(12) **Oversettelse av europeisk patentskrift**

(11) **NO/EP 4133330 B1**

NORGE

(19) NO
(51) Int Cl.

G02F 1/167 (2019.01)
G02F 1/1343 (2006.01)
G02F 1/1675 (2019.01)
G02F 1/1676 (2019.01)
G02F 1/16761 (2019.01)
G02F 1/16762 (2019.01)
G02F 1/1677 (2019.01)

Patentstyret

(45)	Oversettelse publisert	2024.12.23
(80)	Dato for Den Europeiske Patentmyndighets publisering av det meddelte patentet	2024.08.07
(86)	Europeisk søknadsnr	21718966.1
(86)	Europeisk innleveringsdag	2021.03.29
(87)	Den europeiske søknadens Publiseringsdato	2023.02.15
(30)	Prioritet	2020.04.08, FR, 2003338
(84)	Utpekte stater	AL ; AT ; BE ; BG ; CH ; CY ; CZ ; DE ; DK ; EE ; ES ; FI ; FR ; GB ; GR ; HR ; HU ; IE ; IS ; IT ; LI ; LT ; LU ; LV ; MC ; MK ; MT ; NL ; NO ; PL ; PT ; RO ; RS ; SE ; SI ; SK ; SM ; TR
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(54) Benevnelse **INFRARED REFLECTIVITY CONTROL DEVICE**

(56) Anførte publikasjoner

JP-A- S 604 828
US-A1- 2008 211 764
US-B2- 7 034 987
US-A1- 2018 046 055
US-A1- 2009 295 765

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Description

Title of the invention: Device for controlling the infrared reflectivity

The technical field of the invention is that of devices for controlling the infrared reflectivity of a support.

The problem of controlling the infrared reflectivity of a support arises in many fields. Temperature control of structures exposed to solar radiation, e.g. glazing or satellites orbiting the earth, can be cited. Such reflectivity control is further encountered in the military field in the design of camouflages for vehicles, stationary structures or even persons.

Patent US2018/0267382 is known in the field of camouflage, which proposes a structure comprising two arrays of crossed electrodes arranged on both sides of cells wherein are housed beads containing a fluid loaded with particles of various sizes and natures.

The electrode array allows pixel-by-pixel addressing and selective cell control. Associated with a suitable control means, such device can be used for producing camouflage patterns of various colors and also an infrared masking by using particles which either reflect or absorb well near infrared radiation (wavelength less than 2 micrometers).

A lower layer of the device blocks infrared radiation, in particular the radiation coming from the structure to be masked. The variations in the electric field between the electrodes make it possible to distribute the particles so as to obtain the desired camouflage in the visible or near infrared range.

Such structure of device is particularly complex and cannot be used for an effective infrared masking of a support, in particular in the mid-infrared range (range generally covering wavelengths from 2.5 micrometers to 20 micrometers). Particles with multiple masses and electrical properties impair the effectiveness of masking, particularly in the infrared range.

In particular, it is difficult to provide either absorption of infrared radiation or reflection of said radiation, because each type of behavior is associated with particles of a different nature which are mixed in the same fluid and which have then to be moved in a differentiated manner.

U.S. Pat. No. 2008/211764 discloses a display for controlling the reflectivity, the display using a fluid which is transparent in the visible range, and is loaded with particles. Such display uses the phenomenon of electrophoresis for producing different types of displays. However, such display is limited to controlling the color of the display between white and black or between two or a plurality of colors. Such a display cannot be used for controlling the reflectivity or the emissivity of a cell in the mid-infrared range, as defined above. It does not give either any details on the absorption or transparency properties of the fluid in said wavelength range.

U.S. Pat. No. 7034987 discloses an electrophoretic display which can generate a colored image. The display comprises a visible volume to which at least one reservoir for electrophoretic particles is attached. The reservoir contains at least two types of particles, each of which is transparent in a first portion of the optical spectrum and either absorbent or reflecting for a second portion of the spectrum. Such display increases the contrast and brightness of the display, but does not allow to control the infrared reflectivity or emissivity in the mid-infrared range.

US2018/046055 also illustrates the technological background of an infrared reflectivity control device according to claim 1.

Document JPS604828A discloses an infrared reflectivity control device comprising at least one cell forming a housing comprising a top cover transparent in the infrared range, a bottom plate and at least two electrodes connectable to an electrical generator, the housing containing a fluid charged with particles, the top cover being transparent in the infrared wavelength range, one of the electrodes being carried by the bottom plate, the particles comprising at least one material which can be electrically charged (non-zero zeta potential) and ensures reflection of the infrared radiation.

It is the aim of the present invention to propose a simple-design device for controlling infrared reflectivity, providing continuous performance with respect to infrared radiation, ranging from the absorption of radiation to the reflection of radiation.

