductors. It is well known that a current passing, in a suitable direction, through a contact surface between two such conductors will absorb a certain amount of heat. A number of devices have been fabricated using this effect, one such design having two flat, square conductor surfaces joined by a large number of junctions through which current passes to transfer heat from a receiving side to a rejection side of the Peltier device. The Peltier device can be used to perform either a heating or cooling function depending upon the direction and amount of current supplied.

In one application, shown in U.S. Patent No. 4,238,759, a Peltier device is integrated next to a P-N junction used to produce a laser in order to precisely control a temperature and thus the wavelength of the laser. By monitoring the temperature, a control circuit can adjust the current applied to the Peltier to precisely control the temperature.

Another device disclosed in U.S. Patent No. 4,812,733 shows a Pelter device connected to a semiconductor element, which is a microprocessor, cooling the microprocessor to both increase its reliability and allow higher speed of operation. If the semiconductor chip is cooled too much, the leads to it will attract condensation, which can cause shorting. Accordingly, this disclosure teaches hermetically encapsulating the combination of the Peltier device and the semiconductor element to avoid such condensation. In addition, a controller circuit is provided to control the amount of current provided to the Peltier device.

Another device is shown in U.S. Patent No. 4,685,081 to precisely control the temperature of a bubble memory with a Peltier device to maintain a narrow temperature band of operation. This circuit uses a temperature sensor to provide a signal to the controller circuit which controls the current provided to the Peltier.

SUMMARY OF THE INVENTION

The present invention provides a self-correcting cooling control device. In one embodiment, the invention uses an intrinsic semiconductor layer which is connected to the receiving side of the cooling device or the apparatus to be cooled. The intrinsic layer has an electrical resistance which varies with temperature. In one embodiment, the cooling device is a thermoelectric or Peltier device and the intrinsic layer is a positive temperature coefficient layer mounted between the apparatus and the thermoelectric device. A fixed voltage is applied to the thermoelectric device and also to the intrinsic layer. The fixed voltage is chosen to give the desired amount of cooling with the thermoelectric device. The intrinsic layer has the property of decreasing its resistance as it is cooled, thereby increasing the amount of current drawn and the quantity of heat it will deliver. Conversely, as it is heated, its resistance increases, thus lowering the amount of current it will draw and lowering the heat it will generate. Thus, it provides a self-correcting function to the thermoelectric device to maintain the apparatus at the desired temperature. If the thermoelectric device tries to cool the apparatus too much, the intrinsic layer will generate heat to offset this effect, and vice versa if the apparatus gets too hot.

The present invention can be used to cool any apparatus, including in particular electronic circuits. It can be applied to electronic housings, circuit boards or electrical components themselves. In particular, microprocessors, embedded controllers, and other high density, large circuits which generate a lot of heat would benefit from having the apparatus of the present invention attached. The present invention, by allowing precise cooling of the electronics, provides for more consistency of operation, higher speed of operation and reliability.

In the preferred embodiment, the thermoelectric device is a Peltier device with a heat sink on top of it. The heat sink may optionally have a fan attached to it as well. The control circuitry of the prior art is eliminated, and replaced with the intrinsic layer design which will use a comparable amount of current.

In an alternate embodiment, the present invention uses a negative thermal coefficient intrinsic layer which is thermally in parallel with and electrically in series with the thermoelectric Peltier device. In such an arrangement, instead of being used to generate heat, the intrinsic is used to sense the amount of heat from the apparatus being cooled and accordingly control the current being provided to the Peltier. As the intrinsic is heated, its resistance will decrease, causing it to provide more current to the Peltier to increase its cooling effect. Conversely, as the intrinsic is cooled, its resistance will increase, limiting the current to the Peltier and thus limiting the cooling effect of the Peltier.

In another embodiment, the intrinsic layer is used in connection with a voltage regulator circuit to throttle the amount of current applied to the thermoelectric or Peltier device. The voltage regulator would be connected to the thermoelectric device by its output voltage terminal, and a positive temperature coefficient intrinsic layer would be connected between the adjustment input of the voltage regulator and the other terminal of the thermoelectric device. A fixed resistor would be coupled between the adjusting input and the voltage output, effectively giving a voltage divider effect controlled by the positive temperature coefficient device. Alternately, a negative temperature coefficient device could be used in the place of the resistor, with the resistor being in the position of the positive temperature coefficient device, or a combination of positive and negative temperature coefficient devices could be used.

In yet another embodiment, the intrinsic layer is eliminated and an intrinsic control function is provided by selecting appropriate geometry and power supply level for a Peltier device. Prior art systems, such as that shown in U.S. Patent No. 4,812,733, have attempted to provide one circuit which can be used to precisely control any one of a number of microprocessors or other semiconductor devices to a desired temperature. This inventor has recognized that any particular microprocessor runs at a fairly constant wattage regardless of whether it is idling or running at full speed. By hooking the Peltier device to a selected power supply available on the microprocessor board, and by varying the number of couples, and their height and width in the Peltier device itself, taking into account the characteristics of the heat sink, an optimum heat pumping capacity for the Peltier can be achieved which will cool the microprocessor below ambient temperature without cooling it below a condensation temperature. Thus, different geometry structures are provided for different wattage microprocessor applications to customize the cooling device to the particular microprocessor so that the total heat pumping capacity of the Peltier device at the selected voltage is itself the intrinsic control device which prevents the Peltier device from cooling the microprocessor below the condensation temperature.

A unique semiconductor container/filter design is used with the present invention which also functions as a heat exchanger. The container has a central cavity with a large number of thin slots around its perimeter. A fan is mounted over the central cavity, with air being drawn through the slots, which also function as a dust filter. The opposite side of the container has another cavity into which the Peltier device and the semiconductor element or the element to be cooled can be placed. The container design with the cavity for holding the Peltier device and the semiconductor element provides maximum heat transmission capabilities while at the same time providing a container to isolate the Peltier and semiconductor from the fan. The slots define fins at the edge of the container to provide maximum cooling, which is maximum at the edges, while taking advantage of the dead space below the fan as a pathway for air passing through the fins and then through the fan.

The present invention also provides another unique heat exchanger design which uses a central core surrounded by radially extending fins. This design takes advantage of the heat propagation characteristics of an integrated circuit which will tend to go at approximately a 45° angle upward, thus intersecting all the fins in the present design, rather than some as in the prior art. In addition, the central core provides an additional heat conducting area while occupying a space which would otherwise be dead air under a normal circular fan construction. Thus, a circular fan can be attached to the top of the heat exchanger and give optimum performance.

