July 18, 1967 E. S. COTTON 3,331,432

ASYMMETRICAL HEAT CONDUCTOR

Filed Oct. 6, 1964

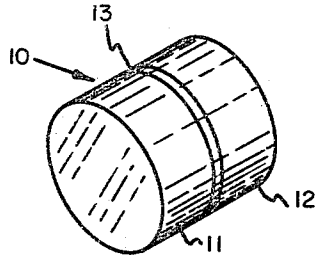


FIG. 1

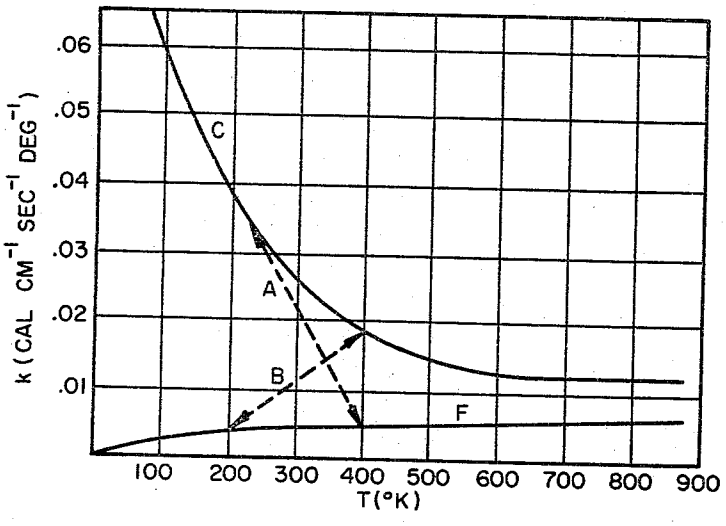


FIG. 2

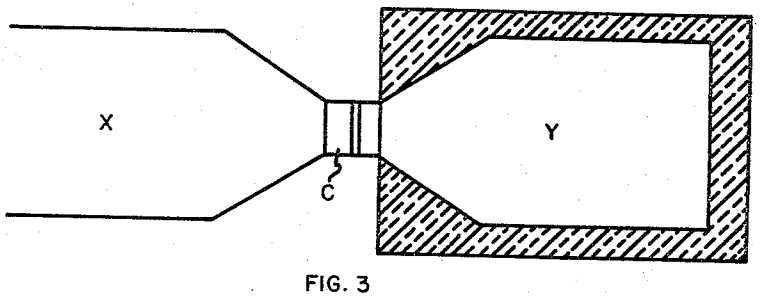


FIG. 3

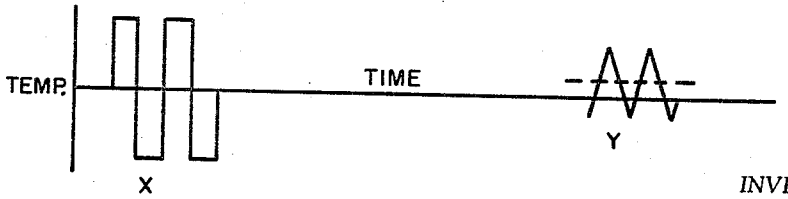


FIG. 4

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United States Patent Office 3,331,432 Patented July 18, 1967

3,331,432

ASYMMETRICAL HEAT CONDUCTOR

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Filed Oct. 6, 1964, Ser. No. 402,039
12 Claims. (Cl. 165—14)

The invention described herein, if patented, may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.

This invention relates to heat conduction and, more particularly, to solid bodies having asymmetrical heat conducting properties.

Thermal conductivity of solid homogeneous materials, conventionally expressed as the quantity of heat conducted across a given area normal to the flow path for a given time and a given temperature gradient, will vary depending on the composition, physical structure and physical state of the materials. With respect to their thermal conductivities most materials are isotropic, i.e., they have the same conductivity values when measured along axes in all possible directions. Some materials, e.g., pyrolytically formed graphite, exhibit anisotropic properties, i.e., they have different conductivities in mutually orthogonal directions. All homogeneous materials whether isotropic or anisotropic, however, display a fundamental symmetry with respect to their ability to conduct heat in either direction along a particular flow path through the material, such that a reversal of the temperature gradient produces a reverse heat flow of the same magnitude.

