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(54) Title: LOW STRESS THERMOELECTRIC MODULE

(57) Abstract: Applicants have identified four methods to minimize the stress in the module and thereby minimize the warping the module experiences during the fabrication process. These include: breaking up the slab, thin plastic between elements, use of Bridgeman cast legs, and soldering the cold side. The primary cost driver of thermoelectric modules is the costs associated with the N and P thermoelectric material needed to make the N and P thermoelectric legs of the module. Preferred embodiments designed by applicants utilize legs that require only a small fraction of the thermoelectric material compared to typical prior art thermoelectric modules with only a slight decrease in efficiencies. These smaller legs result in projected high-volume module costs of less than \$1.00 per watt.

LOW STRESS THERMOELECTRIC MODULE

FIELD OF THE INVENTION

The present invention relates to thermoelectric modules and to methods of making modules with a minimum warpage.

BACKGROUND OF THE INVENTION

Thermoelectric Modules

Electric power generating thermoelectric modules are well known. These modules typically are comprised of a number of thermoelectric elements called n-legs and p-legs connected electrically in series. The effect is that a voltage differential of a few millivolts is created in the presence of a temperature difference at the two junctions of p-type thermoelectric semiconductor elements and n-type thermoelectric semiconductor elements. Since the voltage differential is small, many of these elements (such as about 100 elements) are typically positioned in parallel between a hot surface and a cold surface and are connected electrically in series to produce potentials of a few volts. Electrons flow from the hot side to the cold side through the n-legs and from the cold side to the hot side through the p-legs. Many references refer to the current in the p-legs as holes flowing from the hot side to the cold side.

Hi-Z Prior Art Bismuth Telluride Molded Egg-Crate Modules

For example Hi-Z Technology, Inc. offers a Model HZ-14 thermoelectric bismuth telluride thermoelectric module designed to produce about 14 watts at a load potential of 1.66 volts with a 200°C temperature differential. Its open circuit potential is 3.5 volts. The module contains 49 n-legs and 49 p-legs connected electrically in series. It is a 0.5 cm thick square module with 6.27 cm sides. The legs are p-type and n-type bismuth telluride semiconductor legs and are positioned in an egg-crate type structure that insulates the legs from each other except where they are intentionally connected in series at the top and bottom surfaces of the module. That

egg-crate structure which has spaces for 100 legs is described in US Patent No. 5,875,098 which is hereby incorporated herein by reference. The egg-crate is injection molded in a process described in detail in the patent. This egg-crate has greatly reduced the fabrication cost of these modules and improved performance for reasons explained in the patent. Insulating walls keep the electrons flowing in the desired series circuit. Other Bi_2Te_3 thermoelectric modules that are available at Hi-Z are designed to produce 2.5 watts, 9 watts and 20 watts at the 200°C temperature differential. The term bismuth telluride is often used to refer to all combinations of Bi_2Te_3 , Bi_2Se_3 , Sb_2Te_3 and Sb_2Se_3 . In this document where the term Bi_2Te_3 is used, it means any combination of Bi_2Te_3 , Bi_2Se_3 , Sb_2Te_3 and Sb_2Se_3 .

Thermal Stress and Warpage

Modules made using Hi-Z's eggcrate technology require that a metal (usually aluminum) be thermally deposited onto the module surface. When this is done the molten aluminum strikes the module surface and is instantly cooled. As the aluminum cools the metal shrinks thereby adding significant stress in the aluminum and in the thermoelectric elements that it is deposited onto. This stress can cause the elements to crack, the metal/semiconductor bond to fail and warp the module giving it a spherical shape. Cracked elements and interfaces destroy the module and a warped module compromises subsequent fabrication process steps that rely on a flat module. One example is the grinding step. Because the grinding step creates a flat surface on the face of the module, a module face that is already warped will preferentially grind metal off the high spots. If a concave surface is being ground then the metal on the outside perimeter of the module will be thinner than the metal in the center of the module. If a convex surface is being ground then the metal in the outside perimeter will be thicker than the metal in the center of the module. If the module is too severely warped then the grinding process may actually grind through the metal layer exposing the semiconductor material beneath the metal causing the module to fail.

Temperature Limitations

The egg-crates for the above described Bi_2Te_3 modules are injection molded using a thermoplastic supplied by Dupont under the trade name "Zenite". Zenite melts at a temperature of about 350°C. The ZT thermoelectric properties of Bi_2Te_3 peak at about 150°C and are greatly

reduced at about 250°C. For both of these reasons, use of these modules are limited to applications where the hot side temperatures are lower than about 250 °C to 300 °C.