For a fuller understanding of the nature and advantages of the present invention, reference should be made to the ensuing detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of an embodiment of the invention with a positive temperature coefficient intrinsic attached to a microprocessor;

Figs. 2A and 2B are assembled and exploded views of the connection of the Peltier and intrinsic to a conductive plate according to one embodiment of the present invention;

Fig. 3 is a graph illustrating the temperature V. resistance curves of two intrinsic materials;

Fig. 4 is a perspective view of a preferred embodiment of a heat exchanger according to the present invention;

Figs. 5A and 5B are top and side views of the core of the heat exchanger of Fig. 4;

Figs. 6A and 6B are diagrams illustrating the conduction of prior art heat sinks;

Fig. 7 is a diagram illustrating the heat conduction of the heat exchanger of Fig. 4;

Fig. 8 is a diagram of an embodiment using a negative temperature coefficient intrinsic;

Fig. 9 is a diagram of an embodiment of the invention using the container/heat exchanger;

Figs. 10A-10D are different views of the container/heat exchanger of Fig. 9;

Fig. 11 is a diagram of a flextape electrical connection used in the embodiment of Fig. 9;

Fig. 12 is an electrical diagram of the intrinsic used in combination with the voltage regulator connected to a Peltier device; and

Fig. 13 is a diagram of a Peltier device.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is an illustration of the construction of a first embodiment of the present invention. A microprocessor semiconductor package 10 has a cold plate 12 attached to its top. On top of the cold plate is a positive temperature coefficient intrinsic layer 14, followed by a Peltier device 16, a heat exchanger 18 and a fan 20. A 12 volt power supply 22 powers the Peltier and intrinsic. In one embodiment, the structure of Fig. 1 can be attached to the top of a semiconductor chip package, such as a microprocessor.

Figs. 2A and 2B provide assembled and exploded views of the Peltier and intrinsic on the conductor plate. As can be seen, the Peltier device has a rejection side 24 for connecting to the heat sink and a receiver side 26. In-between these two plates are numerous electrical connections 28 which are connected to each other in a known manner. An electrical contact 30 provides the input voltage from the 12 volt power supply, while a second contact 32 on the end of the Peltier is connected to ground. An intermediate contact 34 couples contact 32 to the top side of intrinsic layer 14, which is coated with a conducting copper layer. A second electrical interconnection 36 connects to the top of conductive plate 12. Plate 12 is conductive and connects to the conductive coating on the bottom of intrinsic layer 14 to provide the ground connection.

In a typical application, the 12 volt power supply is obtained from a connection to the power supply in a standard personal computer. For electronics' applications, the intrinsic is chosen to keep the temperature from going below approximately 18°C, since undesirable condensation will form at approximately 15°C.

The method of the present invention uses a semiconducting material such as barium titanate, to produce a quantity of heat that is a function of its temperature. Simply, as the temperature of the cooling device, or cooled region decreases, the resistance of the semiconductor decreases, thereby increasing the quantity of heat delivered by the semiconductor. If the quantity of heat is increased, the temperature of the cooling device or cooled region will increase, and as the temperature increases, the semiconductor's resistance increases, thus the quantity of heat delivered decreases. Since the change in temperature causes a change in resistance, and the opposite is also true, the semiconductor is providing temperature stability, intrinsically.

Changing the intrinsic controller's geometry and chemistry, changes the resistance curve (Fig. 3). There are two main design parameters, the operating range slope position, and the operating range slope. As seen in Fig. 3, materials 1 and 2 have different resistance curves. However, the position and slope of the operating range are the same. Thus for a given application, both materials would have the same performance. This is an indication of the design flexibility.

In the case of controlling the temperature of a Peltier device, one embodiment is shown in Figs. 2A and 2B. The Peltier receiver side 26 is mounted directly to the intrinsic control 14, which in turn is mounted to an electrically and thermally conductive plate 12. Plate 12 would then serve as the receiver. The rejection side 24 of the Peltier would be mounted to a heat exchanger, which draws away the heat generated by both the heat source (e.g., microprocessor) and the Peltier 16. If the source is attached to the receiver (plate) 26 and the source is delivering a small quantity of heat the Peltier cold side (receiver) temperature would normally decrease. However, as the Peltier cold side temperature decreases, the resistance of the intrinsic controller 14 decreases, and the quantity of heat generated by the intrinsic controller increases. If the source is delivering a large quantity of heat the cold side temperature of the Peltier increases, the resistance of the intrinsic controller increases, and the quantity of heat delivered by the intrinsic controller decreases. If the source is to be maintained at a specific temperature (set point), then it is a matter of determining the set point, and the minimum and maximum quantity of heat delivered by the source. Once this is determined, the chemistry and geometry of the intrinsic would be determined.

Essentially, the intrinsic needs to generate a large quantity of heat, at a temperature that is below the set point by as few a number of degrees temperature as possible, and generate a small amount of heat at a temperature that is above the set point by as few a number of degrees temperature as possible. The attributes of the intrinsic controller are solid state, simplicity, continuously controlling, and instantaneously controlling.

Intrinsic materials have previously been used in other applications, such as controlling a coffeepot burner or controlling the temperature of the tip of a soldering iron. Since intrinsic materials with ranges from -40°C to 500°C are known, it is well adapted for working with Peltier devices which have ranges from -40°C to 100°C for the preferred operation. In some embodiments, it may be desirable to have the conductive plate 12 non-electrical conducting so that the attachment to an integrated circuit is not itself electrically conducting. In this case, a material such as AL_20_3 can be used which is not electrically conducting but is heat conducting. In this case, the connections to the intrinsic control can be by interdigitated (interdigital) contacts on the top of the intrinsic layer. These are simply fingers extending from one side and from the other side providing the positive and negative voltages, respectively, with the current flowing in-between the fingers in a known manner. This eliminates the need to place any contacts on the bottom.

Fig. 4 shows one embodiment of a heat exchanger for use with the present invention. The heat exchanger is mounted on a plate 40 with a solid core 42 and a plurality of radially extending fins 44. A top view of the heat exchanger without the fins is shown in Fig. 5A, showing the core, which is shown in the side view of Fig. 5B. The heat exchanger can be assembled by wrapping the fins around the core using a flat strip which can be bent around and secured.

The heat exchanger design of Fig. 4 has a number of advantages. It is designed for use with a fan mounted on top of it as shown in Fig. 1. The fans, with their rotating blades, are circular in shape. The velocity of air generated by the fans is fastest at the edges of the fan blades and slowest near the center. There is a dead spot where no air is moved at the hub portion of the fan which holds the blades. Since this dead spot is not useable for moving air, the center core 42 of the heat sink is used to occupy this dead spot. This allows a mounting place for the fan and provides a use for the dead spot as illustrated in Figs. 6 and 7.

Figs. 6A and 6B show side and front views of a prior art heat sink which has a series of rectangular fins. A semiconductor chip 50 is shown attached to the bottom of a heat sink plate 52 with a number of fins 54 on top of it. As illustrated by dotted lines 56, the heat propagation from the semiconductor chip typically expands outward at approximately a 45° angle. Since the semiconductor chip is itself very small, portions of the heat sink below the lines 56 as shown in Figs. 6A and 6B do not receive heat from the chip and are not very effective in dissipating the heat. This is not a problem for an individual fin in the center of the heat sink in the direction as shown in Fig. 6A, but is a problem for the other direction as shown in Fig. 6B. As can be seen, fins 54 near the edges cannot ever receive maximum heat since their attachment to block 52 is outside of the 45° range. Thus the bottom of these outside fins do not receive substantial heat at their attachment to the block. This deficiency is overcome by the design of the present invention shown in Fig. 7.

As shown in Fig. 7, heat exchanger plate 40 has a semiconductor chip 60 attached to its bottom. The dotted lines 62 show that the heat conducted will intersect with each of fins 54 extending from central core 42. Central core 42 provides an additional surface for allowing the heat to reach the fins, conducting heat along the side of the fins in addition to the bottom of the fins receiving heat from the semiconductor chip through plate 40.