The present invention is concerned with solid conductors which have asymmetrical heat conducting characteristics along a particular flow path and which will, upon reversal of the temperatures gradient, produce a reverse heat flow of a different magnitude. Such heat conductors are somewhat analogous to electrical rectifying junctions. Like these junctions, the asymmetrical heat conductor might be used to "rectify" a large alternating temperature gradient imposed from an external heat reservoir. The propagation of harmonic temperature waves through such a conductor is non-symmetrical, distorting the wave form and altering the phase velocity; the magnitude of such changes depends upon the direction of propagation. For example, an isolated region which is surrounded by an asymmetrical heat conductor is forced to maintain an average temperature higher or lower than the average temperature of the environment which is subject to periodic temperature variations. Since the "reverse current" in this case could not be made as large as in the electrical analogy, rather large temperature differences would be needed in order to achieve useful applications.

In accordance with the present invention, solid conductors which have asymmetrical heat conducting characteristics are prepared by joining together two different, isotropic, materials having temperature dependent conductivities which vary oppositely with temperature. It is essential that there be good thermal contact between the two media otherwise a great deal of energy will necessarily be expended in overcoming the resistance to the flow of heat at the contact interfaces of the materials. Good thermal contact is defined as a contact that does not decrease the thermal conductivity of the composite sample by more than 10% of the calculated value. Too great an interface thermal resistance would distort or completely mask the asymmetrical heat flow properties of the conductor. Optimum thermal contacts can be obtained by fusing the two materials together. Good contacts are also obtained by cementing the materials together with a highly conductive cementitious material. The asymmetric

heat conducting phenomenon occurs along any continuous flow path that traverses the two media.

Materials which have a positive slope to their thermal conductivity (k) versus temperature (T) curves, include in general, disordered solids, such as glasses, ceramics, metal alloys, polycrystalline aggregates, and synthetic plastic materials, e.g., fused quartz, and other glasses, brass, alumina brick, graphite and polystyrene. Most of the solid materials which have negative slopes to their k vs. T curves are either pure metals, as for example gold, copper, nickel, lead, and zinc, or dielectric crystals, such as quartz, sapphire and diamond.

It is among the objects of the present invention to provide a solid conductor having asymmetrical heat-conducting properties.

Another object is to provide a conducting body which can alter the wave form, temperature gradient and phase velocity of periodic or harmonic alternating temperature gradients flowing through the body.

An additional object is to provide a conducting body which can maintain at one end thereof an average temperature, higher or lower, than the average temperature applied to the opposite face.

A further object is to provide a heat system whereby external fluctuating or regular harmonic temperature changes are utilized to heat an enclosed area or space and to maintain within said space an average temperature higher or lower than the external average temperature.

The invention will be better understood from the following detailed description taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a perspective view of a composite body having asymmetrical heat conducting properties;

FIGURE 2 is a graph showing thermal conductivity values of quartz crystal and fused quartz at various temperature levels;

FIGURE 3 is a transverse section of heat system scheme employing an asymmetrical heat conductor.

FIGURE 4 is a graphic representation of temperature changes within the system depicted in FIGURE 3.

Referring more specifically to FIGURE 1 there is shown an embodiment of an asymmetrical heat conductor, which is a composite body consisting of two cylindrical slabs of different materials which are joined together so as to be in good thermal contact. The two materials selected have temperature dependent conductivities which vary oppositely with temperature. In the present example, the two materials are crystalline quartz and fused quartz. The temperature-dependent conductivity of these materials is shown in FIGURE 2 wherein curve F represents the conductivity of fused quartz which increases as the temperature increases and curve C represents the conductivity of quartz crystal which decreases as the temperature increases.