Thermoelectric Efficiencies

Despite the fact that there exists a great need for non-polluting electric power and the facts that there exists a very wide variety of un-tapped heat sources, and the thermoelectric electricity would be free, thermoelectric electric power generation in the United States and other countries is minimal as compared to other sources of electric power. The reason primarily is that thermoelectric efficiencies are typically low compared to other technologies for electric power generation and the cost of thermoelectric systems per watt generated is high relative to other power generating sources. Generally the efficiencies of thermoelectric power generating systems are in the range of about 5 percent. Proposals to increase these efficiencies by stacking different types of materials have been made but these stacked designs become complicated and expensive to produce and the resulting efficiencies are not much better than about 10 percent. Workers in the thermoelectric industry have also recognized that since thermoelectric efficiency is low, the cost of the modules must be kept low in order for thermoelectric power to be competitive. For thermoelectric modules of the type described above in order to be generally competitive with other power generating methods must be made at costs in the range of about \$1.00 per watt. The costs of prior art modules described above are many times this value.

What is needed is a low-stress, substantially warp free thermoelectric modules that can be manufactured at costs of less than about \$1.00 per watt.

SUMMARY OF THE INVENTION

Small Thermoelectric Legs

Thermoelectric properties are to a large extent determined by the ratio of the leg area divided by the leg length (A/L). A large A/L will result in a leg with a low resistance and a low A/L will result in a leg with a high resistance. Applicant has designed preferred embodiments with

smaller cross-sectional areas and smaller lengths in order to reduce the thermoelectric material in the module without a substantial reduction in performance. The cost savings are substantial.

In the prior art module the cost of the thermoelectric semiconductor material Bi_2Te_3 was the largest single material cost representing 60% of the total cost of materials. The leg used in this module was 5mm x 5mm x 2.7mm with a volume of 67.5mm^3 and had an A/L ratio of 9.3mm. Keeping the same A/L ratio and reducing the size of the leg to 3mm x 3mm x 1mm results in a leg with a volume of 9mm^3 . Which is about 13% of the volume of the leg used in the prior art module. In the prior art module the cost of the expensive Bi_2Te_3 represented more than 60% of the total materials costs. In the preferred embodiment the Bi_2Te_3 represents only 20% of the total materials costs.

To reduce cost, the thermoelectric leg should be as small as possible but several problems limit how small the leg can be made. One of those problems is that as the size of the leg is reduced it becomes weaker and more easily broken or the contacts to the leg are weaker and easily broken due to their small size. This problem may be compounded if the legs are spaced far apart to keep the heat flux of the module at a manageable level. Spacing the legs far apart requires using more eggcrate material between the legs. A large difference between the thermal expansion coefficient of the eggcrate material and the leg can cause higher stresses in a small leg than in a large leg. The weakness of the small leg and the larger stresses can be accommodated by using a flexible material for either the hot side conductor or the cold side conductor (or both the hot and cold side conductors) joining N legs to P legs. A flexible conductor will accommodate small displacements of the leg and/or eggcrate preventing the buildup of stress. Using an eggcrate of only partial thickness will also reduce the stresses experienced by the legs.

Applicants have identified four methods to minimize the stress in the module and thereby minimize the warping the module experiences during the fabrication process. These include:

1. Breaking up the slab,
2. Thin plastic between elements,
3. Use of Bridgeman cast legs, and
4. Soldering the cold side.

As discussed, the primary cost driver of thermoelectric modules is the cost associated with the N and P thermoelectric material needed to make the N and P thermoelectric legs of the module. Preferred embodiments designed by applicants utilize legs that require only a small fraction of the thermoelectric material compared to typical prior art thermoelectric modules with only a slight decrease in efficiencies. These smaller legs result in projected high-volume module cost of less than \$1.00 per watt.

Breaking up the Slab

A prior art technique for making a thermoelectric module with a polymer eggcrate is shown in FIGS. 1-4. The eggcrate 1 is loaded with N and P type thermoelectric elements 2 as shown in FIG. 1. The eggcrate holds the elements in their proper position and leaves the top and bottom of the elements exposed so that electrical connections can be made from one element to the adjacent element. This is accomplished by thermal spraying aluminum metal (using a Mo bond coat) onto both surfaces of the loaded eggcrate. This forms a continuous metal slab 3 as shown in FIG. 2. When this metal slab is ground down to expose the tops and bottoms of the eggcrate electrical connections are formed between two adjacent thermoelectric elements. These connections create an electrical circuit 4 as shown in FIG. 3.

The problem begins when the first metal slab is deposited as shown in FIG.4. Because the metal layer covers the entire module (typically several centimeters across) the entire slab shrinks about 0.5%. For a 6 cm module that is shrinkage of about 300 μ m. A deformation of 300 μ m could impart significant stress in a module and cause unacceptable warpage as shown in FIG. 4. This warpage is not reversed when the second surface of the module is thermally deposited.

