(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
8 July 2010 (08.07.2010)

PCT

(10) International Publication Number
WO 2010/076218 A1

(51) International Patent Classification:
H01L 37/04 (2006.01)

(21) International Application Number:
PCT/EP2009/067287

(22) International Filing Date:
16 December 2009 (16.12.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
08172994.9 29 December 2008 (29.12.2008) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) Title: GENERATOR APPARATUS

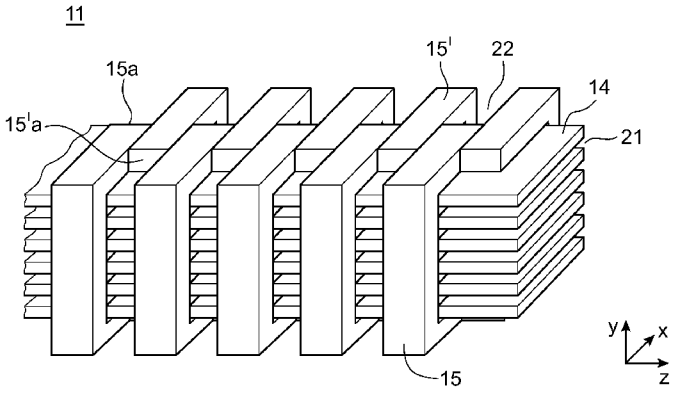

Fig. 2

(57) Abstract: A generator apparatus (11) for converting thermal energy to electric energy comprises a core region (12) made of a magnetic material having a temperature dependent reluctance, the core region having channels (13) running from a first (12a) to a second (12b) vertical side of the core region; windings (14) arranged above one another in horizontal planes around the core region; C-shaped frame sections (15, 15') arranged vertically and in a staggered row alternately around the first and second vertical sides the core region; a hot and cold fluid distribution system (6) connected to the channels of the core region for distributing alternately hot and cold fluid through the channels of the core region to vary the temperature of the core region alternately above and below a selected temperature, thereby varying the reluctance of a magnetic circuit formed by the core region and the C-shaped frame sections; and means (7) for creating a magnetic flux in the magnetic circuit wherein electric currents are induced in the windings in response to a varying magnetic flux in the magnetic circuit caused by the varying reluctance of the core region.

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GENERATOR APPARATUS

TECHNICAL FIELD OF THE INVENTION

The present invention generally relates to a generator apparatus for converting thermal energy to electric energy.

DESCRIPTION OF RELATED ART AND BACKGROUND OF THE INVENTION

Apparatuses for transforming thermal energy directly into electric energy using a minimum of moving parts have been known since long.

At the end of the 19'th century, Edison and Tesla described devices based on thermomagnetic materials for converting thermal energy into electricity. Edison's pyro-magnetic generator as described in the British patent No. 16709 includes a thermomagnetic working material, means for magnetizing the working material, sources of heat and cold connected to the working material, and a winding enclosing the working material and in which an alternating electric current is induced by thermally cycling the working material. Tesla discloses in U.S. patent No. 428,057 some improvements of Edison's generator by suggesting an alternative heat exchanging mechanism.

Chilowsky discloses in U.S. patent No. 2,510,806 a device for thermomagnetic energy conversion, wherein the temperature variations are achieved by hot and cold fluids in a closed fluid circuit.

Bartels discloses in German patent No. 23 47 377 a device similar to Edison's generator, but suggests gadolinium as magnetic working medium. In one embodiment a permanent magnet is provided to create the magnetic flux in the thermomagnetic material and in another embodiment a battery is used to induce a current in a coil to thereby form an electromagnet to create the magnetic flux.

While the apparatuses described above do convert thermal energy directly to electric energy, they seem not to be efficient, compact, optimized for practical use, and/or cost-efficient to manufacture.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a generator apparatus for converting thermal energy to electric energy, which is adopted for practical use and which has an improved structure and operation.

It is a particular object of the invention to provide such apparatus, which use a smooth and energetically efficient thermal cycling.

It is still a further object to provide such apparatus, which is reliable, flexible, and of reasonable cost.

