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None

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UK CL (Edition M) **H1K KTP**
INT CL^5 **H01L**

(54) **Thermoelectric power generation**

(57) A transformer able to generate electricity directly from heat input comprises bimetallic ferromagnetic laminations 4 subjected to a temperature gradient along an axis in the plane of the lamination and sandwiched by insulation 8 between electrode plates 7 to which an oscillatory voltage potential is applied. Ferrite cores 5 having output windings 6 are inductively coupled with the laminations and provide electrical power output at the frequency of the oscillatory voltage potential which controls the magnetic polarization arising from the thermally powered thermoelectric current circulating around the bimetallic thermocouple path within each lamination. The laminations preferably comprise n-type and p-type materials.

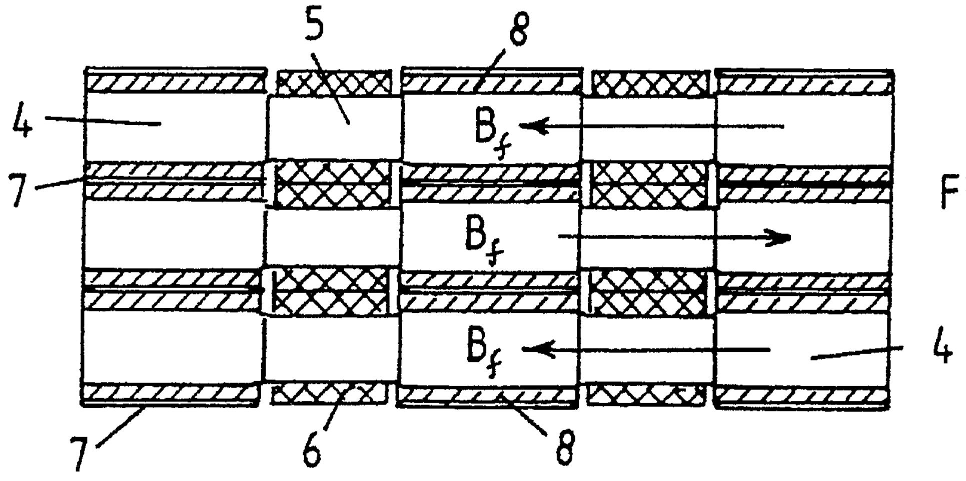


FIG. 4

GB 2 275 128 A

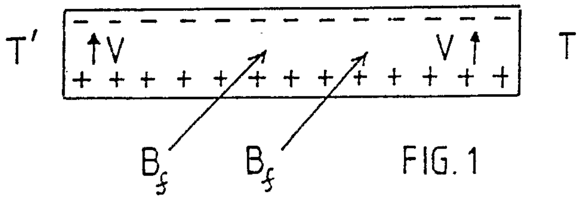


FIG. 1

FIG. 2

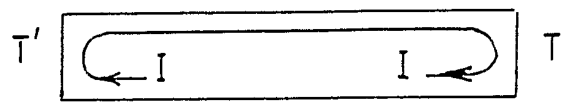
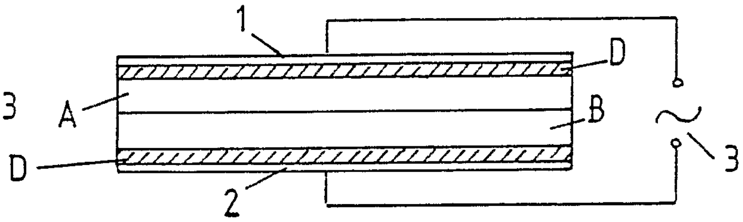