If the walls 5 of the eggcrate separating the thermoelectric elements are made high enough to prevent the metal deposit from forming a single slab then several smaller metal deposits 6 will form as shown in FIG. 5. This means that the shrinkage will occur only over the distance of a single thermocouple. This distance is typically much less than 1 cm meaning that the shrinkage will be less than 50 μ m. While any shrinkage will cause stress, the stress and deformation will be an order of magnitude less.

In addition to breaking the large metal slab into several smaller discrete metal deposits, the tall walls act as structural members making the eggcrate stiffer and stronger and therefore less likely

to warp. The stronger eggcrate along with less stresses result in a finished module with little to no warpage.

Thin Plastic between Conductors

The difference in thermal expansion between the eggcrate and the thermoelectric materials can induce stresses into the thermoelectric materials. Due to their low thermal conductivity, ease with which they can be formed, durability, insulating properties and low cost, polymers are common materials to use for an eggcrate. Unfortunately most polymers have very high coefficients of thermal expansion and this difference can induce stresses into the thermoelectric alloys as illustrated in FIG. 6. These coefficients of thermal expansion often exceed 60 ppm/°C as compared to 13 ppm/°C for the bismuth telluride.

FIG. 7 compares a couple with a thick wall between the conductors FIG. 7a with a couple that has a thin wall between the conductors FIG. 7b. This demonstrates that as the size of the thermoelectric elements are reduced to minimize cost; the space between the elements 16 must be increased to prevent the heat flux of the module from becoming excessively high by maintaining the same center to center distance between the legs. Due to the large difference between the thermal expansion of the polymer and the Bi_2Te_3 , the wide walls will exert a large force 17 on the conductor 18 causing it to lift off the small legs 19.

Applicant has changed the shape of the walls of the eggcrate as shown in FIG. 7b by keeping the wall between the conductors 20 as thin as possible (preferably between 0.5 mm and 1.0 mm). The thin walls will exert a much smaller force on the conductor.

Bridgman Cast Elements

No matter how much care is taken to minimize the stresses in the thermoelectric alloy, some stress will always remain. If for some reason the stresses become large enough to cause the element to crack it is helpful if the direction in which the crack propagates can be controlled. If the element has been formed from a bismuth telluride ingot that has been directionally solidified as represented in FIG. 8a then any crack 11 that forms will likely follow the grain boundaries 10. Since the grain boundaries 10 in a directionally solidified bismuth telluride alloy are aligned in the direction that gives the best thermoelectric properties any crack is likely to form parallel with

the direction of current flow 12 since modules are normally designed to have the current flow in the direction that has the best thermoelectric properties. Cracks 13 that form in fine grained bismuth telluride will travel randomly as illustrated in FIG. 8b and will likely cross the current path 12 causing a high resistance in that element. FIG. 8 shows how cracks may form in an element that has been directionally solidified (as in Bridgman casting) and an element formed from fine grained material such as in extrusions, spark plasma sintering or vacuum hot pressing. For these reasons preferred embodiments utilize legs cut from directionally solidified ingots or Bridgman cast ingots.

Solder Cold Side

Most bismuth telluride modules that are not intended to operate at temperatures higher than 175°C use solders to join the bismuth telluride elements to metal conductors to form an electrical path through the module. Using solders will limit the temperature at which these modules can operate for extended periods due to reactions between the elements and the solders, oxidation of the solder and due to the temperatures at which the solders melt. Since the cold side of a power module is rarely exposed to high temperatures it may be acceptable to solder the cold side of the element to a metal conductor and only metalize the hot side of the module. If two elements are soldered to a single conductor then little stress is added to the elements. Adding these couples to the eggcrate will add little stress to the assembly. The hot side of the elements can then be metalized as previously described and since only one side of the module is being metalized the resultant stresses in the module will be reduced.

Soldered elements can be added to the module in several ways. FIG. 9 shows two elements 14 soldered to a single conductor 15 and then inserted to an eggcrate as a single thermocouple. The couples can be held in place by heat staking, an adhesive, features designed into the eggcrate or other methods. Once the elements are all in place then the hot side can be metalized as previously discussed and as described in prior art Hi-Z patents.

Heat Staking Elements

When elements are placed in an eggcrate they can be prevented from falling through the cavity in the eggcrate by a fixture that holds them in place such as a ledge 16 molded into the eggcrate as shown in FIG. 10. The elements must fit loosely in the eggcrate to make insertion of the

elements simpler and more reliable. To prevent the elements from falling out of the eggcrate during subsequent assembly operations a heat staking tool 17 can be pressed into the polymer wall between two elements and melting the polymer. The force of the heat staking tool pushes the heated polymer to the sides forcing the element against the side of the cavity and filling any gap with molten polymer 18.