These objects, among others, are according to the present invention attained by generator apparatuses as specified in the appended patent claims.

According to one aspect of the invention there is provided a generator apparatus for converting thermal energy to electric energy comprising a core region, windings, C-shaped frame sections, a hot and cold fluid distribution system, and means for creating a magnetic flux.

The core region is made of a magnetic material with a temperature dependent reluctance and has channels running from a first vertical side to a second vertical side of the core region opposite to the first side. The windings are arranged above one another in horizontal planes around the core region. The C-shaped frame sections are made of a magnetic material and are arranged vertically and in a staggered row alternately around the first and second vertical sides the core region. The

core region and the C-shaped frame sections form together a magnetic circuit.

The hot and cold fluid distribution system is connected to the channels of the core region for distributing alternately hot and cold fluid through the channels of the core region to vary the temperature of the core region alternately above and below a selected temperature to, in turn, vary the reluctance of the magnetic circuit. Access to the channels is obtained through spaces between the windings and the C-shaped frame sections on each of the first and second sides of the generator apparatus.

The means for creating a magnetic flux is adapted to create a magnetic flux in the magnetic circuit and may be implemented by a capacitor device connected to the windings, by a current source connected to separate winding arranged around the magnetic circuit, or by a permanent magnet arranged in the magnetic circuit.

The apparatus operates by means of electric currents being induced in the windings in response to a varying magnetic flux in the magnetic circuit caused by the varying reluctance, which in turn is caused by the temperature variation of the core region.

The core region may be made of a material having a magnetic phase transition temperature, such as a Curie temperature or a Néel temperature, which coincides with the selected temperature. Alternatively, the core region may be made of a material having a significant temperature dependent reluctance at the selected temperature.

The generator device of the invention has an efficient design by which large electric power outputs can be obtained without requiring large and thick frames closing the magnetic path and without essential fluid frictional losses and thermal gradients.

Further characteristics of the invention and advantages thereof, will be evident from the following detailed description of preferred embodiments of the present invention given hereinafter and the accompanying Figs. 1-5, which are given by way of illustration only and thus, are not limitative of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 displays schematically the general principles of a generator apparatus in accordance with the invention.

Fig. 2 displays schematically in a perspective view major parts of a generator apparatus in accordance with an embodiment of the invention.

Fig. 3 displays schematically in a perspective view a core region as being comprised in the generator apparatus of Fig. 2.

Fig. 4 displays schematically in a transversal cross section the generator apparatus of Fig. 2.

Fig. 5 displays schematically in a longitudinal cross section the generator apparatus of Fig. 2.

DETAILED DESCRIPTION OF EMBODIMENTS

A generator apparatus for converting thermal energy into electric energy in accordance with the invention comprises, as shown in Fig. 1, a core region 2 made of a magnetic material having a reluctance that is temperature-dependent, preferably highly temperature-dependent, a coil or winding 4, a yoke 5 made of iron or other magnetic material, a hot and cold fluid distribution system 6, and means 7 for creating a magnetic flux in the magnetic circuit formed by the core region 2 and the yoke 5.

The core region 2 has a plurality of channels 3 running through the core region 2. The winding 4 is arranged around the core region 2. The hot and cold fluid distribution system 6 is connected to the channels 3 of the core region 2 for distributing alternately hot and cold fluid through the channels 3 to vary the temperature of the core region 2 alternately above and below a selected temperature to thereby vary the reluctance of the magnetic circuit.

The apparatus operates by means of electric currents being induced in the winding 4 in response to a varying magnetic flux in the magnetic circuit caused by the varying reluctance, which in turn is caused by the temperature variation of the core region 2. The core region 2 may be made of a material having a magnetic phase transition temperature, such as a Curie temperature or a Néel temperature, which coincides with the selected temperature. Alternatively, the core region 2 is made of a material having a significant temperature dependent reluctance at and around the selected temperature. Examples of materials include gadolinium, bismuth, zinc, antimony, tellurium, selenium, lead, silicon, germanium, tin, magnesium, manganese, arsenic, nickel, lanthanum, gallium, phosphorus,

calcium, barium, strontium, ytterbium, iron, and any alloy or compound thereof.