The device according to the invention is thus a device with variable emissivity which is more particularly intended for providing a control of the reflectivity in the wavelength range from 2.5 micrometers to 20 micrometers (range corresponding to what is generally called mid-infrared). Said range includes in particular, the bands II and III. Band II: Wavelength from 3 micrometers to 5 micrometers. Band III: Wavelengths from 8 micrometers to 12 micrometers.

Thus, the device according to the invention is a device for an effective control of the infrared emissivity of the support to which it is applied, which greatly increases the masking potential in the mid-infrared range.

Such performance provides excellent infrared masking whatever the nature of the environment of the structure to be masked.

It also makes it possible to provide a good control of the temperature of the support, which allows glazing or insulating walls to be produced.

Thus, the subject matter of the invention is an infrared reflectivity control device comprising at least one cell forming a housing comprising an upper cover transparent in the visible range and a bottom plate bearing at least two electrodes which can be connected to an electric generator, the housing containing a fluid which is transparent in the visible range and is loaded with particles, the device further comprising the following features:

- the upper cover (2) and the fluid (6) are transparent in the wavelength range from 2.5 micrometers to 20 micrometers, corresponding to the mid-infrared;
- the electrodes are reflecting in the infrared range;
- the electrodes are carried by the bottom plate and are unsymmetrical, a first electrode having a first surface area and a second electrode having a second surface area, the first surface area being greater than the second surface area;
- the particles have nanometric particle size and comprise at least one material which can be electrically charged (non-zero zeta potential), the particle size being chosen so as to ensure infrared absorption in the wavelength range from 2.5 micrometers to 20 micrometers.

Advantageously, the electrodes can cover at least 90% of the surface area of the bottom plate.

Advantageously, the first surface area will be much greater than that of the second surface area, e.g. the first surface area will be at least ten times greater than the second surface area.

According to a particular embodiment, the electrodes can be transparent in the visible range.

According to a particular embodiment, the electrodes can be formed of parallel strips arranged in an alternating manner, the first electrode including wide strips and the second electrode including narrow strips, two consecutive wide strips being separated from each other by a narrow strip.

According to a particular embodiment, the strips can include an alternation of slots and tabs.

According to a first variant, the slots and tabs can have rectangular shapes.

According to a second variant, the slots and tabs can have triangular shapes.

Advantageously, the material which can be charged can be a metal oxide doped with a metal, such material having a particle size comprised between 40 and 80 nanometers.

In particular, the material which can be charged can be chosen from the following materials: aluminum-doped zinc oxide (Al: ZnO), gallium-doped Zinc Oxide (Ga: ZnO), indium-doped Zinc Oxide (In: ZnO), niobium-doped titanium dioxide (Nb: TiO2), tin-doped indium oxide (ITO). ITO is concretely a mixture of indium oxide In2O3 and tin oxide SnO2.

Advantageously, the material can be present in the fluid at a concentration of 10 to 60 milligrams per milliliter.

The invention will be better understood by reading a detailed description made with reference to the appended drawings wherein:

[Fig. 1] shows schematically an exemplary embodiment of a cell of a reflectivity control device according to the invention;

[Fig. 2] represents the cell in emissive mode;

[Fig. 3] represents the cell in reflecting mode;

[Fig. 4] shows a front view of a first embodiment of the electrodes of the cell;

[Fig. 5] shows a cell comprising electrodes according to the first exemplary embodiment, and a sectional view along the plane of which line AA is identified in Figure 4;

[Fig. 6a] shows, in front view, a second exemplary embodiment of the electrodes of the cell;

[Fig. 6b] shows, in front view, a third exemplary embodiment of the electrodes of the cell;

[Fig. 7] is a diagram of an infrared reflectivity control device implementing a plurality of cells;

[Fig. 8] is a diagram showing an infrared reflectivity control device according to the invention associated with masking cells in the visible range.

Figure 1 shows schematically a cell 1 of an infrared reflectivity control device for a structure, e.g. a vehicle (structure not shown).

The cell 1 forms a housing 1 comprising an upper cover 2 which is transparent in the visible range and the range of wavelengths from 2.5 micrometers to 20 micrometers (mid-infrared), and a bottom plate 3 which bears at least two electrodes 4a and 4b which can be connected to an electric generator 5. The housing 1 contains a fluid 6 which is transparent in the visible range and the range of wavelengths from 2.5 micrometers to 20 micrometers (mid-infrared), and which is loaded with particles 7. As an example, an isoparaffinic hydrocarbon fluid of the type sold by Exxon Mobil under the brand name Isopar (of type L, M or G) can be used as a fluid. It is also possible to use an alkane, such as: octane, nonane, decane, undecane, dodecane, tridecane, tetradecane, hexadecane, etc.