Heat staking the elements is a quick and low cost method of holding the elements in place during subsequent fabrication steps but it also strengthens the assembly. With the elements held rigidly in place the entire eggcrate assembly is more rigid further minimizing any warping that may occur.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross sectional view of a prior art loaded thermoelectric eggcrate prior to adding electrical connections.

FIG. 2 is a prior art drawing showing a section of a metalized module with hot and cold side metal slabs.

FIG. 3 shows directions of electric current flow after the metal slabs have been ground down in a prior art module.

FIG. 4 shows a prior art module with an exaggerated warp.

FIG. 5 is a module with deep walls and discrete metal deposits representing features of the present invention.

FIG. 6 demonstrates stress due to polymer expansion in prior art modules.

FIGS. 7a and 7b demonstrates stresses resulting from smaller thermoelectric legs.

FIGS. 8a and 8b demonstrate the importance of directionally solidified legs.

FIG. 9 demonstrates a technique for inserting pre-soldered legs into a thermoelectric eggcrate.

FIGS. 10a and 10b demonstrated heat staking.

FIG. 11 is a drawing of an eggcrate that is an element of a preferred embodiment of the present invention.

FIG. 12 demonstrates some important features of the preferred embodiment.

FIG. 13 demonstrates some additional features of the preferred embodiment.

FIG. 14 shows how metal is added to the hot side of the preferred embodiment.

FIG. 15 shows the result of grinding down the metal on the hot side.

FIG. 16 demonstrates a preparatory step for soldering the cold side.

FIG. 17 shows features of an almost completed module.

FIG. 18 shows features of a completed module.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Preferred embodiments of the present invention can be described by reference to the drawings. Preferred embodiments utilize thermally deposited conductors on the hot side of an eggcrate thermoelectric module. This allows operation at hot side temperatures in excess of the usable temperatures of typical solders which are in the range of about 180 °C to 210 °C. In these preferred embodiments conventional soldered connections may be used on the cold side. The metal sprayed connections on the hot side allow operation up to and exceeding 350 °C. The soldered connections do not require high temperature operation and take advantage of the low cost of soldering. A soldered cold side permits the use of flexible connectors. A preferred 16 leg X 16 leg thermoelectric eggcrate module may be fabricated in accordance with the following procedure:

- 1) Fabricate an eggcrate by injection molding a liquid crystal polymer such as Zenite 7130 available from Celanese located at 222 W Las Colinas Blvd. Suite 900N at Irving, Texas. The eggcrate shown in FIG. 11 will have a pattern of 16 legs by 16 legs. Two legs are removed from two of the corners to allow for the placement of power leads. FIG. 12 is a cutaway view of the eggcrate. Each opening 201 will be 1.43 mm wide to accommodate a

leg that is 1.38 mm wide. The bottom surface 202 of the eggcrate will be flat and parallel with the ends of the legs. The opposite face will have low walls 203 dividing two legs in a couple and high walls 204 dividing the couples. The tops of the low walls will include ledges 205 that will prevent the legs from passing through the holes. The high walls extend about 2.5 mm above the surface of the leg. The high walls provide structural support to strengthen the eggcrate thereby minimizing warping due to the thermal contraction of the metal spray and to prevent the deposited metal from forming one large slab of metal.

- 2) FIG. 13 represents a portion of one row of legs. It shows the placement of legs 301 into the eggcrate 302. The legs are 1.38 mm x 1.38 mm x 1.3 mm and are held snugly against the stop 303 built into the eggcrate and the cold end of the legs 304 protrude out of the eggcrate by 0.5 mm. The legs may be fabricated using any of several well known techniques such as those described in Thermoelectric Materials edited by Sittig, published in 1970 by Noyes Data Corporation, Park Ridge, NJ. Preferred materials are Lead telluride for high temperature operation and Bismuth telluride for low temperature operation.
- 3) Using the process described in US Patent Number 5,875,098 deposit a 150 μ m thick bond coat of molybdenum followed by 1.5 mm of aluminum 401 on the hot side of the module as shown in FIG. 14.
- 4) Gently sand the cold end 402 of the legs so that they are planar to within $\pm 25\mu$ m.
- 5) Using an 80 grit sanding disk remove material from the hot side of the module to obtain a smooth flat surface 501 that is parallel with the cold side of the legs 502 as shown in FIG. 15. Leave 1.1mm of aluminum.
- 6) Using 125 grit slurry, lap the sanded surface 501 to obtain a smooth flat surface that is planar to within $\pm 25\mu$ m and has a 125 rms surface finish.
- 7) As shown in FIG. 15, place a mask 503 over the cold side of the legs to protect the sides of the legs. A 150 μ m thick coating of nickel is then sprayed onto the cold surface of the legs 502. The nickel should be sprayed using the same conditions as was used to spray the molybdenum. The mask is then removed.
- 8) The cold side of the module is fabricated by forming 500 μ m thick copper electrical connectors 601 onto ceramic substrate 602 (preferably alumina) that is 500 μ m thick, as