FIG. 3



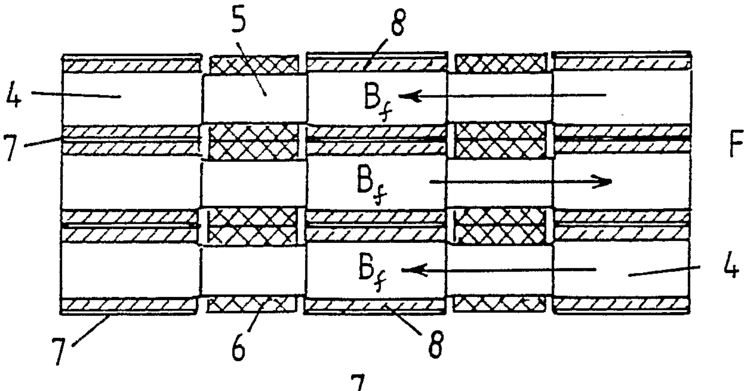


FIG. 4

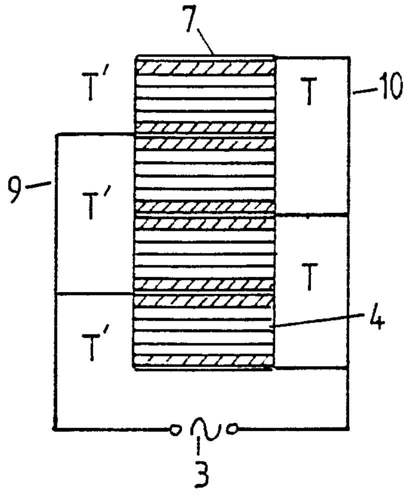


FIG. 5

THERMOELECTRIC POWER GENERATION

FIELD OF INVENTION

This invention relates to thermoelectric energy conversion which harnesses electrical processes occurring within metals when subjected to mutually transverse electric and thermal potential gradients.

This is a field concerned with the physics of the Thomson Effect, along with the Peltier and Seebeck Effects as well as the Nernst-Ettinghausen Effect, and so relates to the nature of charge displacement in metals and thermodynamics generally.

BACKGROUND OF THE INVENTION

The invention arises from research on the diagnostic testing of a device, the subject of G.B. Patent No. 2,225,161 and GB Patent No. 2,227,881 in respect of which the inventor of this application was a co-inventor. Prototypes of that device were found to have what seemed to be inexplicably-high operational efficiency, freezing water extremely rapidly when powered by electricity. They comprised what may be termed a 'series capacitor stack' formed by layers of a substrate dielectric material, each coated using different metals (a layer of nickel and a layer of aluminium) and assembled with edge-on thermal contact between two metal plates which formed heat sinks.

The flow of heat through the bimetallic aluminium:nickel metallized layers from a hot heat sink to a cold heat sink caused the internal circulation of a thermoelectric current within each layer. The device operated by virtue of an electrical current oscillation set up in the stack in a direction transverse to the heat flow direction. Research investigation indicated that this oscillating current activated the device in a most unusual way, primarily in interrupting the thermocouple junction currents at the oscillation frequency, an action which was found to enhance the thermoelectric EMF enormously. Compared with the normal thermo-electric EMF of 17 $\mu V/K$ for an aluminium:nickel thermocouple, an EMF of the order of 300 $\mu V/K$ resulted with the A.C. dynamic excitation at kilocycle frequency.

This led in the prototype research to the construction of extremely efficient thermopiles in the form of a capacitor stack with its heat throughput axis in one direction and the A.C. electric power throughput axis in the transverse direction. The device operated with high efficiency as a solid state heat pump powered directly by electricity or, when subjected to a temperature differential, as an electric power generator. Indeed, the device at room temperature demonstrably operated an electric motor when powered by melting ice and similarly would freeze water when powered by electrical input from a small battery.

The background of this subject invention is, therefore, the above prototype research using transverse oscillating A.C. field excitation in conjunction with the thermoelectric D.C. circulation in thin bimetallic layers forming capacitor plates in a series-connected stack. These bimetallic layers are formed from metals which are respectively electronegative and electropositive in the sense of their Thomson coefficients with a contiguous interface extending between the hot and cold sides of the structure.

The advance which is of primary importance and which is introduced by this invention to distinguish it from the above-referenced patent disclosures comes from a research investigation aimed at testing the effects of the transverse oscillations upon the magnetic field which must arise from the circulation of thermoelectrically powered current.

The abstract of Japanese Patent Application 1-208876 (A) published 22 August 1989 (Applicants MATSUSHITA ELECTRIC IND CO LTD) relates to a thermoelectric device in which copper layers coated with an n-type semiconductor are formed into a stack across which a d.c. voltage is applied. However, in the device there disclosed the applied voltage sets up a potential gradient which is in the same direction as the heat flow and not transverse to the heat flow direction as required in implementing the invention of this specification.

BRIEF DESCRIPTION OF THE INVENTION

The object of this invention is to apply the technology reported earlier in GB Patent No. 2,227,881 in a way which avoids the current capacity limitations of providing output power through a capacitor. The latter is necessarily one that is highly tuned to resonate at high voltages close to breakdown limits, whereas this invention provides a transformer-coupled mode of extracting power directly from heat input and is better suited and more compatible with the established technology of transformer design.