The hot and cold fluid distribution system 6 is further detailed in the International patent application publication WO2008/116789 as well as in JP 7107764.

The means 7 for creating the magnetic flux may be a capacitor device arranged to feed the winding 4 with current induced in the winding 4. Alternatively, the means 7 for creating the magnetic flux may be, a current source connected to a further coil or winding arranged around the magnetic circuit, or a permanent magnet.

The operation of the apparatus is further described in the above identified publications as well as in the International patent application publication WO2008/116785 and WO2008/116792, the contents of which being hereby incorporated by reference.

Fig. 2 displays schematically in a perspective view major parts of a generator apparatus 11 in accordance with an embodiment of the invention. The generator apparatus 11 comprises an interior core region 12 which is not visible in the Fig. 2 perspective view, but is separately illustrated in Fig. 3. The core region 12 is made of a magnetic material with a temperature dependent reluctance such as those disclosed with reference to Fig. 1 and comprises a plurality of channels 13 running from a first vertical side 12a to a second vertical side 12b of the core region 12. The vertical direction is the y direction in Figs. 2-3.

Turning back to Fig. 2, the generator apparatus 11 comprises windings 14 connected in series or in parallel with one another. The windings 14 are arranged above one another in horizontal planes around the core region 12. The horizontal planes are the xz planes in Figs. 2-3. The windings 14 are spaced apart by gaps 21. Essentially C- or U-shaped frame sections or yokes 15, 15'

are arranged vertically alternately around the first 12a and second 12b vertical sides of the core region 12. The C-shaped frame sections 15, 15' are thus arranged alternately facing the first 12a and second 12b vertical sides of the core region 12 in a staggered row, which extends in a direction z essentially perpendicular to a main direction x of the channels 13 of the core region 12. The C-shaped frame sections 15, 15' at each of the first and second vertical sides 12a-b of the core region 12 are thus spaced apart by gaps 22, the width of which is equal to the width of the C-shaped frame sections 15, 15'. Thus, the channels 13 are accessible through the spaces formed by the gaps 21 between the windings 14 and the gaps 22 between the C-shaped frame sections 15, 15'.

The C-shaped frame sections 15, 15' form with the core region 12 a magnetic circuit by closing a magnetic path alternately on opposite sides of the core region 12 and the windings 14. To this end, the C-shaped frame sections 15, 15' are made of a magnetic material such as iron. A magnetic flow in the core region 12 will thus be in a direction y essentially perpendicular to the main direction x of the channels 13.

Figs. 4 and 5 display schematically in transversal and longitudinal cross sections the generator apparatus of Fig. 2.

The outer ends 15a-b of the C-shaped frame sections 15 arranged around the first vertical side 12a of the core region 12 reach preferably the second vertical side 12b of the core region 12 and the outer ends 15'a-b of the C-shaped frame sections 15' arranged around the second vertical side 12b of the core region 12 reach preferably the first vertical side 12a of the core region 12b as can be seen in Fig. 4.

The core region 12 comprises advantageously a plurality of horizontally arranged core plates 31 on top of one another, wherein the core plates 31 comprise each a row of the channels

13. The pitch of the windings 14, i.e. the center distance between two neighboring windings 14, and the pitch of the core plates 31, i.e. the center distance between two neighboring core plates 31, are similar and wherein the windings 14 are displaced with respect to the core plates 31 to allow access to the rows of channels 13 between the windings 14 in a direction x, which coincides with the main direction x of the channels 13.

For smaller electric power outputs, the generator device 11 may comprise passive material 40 which is not magnetic or which has not a temperature dependent reluctance arranged between each pair of neighboring ones of the core plates 31 in order to obtain a practical height of the generator apparatus and to reduce the width of the windings 14. For larger electric power outputs, this is not required or not even beneficial.

The channels 13 may be straight or have any suitable shape. Advantageously, they have each a height which is larger than the gap 21 between the windings 14 in order to use the core region 12 efficiently. The number and shape of the channels may be selected for each application, design, and electric power output required.