shown in FIG. 16. The copper conductors are arranged in such a way as to connect the cold side of one thermocouple to the cold side of an adjacent thermocouple such that all of the thermocouples are connected electrically in series. Metallized ceramic parts can be obtained from companies that support the electronics industry. One such company is CoorsTek located at 16000 Table Mountain Parkway in Golden Colorado. The cold side is attached to the module by heating the substrate and pre-tinning the metal conductors with a lead-tin solder. The pre-tinned ceramic substrate is then gently held against the cold side of the module as seen in FIG. 17 so that the pre-tinned conductors 701 are in contact with the cold side of legs 702. With the cold side pre-tinned ceramic substrate correctly located, the ceramic is heated hot enough to melt the solder and allow it to bond the nickel coating 703 on the cold side of the legs to the copper conductors 701. A flexible circuit with the proper conductor pattern can be substituted for the metallized ceramic substrate. A suitable material is the Pyralux Copper Clad Laminates available from Dupont. Referring again to FIG. 16, thin copper conductors 601 are formed onto a polyimide film 602. If a polyimide film is used it should be no thicker than 50 μ m.

- 9) External electrical connections are made by soldering a wire 704 to the pre-tinned copper conductor 701 that would normally connect to legs that were removed from two of the corners in step 1. A lead-tin solder 705 with a high melting point should be used.
- 10) As illustrated in FIG. 18, a second ceramic wafer 801 that has not been metallized is then placed on the hot side of the module. To ensure good heat transfer, a thin layer (about 50 μ m) of a thermally conductive compound such as Wakefield 120-8 (available from www.newark.com) is placed in the interface between the ceramic wafer 801 and the hot side conductors 802. The hot side ceramic wafer 801 is held in place by applying a silicone adhesive 803 around the perimeter of the module. A suitable silicone adhesive would be MasterSil 803 sold by Master Bond located at 154 Hobart Street in Hackensack, New Jersey.

Variations

Persons skilled in the thermoelectric art will recognize that there could be many variations, within the general scope of the present invention, to the specifics described above. For example, the P and N legs could be formed of a great variety of well-known thermoelectric materials other

than bismuth telluride and lead telluride that are referred to in the above specification. Some of these well-known materials are skutterudites, TAGS, silicides and lead telluride. The eggcrates can be fabricated in a large variety of shapes and can be formed from any insulating material such as ceramics. Any compatible bond coat material can be used in place of molybdenum such as Ni-Al alloys and Al-Si alloys. For greater flexibility the metallized ceramic wafer can be replaced with a thermally conductive high temperature flexible circuit like the Pyralux Flexible Circuit materials available from Dupont. Rather than pre-tinning the circuit and heating with an iron, the points where the legs contact the copper pattern can be coated with a solder paste and the assembly passed through a reflow oven. Legs can be fabricated from Bridgman cast or directionally solidified ingots. Bismuth telluride legs can be substituted with any other suitable thermoelectric alloy. The legs can be coated with Ni after they are sliced and before they are diced. An eggcrate with high walls can create stiffness and break up the metal slab. Using a half eggcrate that doesn't extend all the way from the hot side to the cold side will greatly reduce the bypass heat lost through the eggcrate. Rather than using a ledge to hold the legs in place the legs can be heat staked. Heat staking will also increase stiffness by closing up gaps between the leg and the eggcrate. The legs can be held in place with an adhesive or coating. Coatings and adhesives will also increase stiffness by closing up gaps between the leg and the eggcrate. Both sides of the module can be thermally sprayed. In some cases it may be desirable to use a flexible connector on both the hot and cold sides of the module. Electrodes can be molded into the eggcrate rather than soldered to the cold side. For applications where both sides of the module has to operate with temperatures above 200 degrees °C melting point, both sides could be metalized as described above for only the hot side. Also, for applications where both sides of the module is expected to operate with temperatures below 200 °C, the legs of both sides could be connected as described above for only the cold side. Therefore, for all of these reasons, the scope of the invention should be determined by the appended claims rather than the specific examples described above.