Central core 42 could alternately be a heat pipe, a hollow cylinder capped at both ends with a gas inside. The gas transfers heat by evaporating from the hotter bottom surface and then condensing on the cooler top and side surfaces in a well known manner. Such a design would be advantageous for a large heat exchanger to avoid a large, heavy mass for the hub. The heat exchanger could be made of any number of thermally conducting materials, such as aluminum, copper, ceramic or injection molded high conductivity plastic.

In one embodiment, the heat conducting interfaces in the invention are sealed with thermal grease, preferably a conductive RTV (Room Temperature Vulcanizing) elastomer. This is used between the microprocessor package and the conducting plate, between the conducting plate and the intrinsic layer, between the intrinsic layer and the Peltier device, and between the Peltier device and the heat exchanger. This grease should be elastic so it can compensate for the different coefficients of thermal expansion in the various elements. The grease can be a silicone fluid with a conductive powder such as zinc oxide. Alternately, an adhesive with good heat transfer characteristics can be used to both provide good heat conduction and be used as the fastener for holding the parts together. Such an adhesive is preferably an acrylic transfer adhesive, or acrylic pressure-sensitive adhesive which has a thermal filler, preferably carbon, to make it thermally conductive.

Fig. 8 is diagram of an embodiment of the invention using a negative temperature coefficient (NTC) intrinsic. A microprocessor 90 is shown having a cold plate 92 mounted on top of it. On top of the cold plate is a Peltier device 94 thermally in parallel with an NTC intrinsic 96. On top of the Peltier is a heat exchanger 98 and a fan 100. A 12-volt power supply

102 provides power to NTC intrinsic 96, which is in series with Peltier device via a connection 104. The other side of the Peltier device 94 is connected to a ground 106.

The function of NTC intrinsic 96 in this embodiment is to sense the temperature of cold plate 92, and thus the temperature of microprocessor 90. NTC intrinsic 96 thus acts as a control for gating the amount of current from power supply 102 to the Peltier device. As the NTC intrinsic cools, due to the microprocessor 90 cooling, its resistance will increase, decreasing the amount of current provided to Peltier 94. This will throttle down the Peltier, limiting the cooling effect on microprocessor 90, holding it at the set temperature. Conversely, as the microprocessor heats up, the NTC intrinsic 96 will heat, causing its resistance to decrease and thus providing more current to Peltier 94, throttling it up to provide more cooling action.

A material which will act as an NTC intrinsic around the set temperature which is desired is difficult to find. Most materials have a positive temperature coefficient (PTC). One such material which has a negative temperature coefficient is barium titanate. As noted earlier, barium titanate can also act as a positive temperature coefficient intrinsic. As noted earlier, by varying its geometry and chemistry, its resistance curve can be varied. By varying the geometry and chemistry sufficiently, it becomes a negative temperature coefficient material. Such an NTC barium titanate intrinsic material is available from GTE Corporation.

As shown in Fig. 8, NTC intrinsic 96 is mounted on top of cold plate 92. However, it can be placed in any other area, such as the side of the cold plate, where it will detect the temperature. In this embodiment, it is desirable that the Peltier will cover most of the cold plate with the NTC intrinsic taking up as little room as possible to perform its function.

Fig. 9 is a diagram of an alternate embodiment using a semiconductor container as shown in Figs. 10A-10D. Referring to Fig. 10A, a top view of container 100 is shown with a large number of slots 102 around its edges. The slots are in a wall, and can be cut out of a solid ridge around the side of the container (with a circular saw, for instance), with the solid part being left standing at the corners 104 for support purposes. The spaces are curved where the slots meet the body of the container as a result of being cut with a circular saw. This matches the air flow path up through the fan. A side view in Fig. 10B shows the solid corners 104 and the edge slots 102. Fig. 10C is a side, sectional view cut away to show that the edge ridge leaves a central cavity 106. In addition, a bottom cavity 108 is shown, which is more clearly visible in the bottom view of Fig. 10D.

Returning to Fig. 9, a side view of container 100 corresponding to the view in Fig. 10B is shown, with a fan 110 mounted on top. A Peltier device 112 is mounted in cavity 108, which is visible because that portion of the container is shown in cut away form. On the other side of Peltier 112 is a cold plate 114, which is connected to the device to be cooled, a microprocessor 116 in this case. A positive temperature coefficient intrinsic layer 118 is shown connected to the top of the cold plate, with a flexible wire circuit 120 providing the connections to intrinsic 118, Peltier 112 and fan 110. A pair of insulating gaskets 122 prevent the cold plate from coming into contact with the container/heat exchanger, while also sealing off the Peltier device and intrinsic within the cavity, protecting them from moisture and dust.

The use of the cavity to hold the Peltier device not only improves the heat conduction characteristics, but also provides a container for housing the Peltier. The cavity could be made larger so that it encompasses not only the Peltier, but the cold plate and the microprocessor as well.

As can be seen in Fig. 10A, the container's structure with the slots near the edge leaves a large central open cavity 124. When the fan is mounted on top, the hub of the fan will be over this area, which is dead space not used anyway. The airflow will come through the slots at the edges and up through the fan. The closely spaced slots will also act as a dust filter, collecting dust as the air is pulled through. The wall between the slots has a thin edge, with a larger flat surface extending inward. Thus, the need for a separate filter is eliminated, helping to make the overall device more compact. Compactness is critical for a device which is intended, in one embodiment, to be mounted on a microprocessor chip on a circuit board. The embodiment of

Fig. 9 has been constructed so that the total height above the microprocessor of the device, including the fan, is seven tenths of an inch. The footprint of the device of Fig. 9 has been constructed to be a square with 41 mm to a side, compared to typical Intel 80486 microprocessor chip of 45 mm on a side.

Fig. 11 shows the details of the flex circuit 120 of Fig. 9. Contacts 126 and 128 are used for making electrical connection to the Peltier device 112. A circuit 130 includes intrinsic 118 and other circuitry shown in more detail in Fig. 12. Separate leads for fan 110 can be connected to contacts 132. Finally, a pair of contacts 134 are provided for optional connection to a temperature sensor for monitoring how the device is working.

Fig. 12 shows a circuit 130 for controlling Peltier device 112 of Fig. 9. The input voltage with a ground connection 136 and a high voltage connection (5 volts) 138 is brought on, as shown on the flex circuit diagram of Fig. 7, to circuit 130. The positive end 138 is connected through a thermal fuse 140 to a voltage regulator 142. In a preferred embodiment, the voltage regulator is Part No. LM317 provided by Motorola. The voltage regulator has a voltage input terminal 141, an output terminal 143 and a voltage adjustment terminal 144 which is used to control the current provided to the voltage regulator 142. The adjustment terminal 144 is connected to ground through a positive temperature coefficient intrinsic device 118. This can be used with a resistor 146, which effectively forms a voltage divider to control the current on adjustment input 144, with the current varying with temperature under the control of intrinsic 118.