The windings 14 are favorably arranged between the core region 12 and the essentially C-shaped frame sections 15, 15', wherein the C-shaped frame sections 15, 15' may be spaced apart from the windings 14 in a direction coinciding with the main direction x of the channels 13 of the core region 12 in order to facilitate the connection of a hot and cold fluid distribution system (not illustrated in Figs. 2-5).

The hot and cold fluid distribution system is provided for distributing alternately hot and cold fluid through the channels 13 to vary the temperature of the core region 12 alternately above and below a selected temperature to thereby vary the reluctance of the magnetic circuit. The hot and cold

fluid distribution system comprises advantageously fluid connection end portions 41 as shown in Fig. 4 connected to the channels 13, wherein the fluid connection end portions 41 have cross sectional areas which preferably increase gradually towards the channels 13. A gradually increasing height towards the channels 13 may be required when the channels have a height which is larger than the distance between adjacent windings 14. A gradually increasing width towards the channels 13 may be required when the fluid connection end portions 41 should be connected to channels 13 which are lying straight behind the C-shaped frame sections 15, 15' and which are thus not facing the gaps 22 between the C-shaped frame sections 15, 15'. The fluid connection end portions 41 may be comprised of pipes or hoses or similar structures. In other respects, the hot and cold fluid distribution system may be implemented as described with reference to Fig. 1.

Finally, an arrangement (not illustrated in Figs. 2-5) for creating a magnetic flux in the magnetic circuit is provided. The arrangement for creating the magnetic flux may be implemented as described with reference to Fig. 1.

The generator apparatus of the present invention reduces the requirements on the frame section thickness and allows for direct and simple fluid access to the channels 13.

Fluid frictional losses and thermal gradients set a limit on the thickness of the generator apparatus 11, i.e. on the dimension of the generator apparatus 11 in the main direction x of the channels. This thickness is estimated to be about 0.1-0.2 m.

The generator apparatus 11 is thus designed for a selected output electric power by means of, i.a., the height of the core region 12, the height of the C-shaped frame sections 15, 15', and the number of the windings 14; and/or by means of the length of the core region 12, the length of the windings 14,

and the number of the C-shaped frame sections 15, 15', wherein the lengths of the core region 12 and the windings 14 are the dimensions of the core region 12 and the windings 14 in a horizontal direction z essentially perpendicular to the main direction x of the channels 13. In other words, the generator apparatus 11 is scalable in height (y direction) and length (z direction), but advantageously not in thickness (x direction).

It shall be appreciated by a person skilled in the art that the present invention can be implemented in yet further embodiments. In particular, the hot and cold fluid distribution system and the arrangement for creating a magnetic flux in the magnetic circuit may be implemented in other manners than those disclosed above.

CLAIMS

1. A generator apparatus (11) for converting thermal energy to electric energy comprising:

- a core region (12) made of a magnetic material having a temperature dependent reluctance, the core region having channels (13) running in a main direction (x) from a first vertical side (12a) to a second vertical side (12b) of the core region opposite to the first side of said core region;

- windings (14) arranged above, and spaced apart from, one another in horizontal (xz) planes around said core region;

- essentially C-shaped frame sections (15, 15') of a magnetic material arranged vertically alternately around the first and second vertical sides of the core region so as to alternately face the first and second vertical sides of the core region in a staggered row extending in a horizontal direction (z) essentially perpendicular to the main direction (x) of the channels (13), wherein the core region and the C-shaped frame sections form a magnetic circuit;

- a hot and cold fluid distribution system (6) connected to the channels of said core region for distributing alternately hot and cold fluid through the channels of said core region to vary the temperature of said core region alternately above and below a selected temperature, thereby varying the reluctance of the magnetic circuit; and

- means (7) for creating a magnetic flux in the magnetic circuit.

2. The apparatus of claim 1 wherein said core region is made of a material having a magnetic phase transition temperature, such as a Curie temperature or a Néel temperature, said selected

temperature coinciding with said magnetic phase transition temperature.

3. The apparatus of claim 1 wherein said core region is made of a material having a significant temperature dependent reluctance at said selected temperature.