What is claimed is:

1. A low-stress, hybrid thermoelectric eggcrate module comprising:
 - A) a molded thermoelectric eggcrate,
 - B) a plurality of N and P thermoelectric legs positioned in the eggcrate,
 - C) a hot side metalized electrode layer connecting N legs to P legs and P to N legs, and
 - D) a cold side electrode comprised of a metal conductor and a solder.
2. The hybrid thermoelectric module as in Claim 1 wherein the hot side metalized electrode layer is comprised of aluminum.
3. The hybrid thermoelectric module as in Claim 1 wherein the eggcrate is comprised of a thermoplastic.
4. The hybrid thermoelectric module as in Claim 1 wherein the eggcrate is comprised of a ceramic material.
5. The hybrid thermoelectric module as in Claim 1 wherein the eggcrate comprise walls with thickness of between 0.5 mm and 1.0 mm at elevations above and below the N and P legs.
6. The hybrid thermoelectric module as in Claim 1 and further comprising a bond coating to improve bonding between the thermoelectric legs and hot side metalized layer.
7. The hybrid thermoelectric module as in Claim 1 wherein the N and P legs are comprised of bismuth telluride.
8. The hybrid thermoelectric module as in Claim 1 wherein the N and P legs are comprised of thermoelectric material chosen from the following group of materials: skutterudites, TAGS, silicides, bismuth telluride and lead telluride.
9. The hybrid thermoelectric module as in Claim 1 wherein the module is fabricated in a generally square shape.
10. The hybrid thermoelectric module as in Claim 1 wherein the module is fabricated in a generally rectangular shape.
11. The hybrid thermoelectric module as in Claim 1 wherein a bond coat is deposited between the N and P legs and the metallized electrode layer on the hot side of the module.
12. The hybrid thermoelectric module as in Claim 11 wherein the bond coat is comprised of molybdenum.

13. The hybrid thermoelectric module as in Claim 11 wherein the bond coat is comprised of a Ni-Al alloy.
14. The hybrid thermoelectric module as in Claim 1 wherein cold side of electrode layer module is fabricated by forming metal electrical connectors onto ceramic substrate and pre-tinning the metal connectors with a solder.
15. The hybrid thermoelectric module as in Claim 14 wherein the solder is a lead-tin solder.
16. The hybrid thermoelectric module as in Claim 14 wherein the points where the legs contact the copper pattern are coated with a solder paste and the assembly passed through a reflow oven to connect the N and P legs on the cold side.
17. The hybrid thermoelectric module as in Claim 1 wherein the cold side electrodes comprise flexible conductors.
18. The hybrid thermoelectric module as in Claim 1 wherein the cold side electrodes comprise flexible conductors include flex circuits.
19. The hybrid thermoelectric module as in Claim 1 wherein the cold side electrodes comprise solder layers on a ceramic material.
20. The hybrid thermoelectric module as in Claim 1 wherein the legs are cut from directionally solidified ingots.
21. The hybrid thermoelectric module as in Claim 1 wherein the N and P legs are fabricated from Bridgman cast ingots.
22. The hybrid thermoelectric module as in Claim 1 wherein the N and P legs are fabricated from vacuum hot pressed ingots.
23. A process for fabricating a low-stress, hybrid thermoelectric eggcrate module comprising the steps of:
 - A) making a molded thermoelectric eggcrate,
 - B) positioning a plurality of N and P thermoelectric legs positioned in the eggcrate,
 - C) applying a hot side metalized electrode layer connecting the N legs to P legs and P to N legs, and
 - D) applying a cold side electrode layer comprised of a metal conductor and a solder.
24. The process as in Claim 23 wherein the metalized electrode layer is comprised of aluminum.
25. The process as in Claim 23 wherein the N and P legs are comprised of bismuth telluride.

26. The process as in Claim 23 wherein the solder is a lead-tin solder.
27. The process as in Claim 23 wherein the molded thermoelectric eggcrate comprises walls that are high enough to prevent the metalized layer in step B) from forming a single slab.