According to the invention, thermoelectric power generation apparatus in which heat input sustaining a temperature differential between two heat sink surfaces is used to generate electrical power output from a thermopile located between the heat sink surfaces and comprises a laminated assembly of laminations comprising contiguously interfacing substances A and B having metallic conduction and thermoelectric properties productive of a Peltier EMF across their interface, at least one of the substances A and B being ferromagnetic, the laminations being interspersed between layers of an insulating dielectric, and the thermopile being characterized by the confinement of the circulating thermoelectric currents within individual laminations and by a mutually orthogonal configuration of the heat flow axis, the axis of ferromagnetic polarization resulting from the thermoelectric current circulation and the axis of an externally applied voltage potential provided by an external a.c. power source, which potential offsets and so regulates the effect of a thermally-induced potential in the laminations, there being an inductively-coupled power output winding positioned in relation to the thermopile to sense oscillations of magnetic flux developed by pulsations of the thermoelectric circulating current in response to controlled variation of the externally applied voltage potential.

Preferably, the laminated assembly comprises contiguously interfacing n-type, p-type substances having metallic electrical conduction properties interspersed between layers of an insulating dielectric.

The laminated assembly may further comprise blocks of laminations formed by a multiplicity of alternate layers of the different substances having metallic conduction properties, which blocks are each sandwiched between capacitor electrode plates and insulated therefrom by layers of a dielectric insulator, the capacitor electrode plates of the different blocks being parallel-connected in groups across input terminals for connection to an external source of an oscillatory voltage potential.

The blocks may be grouped in line along a ferromagnetic polarization axis, with ferromagnetic cores positioned between adjacent blocks, the cores having windings inductively linked with the cores for delivering an output current when the apparatus is activated by thermal power input and controlled by an applied oscillatory voltage potential.

Further, the blocks may be grouped in an array of rows and columns in line in each row along a ferromagnetic polarization axis, with ferromagnetic cores positioned between adjacent blocks, the cores having windings inductively linked with the cores for delivering an output current when the apparatus is activated by thermal power input and controlled by an applied oscillatory voltage potential and the ferromagnetic polarization axis of blocks in adjacent columns of the array being opposite in direction, whereby to facilitate magnetic flux closure and minimize magnetic flux leakage.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a section of a metal lamination subjected to a temperature differential T'-T between its edges and illustrates the effect of a magnetic field in developing an electrical potential within the metal.

Fig. 2 shows a metal lamination in which a current I may circulate to set up the magnetic field of Fig. 1.

Fig. 3 shows a test configuration in which a bimetallic lamination is sandwiched between two capacitor plates powered by an A.C. voltage source.

Fig. 4 shows a schematic representation of the layout of a transformer incorporating the invention, this having rows and columns of bimetallic blocks and ferrite cores with output windings.

Fig. 5 shows a sectional end elevation view of the transformer of Fig. 4, particularly indicating how a temperature differential T'-T is applied and how the capacitor plates are connected.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Fig.1 a metal lamination is deemed to have a temperature differential T'-T between its edges promoting heat flow from

T' to T. A magnetic field produces a flux density B_f in the lamination and, as is known from the Nernst-Ettinghausen Effect dating from 1886, this develops an electric potential V inside the laminations. The field direction of this potential may be positive or negative.

The heat flow direction, B_f and V are all mutually orthogonal. There is an electric field in the metal conductor simply because the free electrons (or holes) in the metal convey heat from T' to T and, between their heat transfer collisions, they move faster from T' to T than from T to T'. The transverse potential V is set up by the Lorentz type forces exerted on each charge carrier owing to the magnetic field. Equilibrium exists in the net force balance between the electrodynamic forces, the collision activity in the V direction and the charge displacement that sets up V.

Essentially, therefore, provided there is heat flow from T' to T one has a situation where an electric field exists in a metal conductor.

This invention contemplates the effect of causing a circuital loop current I to flow within a ferromagnetic lamination as shown in Fig. 2, which current sets up the field which, owing to the high ferromagnetic permeability, generates a strong B_f field.

This will mean that adjacent the edges at T'and T the current I will flow through a potential V and there must be a heating effect at one edge and a cooling effect at the other, in measure related to the power VI. This implies the transfer of heat as a function of V and raises the question whether one can control the effect of that potential.

In order to generate the current circulation, the invention requires the use of a bimetallic lamination comprising two metal layers A and B, which are respectively electropositive and electronegative in their thermoelectric properties. The substances A and B must have metallic conduction properties, and at least one must be ferromagnetic, even though they are alloys or compositions including oxides, such as those having perovskite structure. The research findings leading to this invention have, however, been based on the use of nickel and aluminium bimetallic laminations.