In an alternate embodiment, resistor 146 may be a negative temperature coefficient device, and a fixed resistor could be substituted for positive temperature coefficient intrinsic 118. In yet another alternate device, both positive and negative temperature coefficient intrinsic layers could be used as shown in Fig. 12. Finally, optional capacitors 148 and 150 may be provided. The negative temperature coefficient device would be connected to the same place as the positive temperature coefficient device as shown in Fig. 9. That is, to the receiving side of the Peltier device, or anything thermally connected to the receiving side of the Peltier device, such as the cold plate.

Fig. 13 is a diagram of a Peltier device having a receiving plate 150 for connecting to the microprocessor and a rejection plate 152 for connecting to a heat exchanger. A 5-volt power supply 154 has a positive terminal connected to a first, N-type couple 156. Couple 156 is, in turn, connected through a conductor 158 to a second, P-type couple 160. The connections of the couples continue in a number of rows, with only one row showing in Fig. 13, until a final connection to the negative terminal of 5-volt power supply 154 is provided by a P-type couple 162. Peltier devices of this type are well-known, and are typically use bismuth telluride couples. Heat absorbed at the receiver plate 150 is pumped to the rejector plate 152 at a rate proportional to a carrier current passing through the circuits and the number of couples. The amount of current passing through the couples for a fixed voltage is determined by the resistance of the couples, which is a function of the length of the couple between the two plates and the area of the couple. As the ratio of the area to the length increases, the current will increase.

Typically, Peltier devices such as that shown in Fig. 13 are sold with different geometries to give different heat-pumping capacities for different uses.

The practice of the prior art is to control a Peltier device which has the desired heat-pumping capacity using a feedback circuit to ensure that it maintains the microprocessor at the desired temperature. See, for instance, Patent No. 4,812,733. The control circuit provides the necessary feedback to account for differences in the power level of the microprocessor the cooling device may be coupled to, as well as variations in microprocessor power.

The present inventor recognized that an individual type of microprocessor, such as the Intel 80486, will operate at substantially a constant power level regardless of whether it is idling or in full computational operation. In addition, the inventor determined that the maximum heat-pumping capacity of the Peltier device itself could be used as an intrinsic limiting element which would prevent the microprocessor from being cooled below the condensation temperature for a fixed power supply and voltage.

In particular, an Intel 80486 microprocessor will generate approximately 5 watts of heat when operated at 50MHz. When operated at 33MHz, it will dissipate approximately 3.75 watts of heat. When used in conjunction with the container/heat exchanger design of Figs. 10A-10D, which provides a thermal resistance of 1.25°C per watt, a Peltier device design having 71 couples, with an area of 1.0mm each and a height of .05 inches each was chosen. Such Peltier geometry has a maximum suggested voltage of 8.6 volts, at which voltage it has a heat pump capacity of 18.7 watts. By operating this geometry at 5 volts, a 5 watt, 50MHz 80486 microprocessor is cooled below ambient temperature and yet above the condensation temperature. The cooling of the microprocessor causes more than 5 watts to be dissipated through the Peltier since heat is also pulled from the motherboard through the pins of the microprocessor as the microprocessor is cooled. By operating the Peltier device at 5 volts, which is below the manufacturer's recommended operation of 7 volts, less power is consumed by the Peltier device itself. However, as the voltage is dropped, the current drops exponentially, while the heat-pumping capacity drops at a lesser rate. Thus, when the power is dropped to between 50 and 70 percent of its maximum value, the heat-pumping capacity is still around 80 percent. Such a Peltier device is preferably used in combination with the design of Figs. 10A-10D in an embodiment such as shown in Fig. 9 without the intrinsic 118. The couplings between the microprocessor and the cold plate, the cold plate and the Peltier device, and the Peltier device and the container/heat exchanger are preferably made with a thermally conductive adhesive. Such an adhesive is preferably an acrylic transfer adhesive, or acrylic pressure-sensitive adhesive which has a thermal filler, preferably carbon, to make it thermally conductive.

The area of the container 100 of Fig. 9 is preferably a square with 41 mm on the side, as compared to 45 mm on a side of an Intel 80486 microprocessor. The Peltier device is preferably square, with 23 mm on a side, and the cold plate of Fig. 9 is preferably a square with 30 mm on a side. The fan of Fig. 9 is preferably connected to a 12 volt power supply. The flex connection of Fig. 11 is still used, but without the circuit 130.

Alternate geometries have been chosen for use with other microprocessor designs. For instance, the Intel 80386 microprocessor is cooled using a Peltier device with 71 couples each having an area of 1.0 mm^2, but a height of .06 inches. For an Intel 80286 microprocessor, 71 thermocouples with an area of 1mm^2 and a height of .08 inches is a preferred design.

As will be understood by those familiar with the art, the present invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. For example, thermoelectric devices other than the Peltier device can be used, or it could be attached to an apparatus other than a semiconductor chip, such as a refrigerator or for cooling the inside of a motorcycle helmet. Other cooling apparatus than a thermoelectric device could be used, such as vapor compression, Sterling and vortex devices. The intrinsic could also be mounted on the rejection side of the cooling device. In the NTC intrinsic embodiment, the Peltier could be connected to the power supply with the NTC intrinsic connected to ground. The power supply could be other than 12 volts, and could be AC. Control of the cooling device could be achieved by varying the speed of the fan or varying the air gap of the slots of the container by, for instance, using a material which expands and contracts with temperature. Accordingly, the disclosure of the preferred embodiment of the invention is intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

WHAT IS CLAIMED IS:

1. A device for cooling an apparatus comprising:

a positive temperature coefficient intrinsic semiconducting layer having a resistance which increases with increasing temperature;

a cooling device coupled to said intrinsic layer, said cooling device and said intrinsic layer being coupled together and having a surface for coupling to said apparatus; and

means for applying a current to said intrinsic layer.

2. The device of claim 1 wherein said cooling device is a thermoelectric device.

3. The device of claim 1 wherein said intrinsic layer is mounted between said cooling device and said apparatus.

4. The device of claim 1 further comprising a heat exchanger coupled to said cooling device.

5. The device of claim 4 further comprising a fan coupled to said heat exchanger.

6. The device of claim 1 wherein said cooling device is a thermoelectric device and said means for applying a current comprises a power supply line coupled to both said intrinsic layer and said thermoelectric device.

7. The device of claim 1 further comprising a thermally conducting plate coupled between said intrinsic layer and said apparatus.

8. The device of claim 1 wherein said apparatus comprises a semiconductor package.

9. The device of claim 1 further comprising a heat exchanger coupled to said cooling device, said heat exchanger comprising:

a plate having a first side coupled to said cooling device;

a hub connected to a second side of said plate;

a plurality of radially extending fins, each fin being connected to said hub along a first edge and connected to said plate along a second, orthogonal edge.

10. The device of claim 9 further comprising a fan mounted on said heat exchanger, said fan having a central dead air space corresponding to the size of said hub.

11. The device of claim 1 wherein said apparatus is an electronic component and said intrinsic layer, cooling device and means for applying current are chosen to hold said electronic component in a temperature range above the condensation point for water.

12. A device for cooling an apparatus comprising:

a thermally conducting plate for coupling to said apparatus;

an intrinsic semiconducting layer having a first side coupled to said thermally conducting plate;

a thermoelectric device having a first side coupled to a second side of said intrinsic layer;

a heat exchanger coupled to a second side of said thermoelectric device; and

a power supply line coupled to both said intrinsic layer and said thermoelectric device.