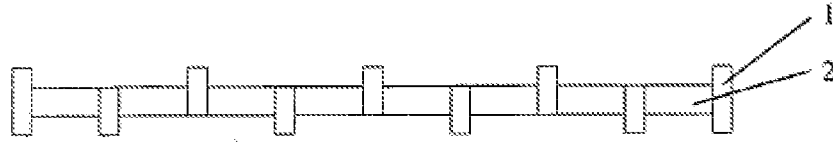


FIG. 1 - Loaded Eggcrate

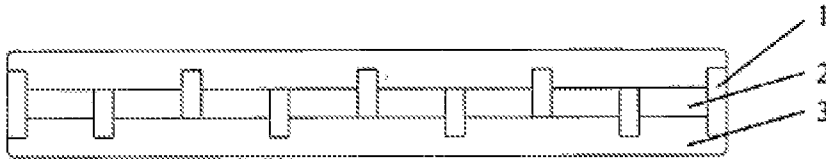


FIG. 2 - Metallized Module



FIG. 3 - Metallized Module

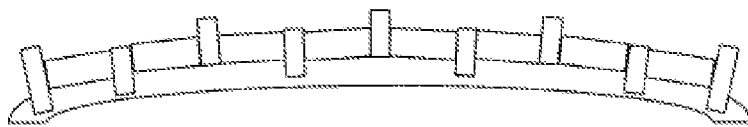


FIG. 4 - Warped Module

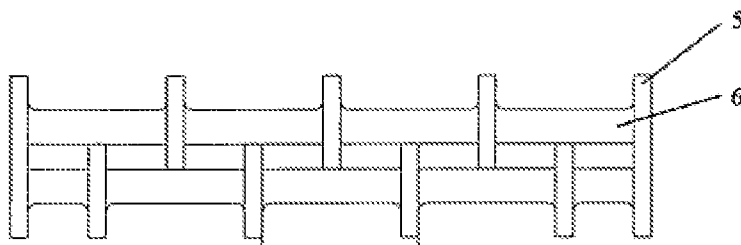


FIG. 5 - Deep Eggcrate Walls and Discrete Metal Deposits

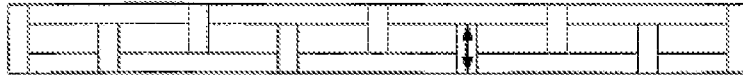


FIG. 6 – Stress in a Module Due to Expansion of the Eggcrate

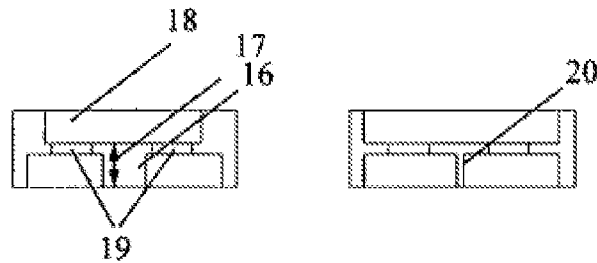


FIG. 7a

FIG. 7b

FIG. 7 – High Stresses Caused by Smaller Legs, Longer Leg Spacing and Thicker Eggcrate

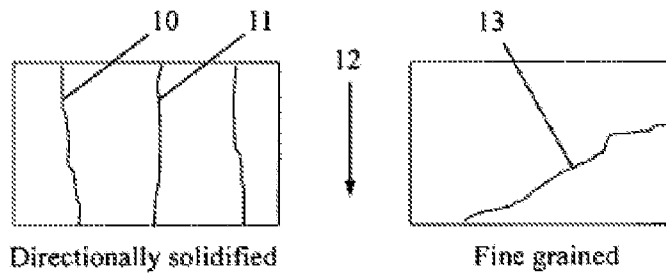


FIG. 8 – Crack Propagation in Fine Grained Material and Directionally Solidified Bismuth Telluride Alloys