Research shows that a T'-T temperature differential of only 10°C will produce a magnetic flux of the order of 1 Tesla in laminations of about 0.2 micron thickness. The B_f-field is self-generated by thermal action and the V potential produced by the Nernst-Ettinghausen Effect must therefore be present inside the metal.

In an experimental study, the Applicants have tested a device depicted schematically in Fig. 3, where the Al:Ni bimetallic lamination is sandwiched between two metal capacitor plates and insulated therefrom by 18 micron thick polymer dielectric layers D.

A heat gradient is applied to set up the T'-T temperature differential in the sense shown in Figs. 1 and 2. Note also that the capacitor plates 1 and 2 can be of thin metal foil and need not extend fully across the test specimen. There is, of course, provision (not shown) for good thermal contact between heat sinks associated with T' and T and the edges of A and B, through a suitable electrically insulating substance as used in mounting heat sinks in the electronic art.

In operation, the test device shown in Fig. 3 was found to respond to the presence of a temperature differential by generating a strong magnetic B_f field attributable to the thermoelectric current circulation, such as I in Fig. 2, set up by Peltier and Thomson Effect action associated with the aluminium and nickel thermocouple formed.

Of itself, this was not surprising, though the power behind the action was such that the test circuit involving a Hall Effect device had to be redesigned to cope with the unexpected level of magnetic flux generated.

The invention, however, derives from the observation in these tests that the polarity of an oscillatory voltage applied by a source at 3 in Fig. 3 controlled the magnetic flux intensity. Typically at a frequency of 14 kHz and a voltage amplitude sufficient to apply an electric stress of 9 million V/m to the dielectric D were used in these tests.

In particular, for the single bimetallic lamination tests, the magnetic flux could be switched on with one polarity of voltage signal and off with the other polarity as if the thermoelectric circulating current is suppressed in the latter mode of excitation. This means that one can construct a thermally-powered electrical transformer which can deliver output electric power directly sourced in heat input.

Although research investigation is not yet complete, it is believed that the application of the oscillatory electric field will, with one polarity, and at appropriate voltage threshold levels, act to oppose and so suppress the V potential in the lamination. This will interfere with the heat transfer process associated with the power VI and so make the operation polarity sensitive.

However, whatever be the physics involved, the tests show that the oscillatory voltage control can for a wide range of frequencies promote the cyclic oscillation of the magnetic flux in the ferromagnetic part of the lamination between zero and near saturation levels.

From the prior research on prototype thermoelectric heat converters using capacitor stacks formed from bimetallic laminations, the

Applicants know that 50 or more bimetallic layers can be assembled between capacitor electrodes and can, with very high efficiency, deliver electrical power through the capacitor circuit drawing on heat input in the manner described above. The primary design limitation in this prior work was the current rating of the capacitor, inasmuch as it involved series coupling of many bimetallic layers in order to generate adequate thermoelectric EMF.

The new discovery leading to this invention is that the heat power can be extracted by tapping directly into the thermocelectric in-lamination circulation, owing to the magnetic flux pulsation and using the capacitor action as a voltage control, much as a grid is used in an electronic switch.

Referring to Fig. 4 and Fig. 5, 50 bimetallic layers are formed as an integral block in which there are alternate layers of aluminium and nickel film fabricated with contiguous interfacing surfaces. A number of such blocks 4 are assembled as part of a transformer core which includes ferrite cores 5. The ferrite cores each carry a magnetizing winding 6 which is part of an output circuit through which transformer-induced power is generated by changes of the induced magnetic field B_f. Each of the blocks 4 is mounted between capacitor plates 7 but insulated therefrom by a dielectric 8. The plates 7 are connected in two groups as shown in Fig. 4 by connections denoted 9 and 10, respectively.

The block of 50 metal layers needs to be sufficiently thin overall to keep eddy-current loss at a tolerable level, failing which the composition of the block must include bimetallic laminations with insulating coatings to keep each lamination electrically independent save for the voltage potential conveyed by capacitor action through the insulation.

In operation, when a temperature differential T'-T is set up across the transformer in one axial direction a magnetic field develops in each block in an orthogonal axial direction and the application of a voltage osclation at 3 provides a controlling electric field on each block 4 in the other orthogonal direction.

The result is that inflow of heat is converted into an inductive magnetic field oscillation which generates an output EMF in the circuit linking windings 6.