13. The device of claim 12 further comprising a fan coupled to said heat exchanger.

14. A heat exchanger for connecting to a device to be cooled, comprising:

a plate having a first side coupled to said device;

a hub connected to a second side of said plate;

a plurality of radially extending fins, each fin being connected to said hub along a first edge and connected to said plate along a second, orthogonal edge.

15. The heat exchanger of claim 14 further comprising a fan mounted on said heat exchanger, said fan having a central dead air space corresponding to the size of said hub.

16. The heat exchanger of claim 14 wherein said hub is solid.

17. The heat exchanger of claim 14 wherein said hub is a heat pipe having an internal gas.

18. A device for cooling an apparatus comprising:

a negative temperature coefficient intrinsic semiconducting layer having a resistance which decreases with increasing temperature, thermally coupled to said apparatus;

an electrically powered cooling device thermally coupled to said apparatus; and

a power supply line coupled to one of said intrinsic layer and said cooling device, said intrinsic layer and said cooling device being electrically in series.

19. The device of claim 18 wherein said cooling device is a thermoelectric device.

20. The device of claim 19 wherein said thermoelectric device is coupled to said apparatus via a cold plate, and said intrinsic layer is in parallel with said thermoelectric device on said cold plate.

21. The device of claim 19 further comprising a heat exchanger coupled to said thermoelectric device.

22. The device of claim 21 further comprising a fan coupled to said heat exchanger.

23. A device for cooling an apparatus comprising:

a negative temperature coefficient intrinsic semiconducting layer having a resistance which decreases with increasing temperature, thermally coupled to said apparatus;

a thermoelectric device having a first side thermally coupled to said apparatus;

a heat exchanger coupled to a second side of said thermoelectric device; and

a power supply line coupled to one of said intrinsic layer and said thermoelectric device, said intrinsic layer and said thermoelectric device being electrically in series.

24. A device for cooling an apparatus comprising:

an intrinsic semiconducting layer having a resistance which varies with temperature;

a cooling device having a receiving side thermally coupled to said intrinsic layer, one of said cooling device and said intrinsic layer being thermally coupled to said apparatus; and

means for applying a current to said intrinsic layer.

25. The device of claim 24 wherein said cooling device is a thermoelectric device and further comprising a voltage regulator having a voltage input, a voltage output and an adjustment terminal, said voltage output being coupled to a first terminal of said thermoelectric device, said intrinsic layer being a positive temperature coefficient layer electrically coupled between said adjustment terminal of said voltage regulator and a second terminal of said thermoelectric device.

26. The device of claim 24 wherein said cooling device is a thermoelectric device and further comprising a voltage regulator having a voltage input, a voltage output and an adjustment terminal, said voltage output being coupled to a first terminal of said thermoelectric device, said intrinsic layer being a negative temperature coefficient layer electrically coupled between said adjustment terminal of said voltage regulator and a second terminal of said thermoelectric device.

27. The device of claim 24 further comprising a heat exchanger coupled to a rejection side of said cooling device.

28. The device of claim 27 wherein said heat exchanger comprises a plate having a ridge with a plurality of slots extending from a first surface of said plate along the perimeter of said plate, said ridge defining a central cavity between interior edges of said ridge and said first surface.

29. The device of claim 28 further comprising a fan mounted on said heat exchanger, said fan having a hub positioned above said cavity.

30. The device of claim 28 wherein said heat exchanger includes a second cavity extending into a second surface of said heat exchanger opposite said first surface, said cooling device being mounted at least partially inside said second cavity.

31. A device for cooling an apparatus comprising:

a positive temperature coefficient intrinsic semiconducting layer;

a thermoelectric cooling device having a receiving side thermally coupled to said intrinsic layer, one of said cooling device and said intrinsic layer being thermally coupled to said apparatus;

means for applying a current to said intrinsic layer;

a voltage regulator having a voltage input, a voltage output and an adjustment terminal, said voltage output being coupled to a first terminal of said thermoelectric device, said intrinsic layer being electrically coupled between said adjustment terminal of said voltage regulator and a second terminal of said thermoelectric device;

a container coupled to a rejection side of said cooling device, said container having a ridge with a plurality of slots extending from a first surface of said container along the perimeter of said container, said ridge defining a first central cavity between interior edges of said ridge and said first surface, said container including a second cavity extending into a second surface of said container opposite said first surface, said cooling device being mounted at least partially inside said second cavity;

a fan mounted on said container, said fan having a hub positioned above said first cavity.

32. A heat exchanger comprising a plate having a ridge with a plurality of slots extending from a first surface of said plate along the perimeter of said plate, said ridge defining a central cavity between interior edges of said ridge and said first surface.

33. The device of claim 32 further comprising a fan mounted on said heat exchanger, said fan having a hub positioned above said cavity.

34. The device of claim 32 wherein said heat exchanger includes a second cavity extending into a second surface of said heat exchanger

opposite said first surface, providing an enclosure for a cooling device to be mounted at least partially inside said second cavity.

35. A method for cooling a semiconductor device on a circuit board having a limited number of fixed voltages available using a Peltier effect thermoelectric cooling device and a heat exchanger, comprising the steps of:

determining an average heat generation of said semiconductor device in operation;

determining the thermal resistance of said heat exchanger;

determining an optimum geometry of said Peltier device in combination with a selected one of said fixed voltages to cool said semiconductor device below an ambient temperature without providing sufficient heat pumping capacity to cool said semiconductor device to a condensation temperature; and

coupling said Peltier device between said semiconductor device and said heat exchanger, with said Peltier device being connected to said selected one of said fixed voltages.

36. The method of claim 35 wherein said selected voltage is five volts, said semiconductor device is a microprocessor and further comprising the step of coupling a fan to said heat exchanger, said fan being coupled to a twelve volt power supply on said circuit board.

37. The method of claim 35 wherein said step of coupling said Peltier device between said semiconductor device and said heat exchanger comprises applying a thermally conductive adhesive between said Peltier device and said heat exchanger and between said Peltier device and said semiconductor device.

38. The method of claim 35 further comprising the step of coupling a cold plate between said semiconductor device and said Peltier device.

39. The method of claim 35 wherein said Peltier device geometry is chosen to have said Peltier device operate at between fifty and seventy percent of the maximum heat pumping capacity of said Peltier device at said selected voltage.

40. The method of claim 35 wherein said step of choosing an optimum geometry comprises selecting an optimum combination of the number of couples, the height of said couples, and the area of said couples.

41. A cooling device mounted on a microprocessor on a circuit board having a twelve volt power supply and a five volt power supply, said cooling device comprising:

a cold plate having a first side coupled to said microprocessor with a thermally conductive adhesive;

a Peltier effect thermoelectric device having a receiving plate and a rejection plate connected together with a number of couples, said receiving plate being coupled to a second side of said cold plate with said thermally conductive adhesive;

a heat exchanger coupled to said rejection side of said Peltier device with said thermally conductive adhesive;

a fan coupled to said heat exchanger, said fan being coupled to said twelve volt power supply;

said Peltier device being coupled to said five volt power supply and having a number of said couples, with an area and height such that, when coupled to said five volt power supply, said Peltier device cools said microprocessor below an ambient temperature without cooling below a condensation temperature.