4. The apparatus of any of claims 1-3 wherein said core region comprises a plurality of horizontally arranged core plates (31) on top of one another, and said channels comprises a row of channels in each of the core plates.

5. The apparatus of claim 4 wherein the pitch of the windings and the pitch of the core plates are similar and wherein the windings are displaced with respect to the core plates to allow access to the rows of channels between the windings in a direction (x) which coincides with said main direction of the channels.

6. The apparatus of claim 4 comprising material which is not magnetic or which has not a temperature dependent reluctance arranged between each pair of neighboring ones of the core plates.

7. The apparatus of any of claims 1-6 wherein said channels have each a height which is larger than an average distance between each pair of neighboring ones of the windings.

8. The apparatus of any of claims 1-7 wherein said windings are connected in parallel or in series.

9. The apparatus of any of claims 1-8 wherein said windings are arranged between said core region and said essentially C-shaped frame sections.

10. The apparatus claim 9 wherein said essentially C-shaped frame sections are spaced apart from said windings in a

direction (x) coinciding with said main direction of the channels of said core region.

11. The apparatus of any of claims 1-10 wherein the outer ends (15a-b) of the C-shaped frame sections (15) arranged around the first vertical side of the core region reach essentially the second vertical side of the core region and the outer ends (15'a-b) of the C-shaped frame sections (15') arranged around the second vertical side of the core region reach essentially the first vertical side of the core region.

12. The apparatus of any of claims 1-11 wherein said apparatus is designed for a selected output electric power by means of the height of said core region, the height of said C-shaped frame sections, and the number of said windings, and/or by means of the length of said core region, the length of said windings, and the number of said C-shaped frame sections, wherein the lengths of said core region and said windings are the dimension of said core region and said windings in a horizontal direction (z) essentially perpendicular to said main direction (x) of the channels.

13. The apparatus of any of claims 1-12 wherein said a hot and cold fluid distribution system comprises fluid connection end portions (41, 42) connected to the channels, said fluid connection end portions having cross sectional areas which increase towards the channels.

14. The apparatus of any of claims 1-12 wherein said means (7) for creating a magnetic flux in the magnetic circuit includes a capacitor device connected to said windings.