By designing a multi-sectioned transformer in this way and arranging the magnetic polarization directions in opposite sense in adjacent core axes, the magnetic flux closure path problems are eased, but ferrite end pieces (not shown) can be provided to minimise flux leakage.

CLAIMS

1. Thermoelectric power generation apparatus in which heat input sustaining a temperature differential between two heat sink surfaces is used to generate electrical power output from a thermopile located between the heat sink surfaces and comprising a laminated assembly of laminations comprising contiguously interfacing substances A and B having metallic conduction and thermoelectric properties productive of a Peltier EMF across their interface, at least one of the substances A and B being ferromagnetic, the laminations being interspersed between layers of an insulating dielectric, and the thermopile being characterized by the confinement of the circulating thermoelectric currents within individual laminations and by a mutually orthogonal configuration of the heat flow axis, the axis of ferromagnetic polarization resulting from the thermoelectric current circulation and the axis of an externally applied voltage potential provided by an external a.c. power source, which potential offsets and so regulates the effect of a thermally-induced potential in the laminations, there being an inductively-coupled power output winding positioned in relation to the thermopile to sense oscillations of magnetic flux developed by pulsations of the thermoelectric circulating current in response to controlled variation of the externally applied voltage potential.

2. Thermoelectric power generation apparatus in which heat input sustaining a temperature differential between two heat sink surfaces is used to generate electrical power output from a thermopile located between the heat sink surfaces and comprising a laminated assembly of contiguously interfacing n-type, p-type substances having metallic electrical conduction properties interspersed between layers of an

insulating dielectric and at least one of which is ferromagnetic, the thermopile being characterized by the confinement of the circulating thermoelectric currents to individual interfacing pairs of n-type and p-type laminations and by a mutually orthogonal configuration of the heat flow axis, the axis of magnetic polarization resulting from the thermoelectric current circulation and the axis of an externally applied voltage potential which regulates the power generation by the capacitative displacement of charge through the layers of insulating dielectric, there being an inductively-coupled power output winding positioned in relation to the thermopile to sense oscillations of magnetic flux developed by pulsations of the thermoelectric circulating current in response to controlled variation of the externally applied voltage potential.

3. Thermoelectric power generation apparatus according to claim 1 or claim 2, wherein the laminated assembly comprises blocks of laminations formed by a multiplicity of alternate layers of the different substances having metallic conduction properties, which blocks are each sandwiched between capacitor electrode plates and insulated therefrom by layers of a dielectric insulator, the capacitor electrode plates of the different blocks being parallel-connected in groups across input terminals for connection to an external source of an oscillatory voltage potential.

4. Thermoelectric power generation apparatus according to claim 1 or claim 2, wherein the laminated assembly comprises blocks of laminations formed by a multiplicity of alternate layers of the different substances having metallic conduction properties, which blocks are each sandwiched between capacitor electrode plates and insulated therefrom by layers of a dielectric insulator, the capacitor electrode plates of the different blocks

being parallel-connected in groups across input terminals for connection to an external source of an oscillatory voltage potential and the blocks being grouped in line along a ferromagnetic polarization axis, with ferromagnetic cores positioned between adjacent blocks, the cores having windings inductively linked with the cores for delivering an output current when the apparatus is activated by thermal power input and controlled by an applied oscillatory voltage potential.

5. Thermoelectric power generation apparatus according to claim 1 or claim 2, wherein the laminated assembly comprises blocks of laminations formed by a multiplicity of alternate layers of the different substances having metallic conduction properties, which blocks are each sandwiched between capacitor electrode plates and insulated therefrom by layers of a dielectric insulator, the capacitor electrode plates of the different blocks being parallel-connected in groups across input terminals for connection to an external source of an oscillatory voltage potential and the blocks being grouped in an array of rows and columns in line in each row along a ferromagnetic polarization axis, with ferromagnetic cores positioned between adjacent blocks, the cores having windings inductively linked with the cores for delivering an output current when the apparatus is activated by thermal power input and controlled by an applied oscillatory voltage potential and the ferromagnetic polarization axis of blocks in adjacent columns of the array being opposite in direction, whereby to facilitate magnetic flux closure and minimize magnetic flux leakage.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(e arch report) -14-

Relevant Technical Fields (i) UK Cl (Ed.M) H1K (KTP) (ii) Int Cl (Ed.5) H01L **Databases** (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii)	Application number GB 9302354.7 Search Examiner C D STONE Date of completion of Search 12 MAY 1994 Documents considered relevant following a search in respect of Claims :- ALL

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Category	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

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