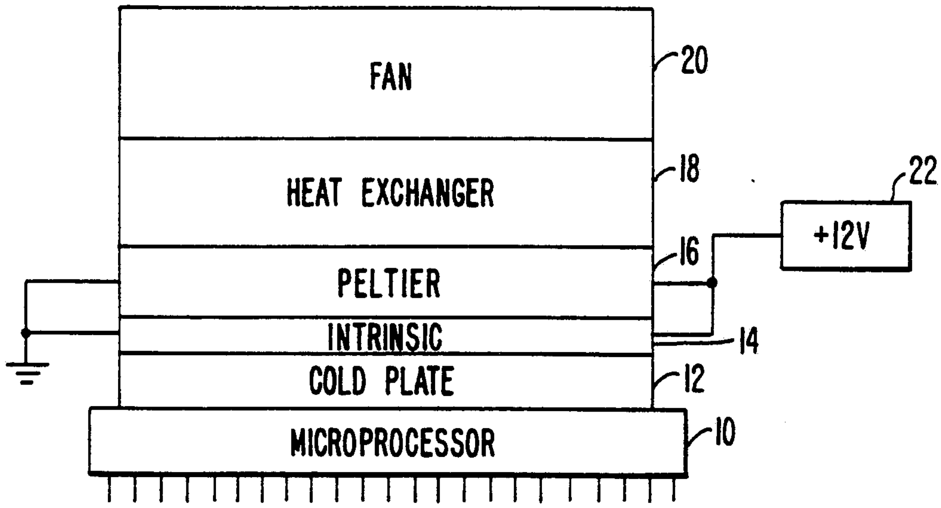


FIG. 1.

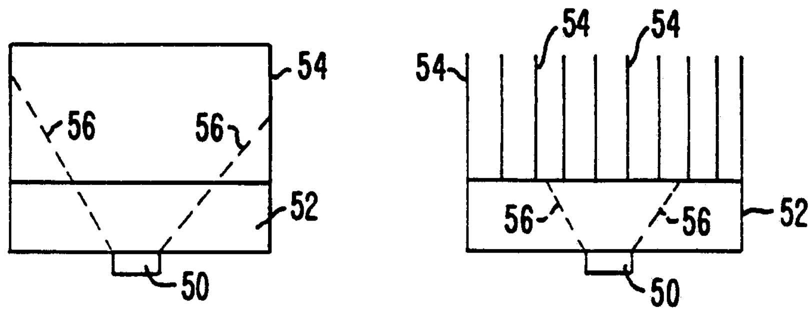


FIG. 6A.
PRIOR ART

FIG. 6B.
PRIOR ART

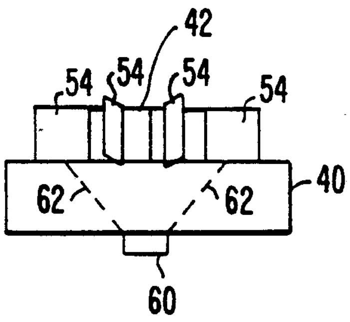


FIG. 7.

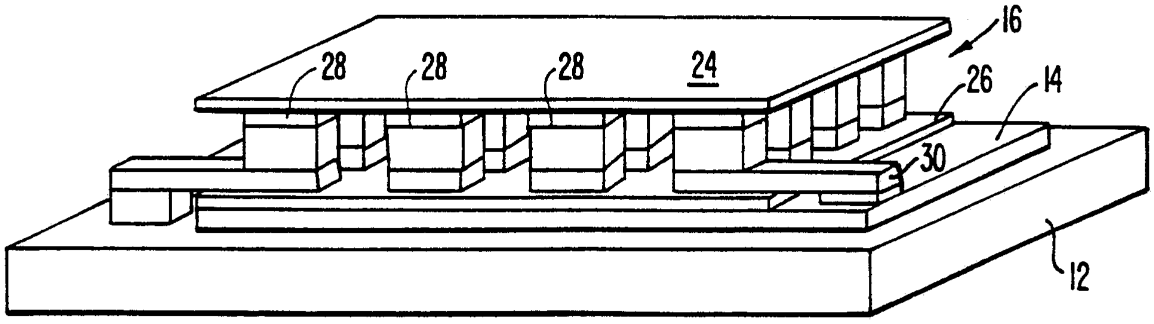


FIG. 2A.

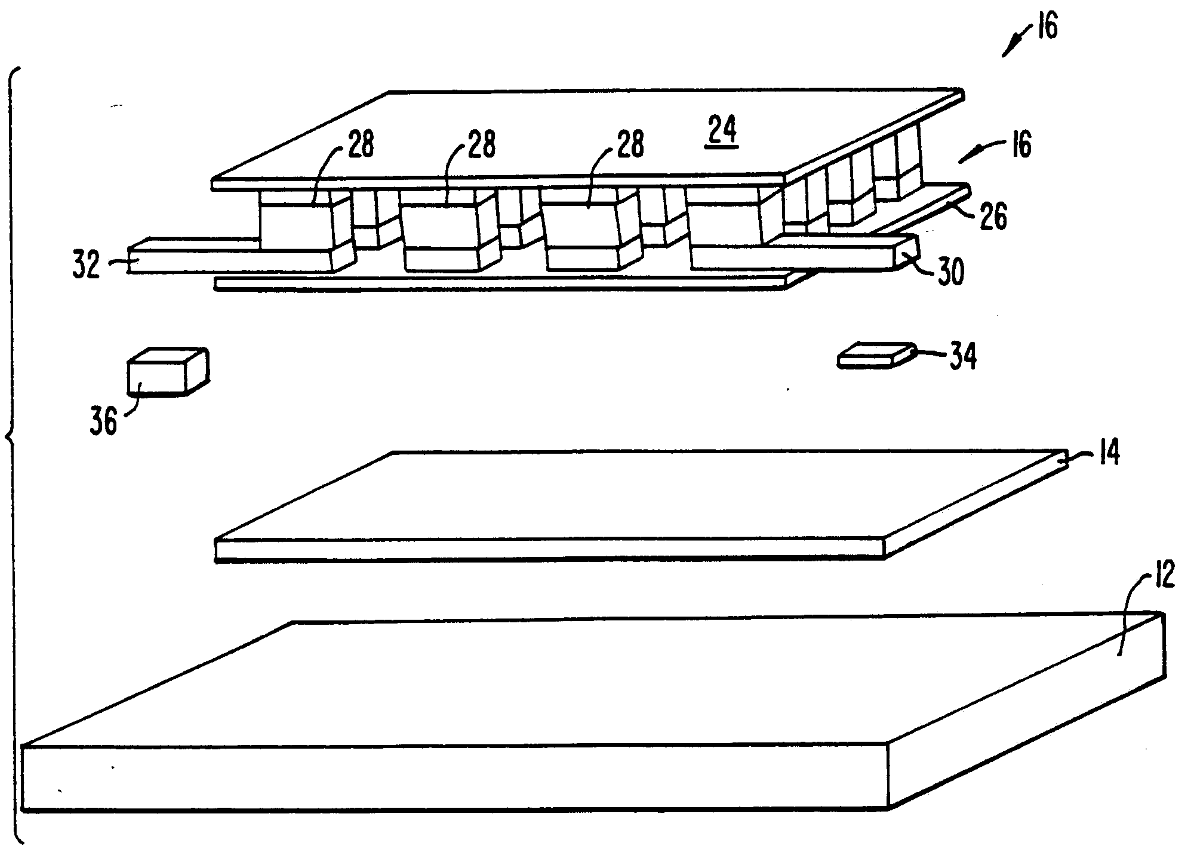


FIG. 2B.