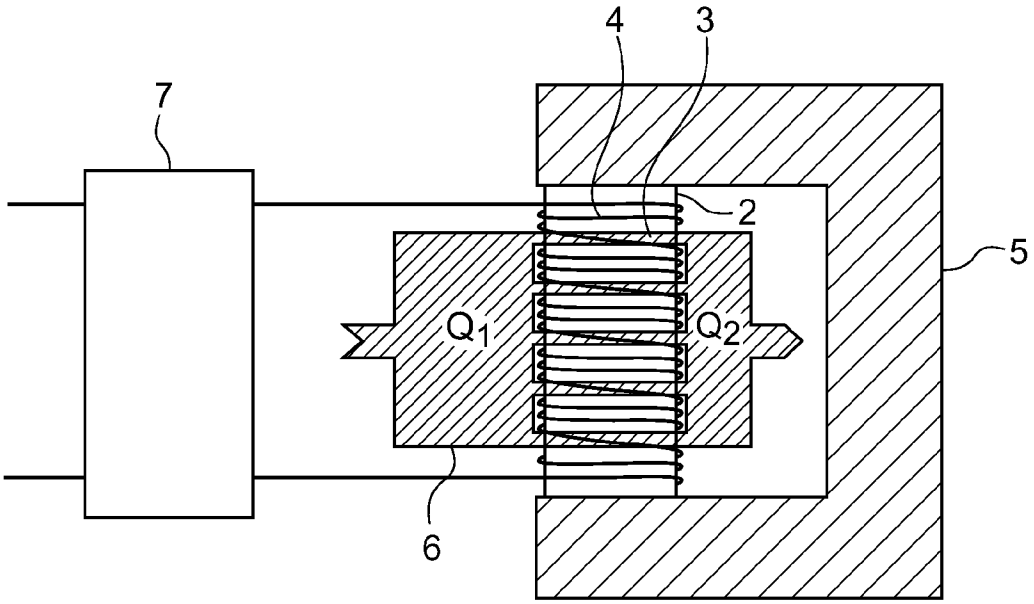

Fig. 1

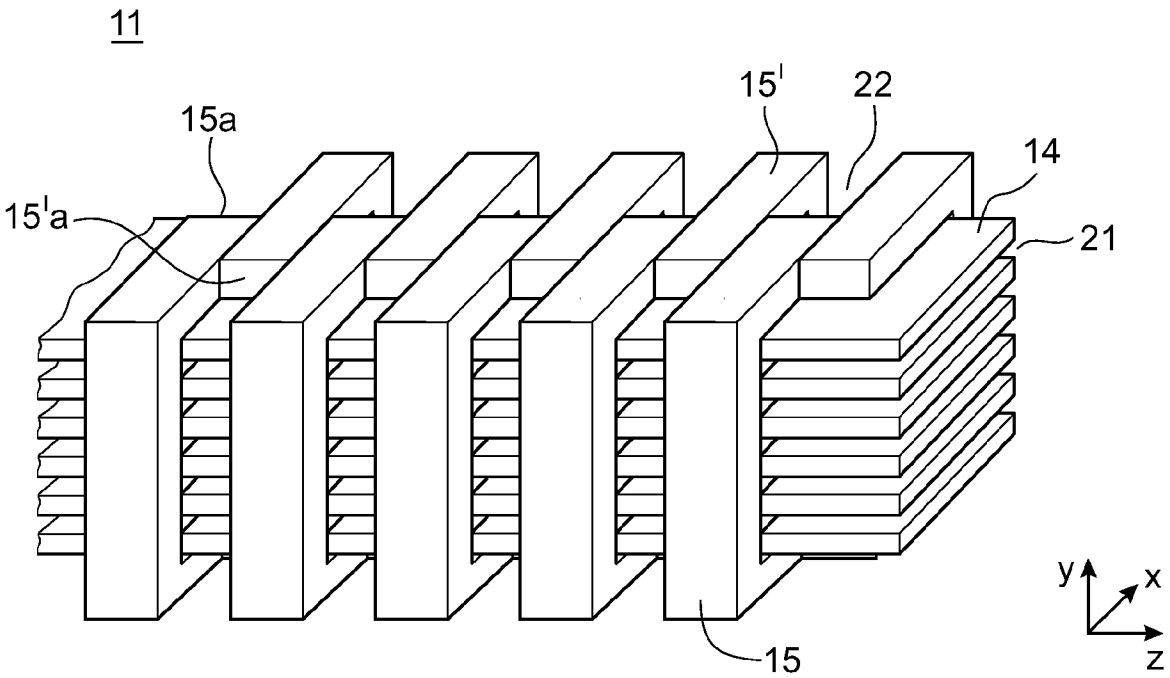

Fig. 2

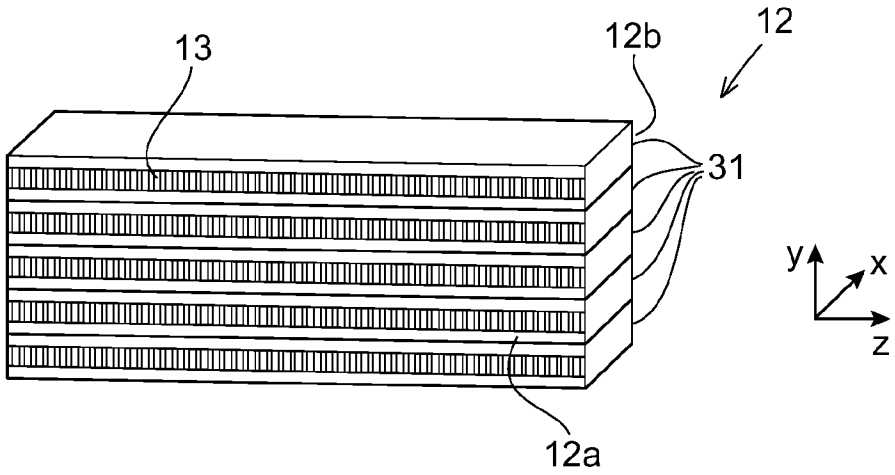

Fig. 3

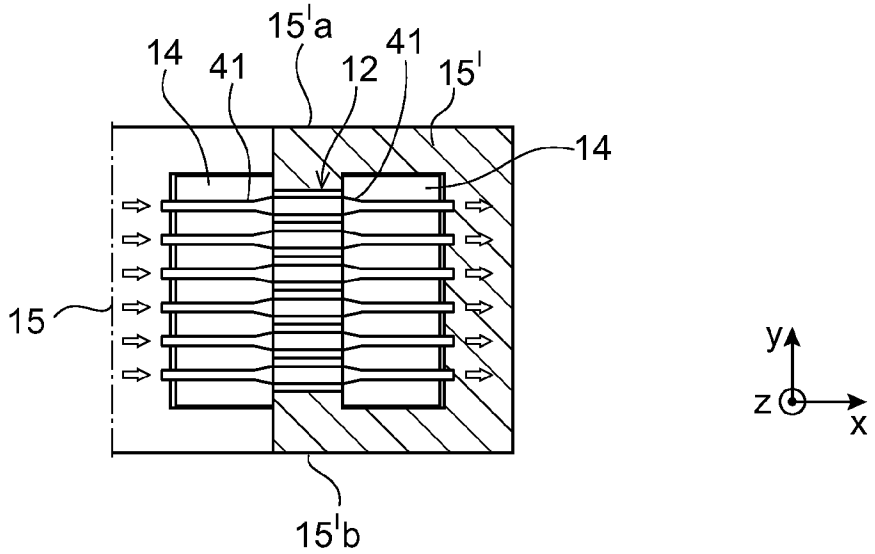

Fig. 4

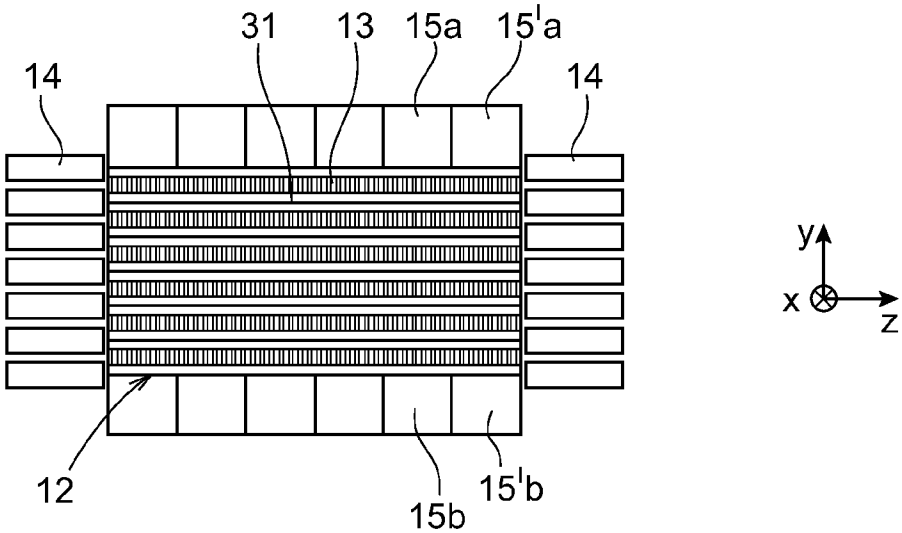

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/067287

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L37/04
ADD.

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)
H01L H02N

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 practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2008/142253 A (B.L.B.S. TECHNOLOGIES SARL [FR]) 27 November 2008 (2008-11-27) figures 2,15,17A	1-14
A	SOLOMON D: "DESIGN OF A THERMOMAGNETIC GENERATOR" ENERGY CONVERSION AND MANAGEMENT, ELSEVIER SCIENCE PUBLISHERS, OXFORD, GB, vol. 31, no. 2, 1 January 1991 (1991-01-01), pages 157-173, XP000177184 ISSN: 0196-8904 figures 1,4,5	1-14

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 April 2010	10/05/2010

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2009/067287

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008142253 A	27-11-2008	FR 2914502 A1	03-10-2008