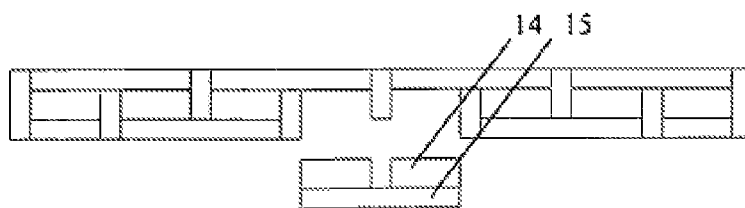


FIG. 9 – Legs Soldered to a Conductor and Inserted into Eggcrate as a Couple

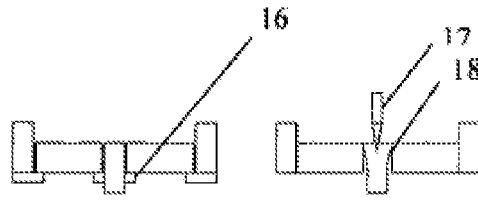


FIG. 10 – Heat Staking to Hold Elements in Place

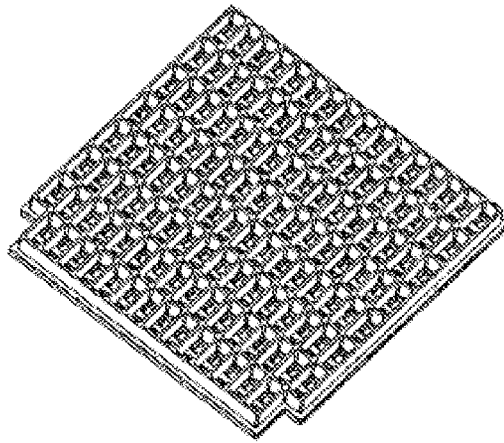


FIG. 11

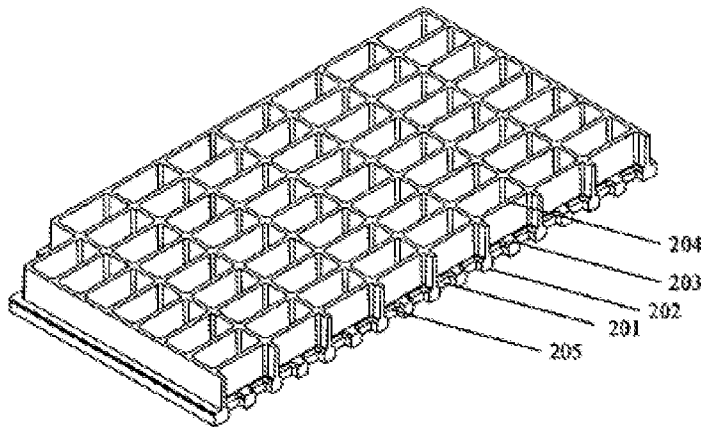


FIG. 12

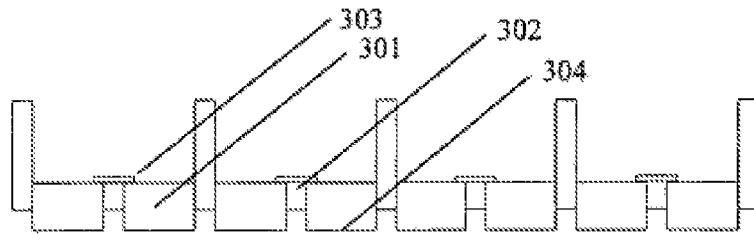


FIG. 13

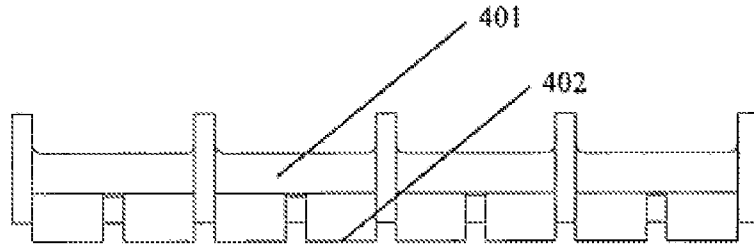


FIG. 14

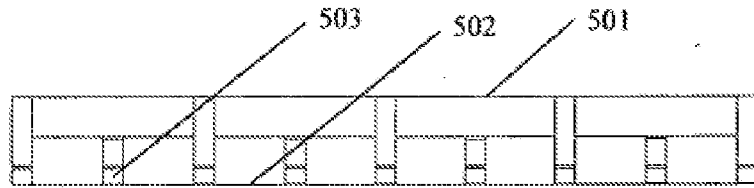


FIG. 15

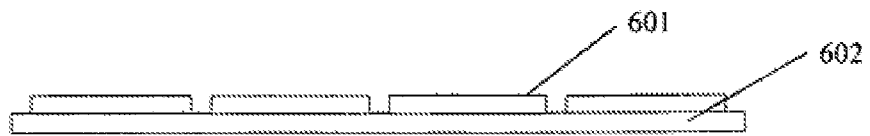


FIG. 16

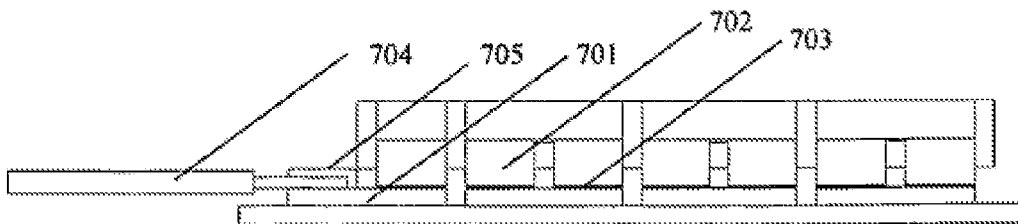


FIG. 17

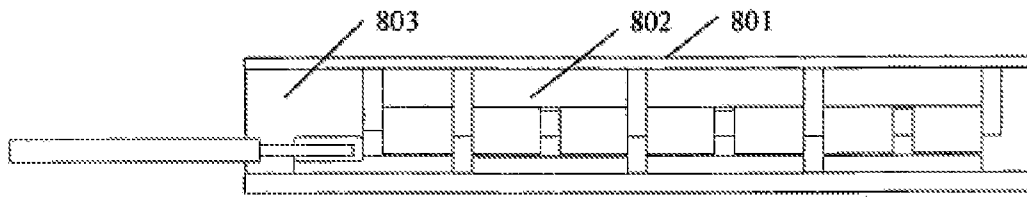


FIG. 18