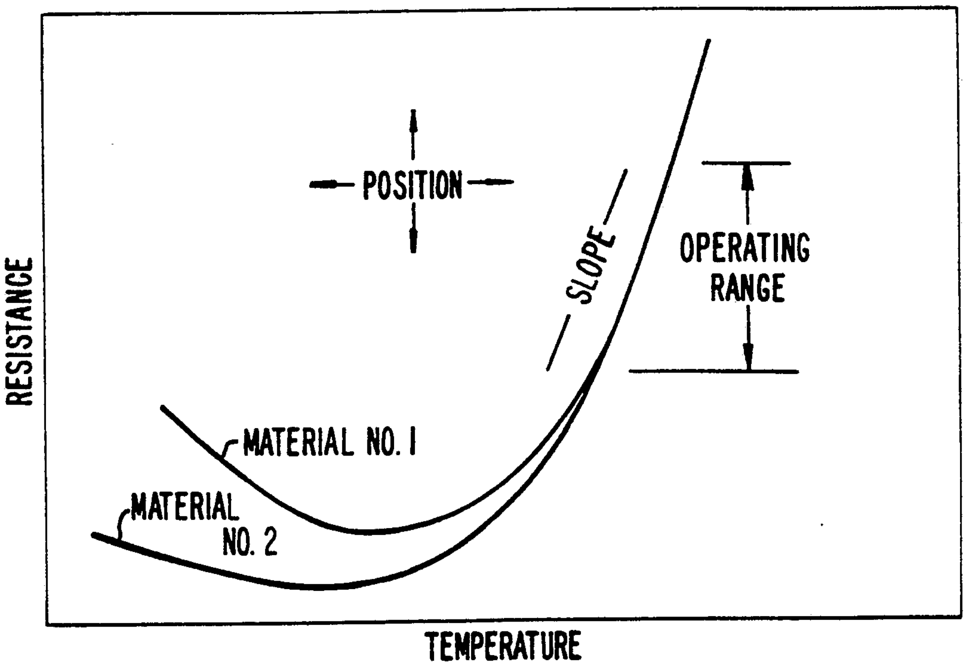


FIG. 3.

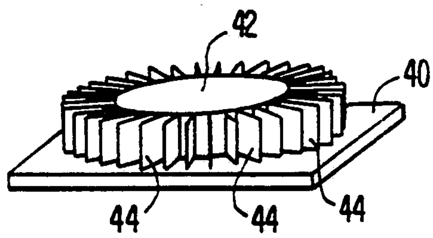


FIG. 4.

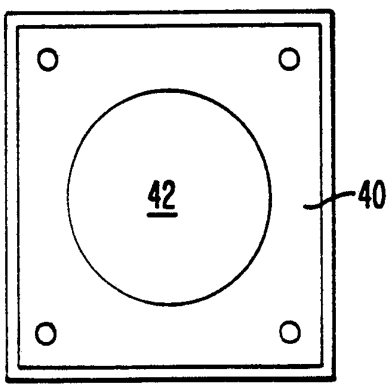


FIG. 5A.

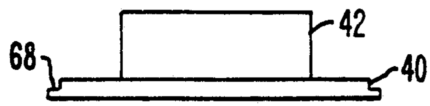


FIG. 5B.

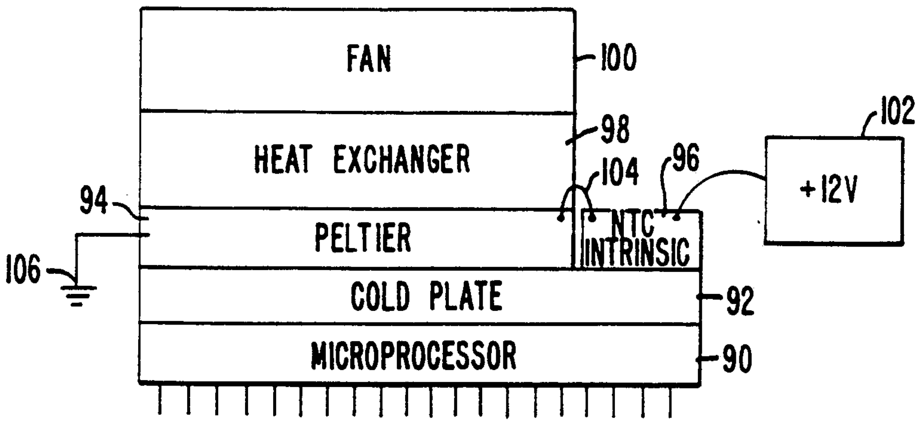


FIG. 8.

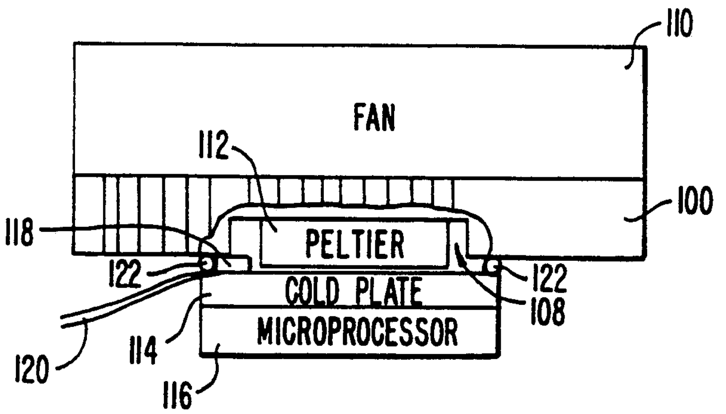


FIG. 9.

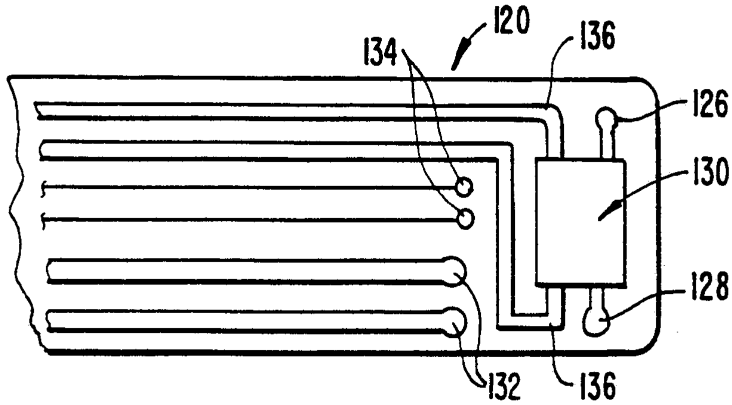


FIG. 11.