The composite conducting body generally designated by numeral **10** in FIGURE 1 is formed of cylindrical slabs of quartz crystal **11** and fused quartz **12** having highly polished, flat ends. Each slab is 2.5 cm. in diameter and 0.6 cm. in thickness. The slabs are held together by a thin, e.g., .005 cm., layer **13** of a special conducting cement which reduces the thermal resistance at the interface contact. The conducting cement consists of a silver powder (60% by wt.) suspension in an epoxy resin base, such as Cepox 510, a product of Chemical Development Corp., Danvers, Mass. Cement coated faces of each slab are brought into contact and held together under pressure for four hours at 100° C.

Temperature changes on the faces of the composite conductor are detected by means of copper-constantan thermocouples. To each face of the conductor there is first attached a thin strip of copper foil, using a conducting

cement, such as Cepox 510, and the thermocouples are soldered in turn to the foil strips. Subsequent to the attachment of the thermocouples, the faces of the conductor are coated with an optical black lacquer.

A series of experiments were performed on the heat conducting sample thus prepared which were designed to measure the thermal conductivity, first in one orientation and then in the opposite orientation. The conductor sample was placed in a rigid non-conducting holder and the thermocouple leads were connected to conventional voltage detecting and measuring instruments with the cold junctions of the thermocouples immersed in an ice-water bath. The thermocouple on the rear surface of the sample was connected to a Sanborn Low-Level Preamplifier, 150–1500; a Sanborn Driver 150–1800 B; and a single channel recorder. The thermal conductivity in each orientation was measured by measuring the times required for the rear face of the sample to attain stated or given fractions of the maximum temperature recorded for given energy inputs at the opposite face. The front face of the sample is exposed to brief high flux-density heat pulses from a solar furnace, such as that described in U.S. Patent No. 2,987,961 issued June 13, 1961 to E. S. Cotton and J. M. Davies. The irradiance of the beam from the solar furnace is of the order of 40 cal. cm.$^{-2}$ sec.$^{-1}$. Exposure time for each experiment is 0.09 second and the total absorbed flux is 3.6 cal./cm.$^{-2}$ (40 cal. cm.$^{-2}$ sec.$^{-1}$ × 0.09).

In Table I below there are recorded the results of six experiments with the crystalline quartz face exposed to the beam from the solar furnace (C-F orientation) and four experiments with the sample reversed so that the fused quartz face is exposed to the beam (F-C orientation). The voltage curve for each experiment was plotted on recorder paper against time. The time in seconds for the sample to transmit each one-tenth fraction of the maximum voltage (V_m) observed at the rear face of the sample for each thermal pulse is tabulated below. The average of the results for each orientation are also set forth. From the results below it can be seen that heat pulses of equal duration are transmitted more rapidly through the sample when the fused quartz face is exposed to the heat source than when the sample is reversed and the crystalline quartz face is exposed to the heat source.

TABLE I

Exposure No.	Front to Back Orientation	.1 V_m	.2 V_m	.3 V_m	.4 V_m	.5 V_m	.6 V_m	.7 V_m	.8 V_m	.9 V_m
1	C-F	5.8	8.0	9.8	11.8	14.0	16.3	19.4	23.0	28.8
2	C-F	5.8	8.0	9.7	11.7	13.8	16.1	19.0	23.0	28.7
3	C-F	5.7	7.8	9.7	11.6	13.6	15.9	18.7	22.4	27.9
4	C-F	5.7	8.0	9.9	11.9	13.8	16.2	19.3	23.3	30.1
5	C-F	5.9	8.0	9.9	11.8	13.8	16.2	19.2	22.9	28.5
6	C-F	5.9	8.1	9.9	11.8	14.0	16.5	19.5	23.6	29.8
7	F-C	3.2	6.3	8.4	10.5	12.7	15.3	18.4	22.6	29.6
8	F-C	3.1	6.4	8.5	10.5	12.9	15.6	18.4	22.7	29.5
9	F-C	3.2	6.4	8.5	10.4	12.6	15.0	17.9	22.2	28.0
10	F-C	3.8	6.6	8.6	10.7	12.9	15.3	18.1	22.6	28.4
Averages	C-F	5.8	8.0	9.8	11.8	13.8	16.2	19.2	23.0	29.0
Averages	F-C	3.3	6.4	8.5	10.5	12.8	15.3	18.2	22.5	28.7