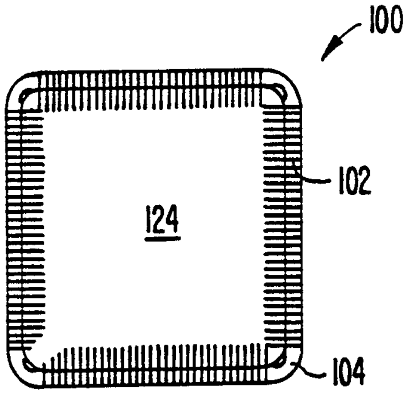


FIG. 10A.

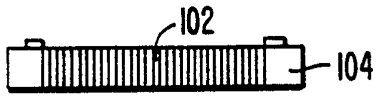


FIG. 10B.

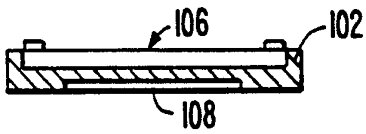


FIG. 10C.

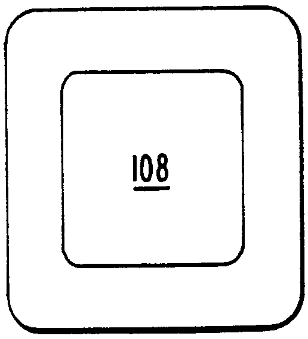
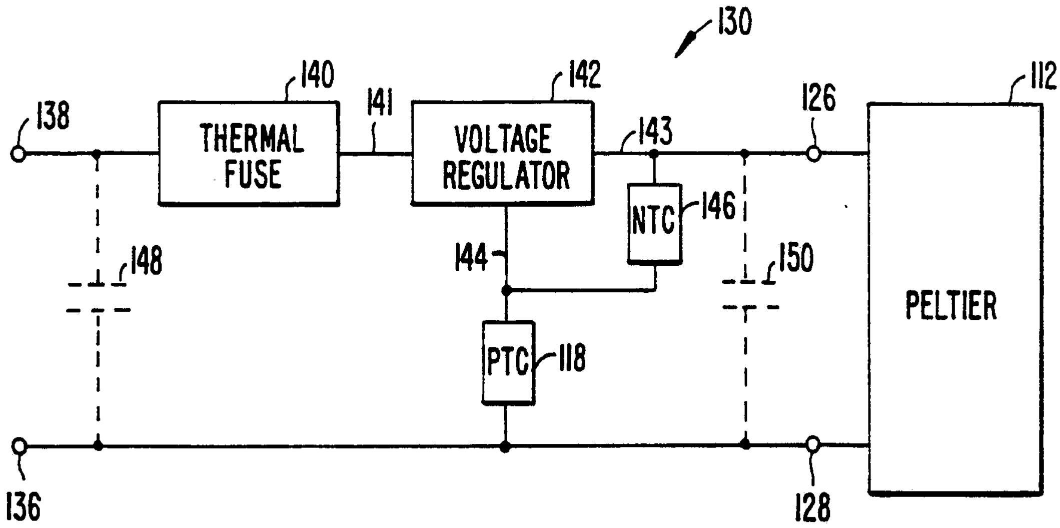


FIG. 10D.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FUSE
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VOLTAGE
REGULATOR
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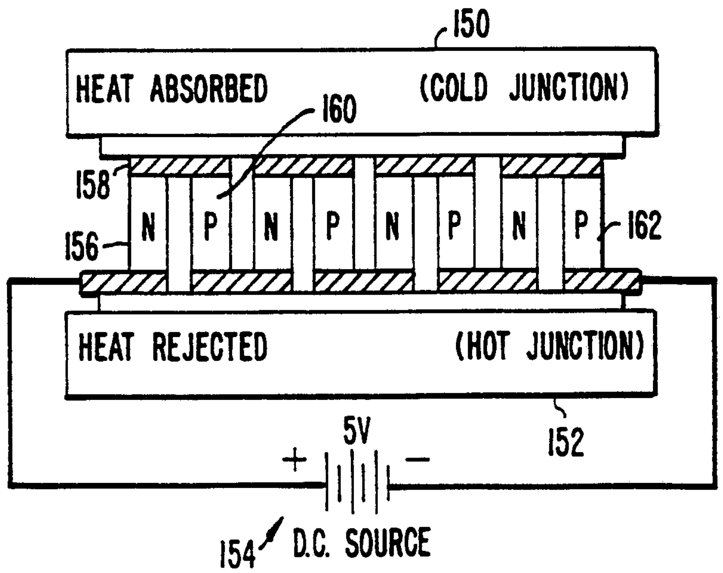
126
NTC
146
144
148
150
PELTIER
PTC
118
136
128

FIG. 12.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158
N
P
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N
P
N
P
162
156
HEAT REJECTED
(HOT JUNCTION)
5V
+
−
152
154
D.C. SOURCE

FIG. 13.

INTERNATIONAL SEARCH REPORT

International Application No.
PCT/US92/08709

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H01L 23/02, 35/28; H02B 1/00; H05K 7/20
US CL :257/712, 722, 930; 136/203, 304; 361/384
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 257/538; 136/222, 224, 230

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS [(Peltier or Thermoelectric) and (Intrinsic or Undoped) and Semiconductor and Resistance and Fin?]

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P Y	US, A, 5,079,618 (Farnworth) 07 January 1992, Figure 3, column 2, lines 34-54, column 10, lines 32-53.	1-13,18-30,35-41 31-34
X Y	US, A, 4,715,438 (Gabuzda) 29 December 1987, Figure 5, column 3, lines 8-24.	14-17 31-34
A	JP, A, 58-137239 (Sony K.K.) 15 August 1983, Constitution lines 1-10.	31-34
A	JP, A, 1-258449 (Nippon Steel Corp) 16 October 1989, Constitution lines 1-14.	1-13,18-30,35-41
A	US, A, 3,419,767 (Dahlberg) 31 December 1968, Column 4, lines 35-48.	1-13,18-30,35-41

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search: 16 DECEMBER 1992

Date of mailing of the international search report: 11 JAN 1993

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Authorized officer: DAVID OSTROWSKI

Telephone No. (703) 308-4408

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US, A, 5,091,822 (Takashima) 25 February 1992, Figure 1, column 4, lines 32-35.	14-17
A	US, A, 4,082,651 (Gabuzda) 28 July 1987, Figure 1 and abstract.	14-17
A	IBM Technical Disclosure Bulletin, Vol. 27, No. 9 February 1985, J.W. Davis, "Peltier Couple" pages 5096-5099.	1-13,18-41
A	US, A, 4,926,242 (Itoh) 15 May 1990, Figure 3.	1-17
A	US, A, 4,238,759 (Hunsperger) 09 December 1980, Column 2, lines 5-42.	1-13,18-30,35-41
A	US, A, 4,918,571 (Grabbe) 17 April 1990, Figure 2, column 3, lines 15-28.	14-17,31-34
A	US, A, 4,812,733 (Tobey) 14 March 1989, Abstract.	1-41
A	US, A, 4,685,081 (Richman) 04 August 1987, Column 2, lines 22-38.	1-13,18-41
A	US, A, 4,253,515 (Swiatosz) 03 March 1981, Figure 1, abstract, column 2, lines 50-58.	1-13,18-30,35-41