The asymmetry in the heat conducting properties of the above sample can also be schematically shown on the graph in FIGURE 2. In a situation in which the sample conductor is placed between two steady state heat reservoirs, one of which is held at 400° K. and the other at 200° K., the conductivity range of the sample can be portrayed by drawing a line between the conductivity curves of each component of the sample. For example, when the fused quartz face is in contact with the 400° K. reservoir and the crystal face is in contact with the 200° K. reservoir the range of conductivity of the body is represented by line A. Conversely when the sample is reversed and the crystal face is in contact with the 400° K. reservoir and the fused quartz face is in contact with the 200° K. reservoir, the range of conductivity of the sample will be represented by Line B. A comparison of lines A and B reveals that the mean conductivity of the sample will always be greater when oriented as in Line A.

Solid bodies which are asymmetrical in their heat conducting properties are usefully employed to separate two environments one of which experiences periodic changes of temperature and another environment wherein it is desired to maintain an average temperature, higher or lower than the average in the first environment. These environments may be regarded as heat reservoirs as shown in FIGURE 3, wherein X refers to the driven heat reservoir and Y refers to an insulated heat reservoir in thermal contact with X through an asymmetrical heat conductor C. When the temperature of the externally driven reservoir X becomes greater than the temperature of Y heat will flow from X through conductor C to Y. When the temperature of X is suddenly lowered below that of Y by the same amount, heat will flow in the opposite direction. However, since the conductivity is asymmetrical, these heat currents will not be the same, for the same finite temperature drop. Thus reservoir Y would gain heat from reservoir X until its average temperature becomes higher or lower than the average temperature of X, depending on the orientation of the conductor. This discussion assumes of course that an external source of energy is causing the temperature fluctuations in X. Such a system as has been described can be used to effect some control over the temperature within an orbiting satellite. Such satellites may revolve about their axis so that portions of the exterior surface are regularly presented towards and away from the sun causing rapid and marked changes in the temperature over portions of the surface. A portion of the external surface of the satellite then serves as the driven reservoir. The interior of the satellite or a special component, such as a fluid filled container, serves as the insulated heat reservoir and is thermally connected to the driven reservoir via the asymmetrical heat conductor. Orientation of the conductor so that flow of heat into the insulated reservoir is facilitated, results in the maintenance therein of an average temperature higher than the average temperature on the external reservoir. In addition, the amplitude of the temperature changes within the insulated reservoir will not be as great as for the external reservoir. FIGURE 4 illustrates the temperature changes occurring in the external reservoir X and in the insulated reservoir Y, after the starting cyclic variations on the external reservoir have continued long enough to build up a steady cyclic variation within the insulated reservoir. The amplitude of the temperature is indicated by the height above or below the abscissa and is plotted against time. The temperature amplitudes for the external reservoir are identified as X and the corresponding temperature amplitudes for the insulated reservoir are identified as Y. The solid base line represents the average temperature maintained within X

and the dotted base line represents the average temperature maintained within Y.

The invention described in detail in the foregoing specification is susceptible to changes in the details, materials, configuration, and arrangement of parts as may occur to persons skilled in the art and is not limited to the precise details of construction as shown and described herein. The terminology used in the specification is used for purposes of description and not of limitation, the scope of the invention being defined in the claims.

I claim:

1. A solid, composite body comprising two dissimilar isotropic materials one of said materials having a negative slope to its conductivity vs. temperature curve and the other of said materials having a positive slope to its conductivity vs. temperature curve, said materials joined together so as to effect a good thermal contact therebetween, said body having asymmetrical heat conducting properties along any continuous flow path traversing said two materials.

2. A solid, composite body comprising two dissimilar isotropic materials one of said materials being selected from the group consisting of dielectric crystals and pure metals and the other of said materials being selected from the group consisting of metal alloys, glasses, ceramics, polymeric and polycrystalline aggregate materials, said two materials joined together so as to effect good thermal contact therebetween, said body having asymmetrical heat conducting properties along any continuous path traversing said two materials.

3. A solid, composite body comprising a crystalline quartz portion and a fused quartz portion, said portions joined together so as to effect good thermal contact therebetween and having asymmetrical heat conducting properties along any continuous path traversing said two materials.

4. A composite solid body comprising a crystalline quartz portion and a fused quartz portion said portions joined together by conducting cement so as to effect good thermal contact therebetween, and having asymmetrical heat conducting properties along a continuous path that traverses said crystalline quartz and fused quartz portions.

5. A heat system comprising a source of heat that fluctuates in temperature, a heat reservoir, and a solid body having asymmetric heat conducting properties in heat transferring relationship between said source and said reservoir and oriented so that the heat flow through said body is asymmetric.

6. A heat system comprising a source of heat that fluctuates in temperature, a heat reservoir, and a solid body having asymmetric heat conducting properties in heat transferring relationship between said source and said reservoir and oriented so that the heat flow through said body is asymmetric, whereby the average temperature developed and maintained within said reservoir is different from the average temperature of the fluctuating heat source.

7. A heat system comprising a source of heat that cyclically varies in temperature, a heat reservoir, and a solid body having asymmetric heat conducting properties in heat transferring relationship between said source and said reservoir and oriented so that the heat flow through said body between said source and said reservoir is asymmetric, which system results in the development of an average temperature within said reservoir different from the average temperature of said source.

8. A method of transferring heat from a source fluctuating in temperature to a heat reservoir wherein the average temperature is to be maintained at a level different from the average temperature of the source, which comprises transferring heat from the source through an asymmetrical heat conductor in heat conducting relationship with said source and said reservoir and oriented so that the heat flow through said conductor is asymmetric and thence to said reservoir.

9. A method of transferring heat from a source that cyclically varies in temperature to a heat reservoir so that the amplitude of temperature variations within the heat reservoir will be less than the amplitude of temperature variations of the source and the average temperature will be maintained at a level different from the average temperature of the source, which comprises transferring heat from said source to said reservoir by means of an asymmetric heat conductor in heat transferring relationship therebetween and oriented so that the heat flow through said conductor is asymmetric.

10. A heat system comprising

a source of heat that fluctuates in temperature,

a heat reservoir,

and a solid composite body comprising two dissimilar isotropic materials, one of said materials having a negative slope to its thermal conductivity versus temperature curve, and the other of said materials having a positive slope to its thermal conductivity versus temperature curve, said isotropic materials joined together so as to effect good thermal contact therebetween, and having said solid composite body in heat transferring relationship between said source and said heat reservoir and oriented so that the heat flow through said body is asymmetric.

11. A heat system comprising

a source of heat that fluctuates in temperature,

a heat reservoir to be maintained at an average temperature higher than the average temperature of the fluctuating heat source,

and a solid composite body comprising two dissimilar isotropic materials one of said materials having a negative slope to its thermal conductivity versus temperature curve and the other of said materials having a positive slope of thermal conductivity versus temperature curve, said isotropic materials joined together so as to effect good thermal contact therebetween, and having said solid composite body in heat transferring relationship between said source such that the positive slope material is in thermal contact with said heat source and the negative slope material is in thermal contact with the heat reservoir.

12. The heat system comprising

a source of heat that fluctuates in temperature,

a heat reservoir to be maintained at an average temperature lower than the average temperature of the fluctuating heat source,

and a solid composite body comprising two dissimilar isotropic materials one of said materials having a negative slope to its thermal conductivity versus temperature curve and the other of said materials having a positive slope to its thermal conductivity versus temperature curve, said isotropic materials joined together so as to effect good thermal contact therebetween, and having said solid composite body in heat transferring relationship between said source and said reservoir such that the negative slope material is in thermal contact with said heat source and the positive slope material is in thermal contact with the heat reservoir.

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