The bottom plate 3 will e.g. be a glass plate and the electrodes 4a and 4b will be deposited on said plate by conventional vapor deposition techniques or by screen printing.

The cover 2 will consist e.g. of a polyethylene film. The only function thereof is to provide leak-tightness to the housing 1 containing the fluid 6 loaded with particles 7. Other transparent materials in the visible range and in the range of wavelengths from 2.5 micrometers to 20 micrometers (mid-infrared) would be possible, e.g. parylene or poly (p-xylylene).

According to a characteristic of the invention, the electrodes are made of a material reflecting in the infrared range. The electrodes 4a and 4b can e.g. be metallic (e.g. chromium deposits on the plate 3).

According to a particular embodiment, the electrodes 4a and 4b can be made of a material which is reflecting in the infrared range and also transparent in the visible range, e.g. of ITO or of PEDOT-PSS. In a manner well known to a person skilled in the art, ITO (or indium tin oxide) is an alloy of indium oxide (In_2O_3) and tin oxide (SnO_2).

PDOT-PSS designates a mixture of two polymers, poly(3,4-ethylenedioxythiophene) (or PEDOT) and sodium polystyrene sulfonate (or PSS).

The choice of transparent electrodes in the visible range provides the transparency of cell 1, which allows the overlay thereof with any other effective camouflage technology in the visible range. A visible camouflage can be a simple static camouflage canvas or an adaptive camouflage means, e.g. an electronically controlled camouflage. Such a variant will be described in detail thereafter.

According to another feature of the invention, the electrodes 4a and 4b are unsymmetrical. Thus, a first electrode 4a has a first surface area and a second electrode 4b has a second surface area and the first surface area is greater than the second surface area. The difference between the values of each surface area makes it possible to characterize the extreme positions the cell can be in, from the point of view of reflection or absorption. Advantageously, a relatively large difference can be taken between the values of the two surface areas, e.g. it is possible to take a first surface area which is at least ten times greater than the second surface area.

Figure 1 shows schematically, a first electrode 4a positioned in the middle of the bottom plate 3 and a second electrode 4b consisting of two small bars arranged on either side of the first electrode 4a and at a distance therefrom.

The two bars 4b are electrically connected to each other, either by external connectors as shown, or by etched tracks (not shown) borne by the bottom plate 3.

According to another feature of the invention, the particles 7 have nanometric particle size and comprise at least one material which can be electrically charged. Such a material which can be charged, is often referred to as having a non-zero zeta potential.

A nanometric particle size for a powder material is generally less than 100 nanometers. For the particles 7 which are used herein, a particle size comprised between 40 and 80 nanometers will be chosen. Such range corresponds to the optimum providing infrared absorption in the wavelength range from 2.5 micrometers to 20 micrometers (mid-infrared) and in particular in the bands II and III which are the observation ranges of the main infrared detectors.

The choice of a material with a non-zero zeta potential makes it possible to obtain a stable suspension of the particles 7 in the fluid 6. The choice of a nanometric particle size coupled with the choice of a material with a non-zero zeta potential (conducting) makes it possible to endow the particles of the material with plasmonic properties. The plasmonic effect makes it possible to have a very intense absorption in a well-defined wavelength range. The nanometric particle size further prevents the effect of light scattering in the visible range.

In particular, the plasmonic properties of a granular material have the advantage of increasing the infrared absorption capacity of the material.

As an example, a metal oxide doped with a metal, e.g. zinc oxide doped with aluminum (Al: ZnO) can be chosen as a material.

Such material can be easily supplied. The doping of the particles is about 2% of aluminum atoms against 98% of zinc atoms. The crystal lattice of such particles is a Würtzite structure.

Preferentially, the material present in the fluid will have a concentration of 10 to 60 milligrams per milliliter.

Such concentration range makes it possible to obtain a significant modulation of the reflectivity and also makes it possible to obtain a stable suspension.

Tests made it possible to verify that, in the infrared frequency bands from 3 to 5 micrometers and from 8 to 12 micrometers, infrared absorption was about 70% higher with a concentration of 40 milligrams per milliliter of aluminum-doped zinc oxide compared to a concentration of 10 milligrams per milliliter.

It should be noted that, in the same infrared bands, the absorption of a fluid loaded with aluminum-doped zinc oxide with a concentration of 10 milligrams per milliliter is 25% to 50% greater than the absorption of the fluid alone.

Such numbers show the significant absorption performance of the granular material which is proposed.

Figure 2 shows the cell 1 when the generator 5 applies a voltage difference between the two electrodes 4a and 4b. The charge of the first electrode 4a is here greater than the charge of the second electrode 4b. As a result, an electrophoretic displacement of the particles 7 in the fluid 6 (said particles are naturally negatively charged) takes place. Said displacement mainly occurs in a lateral direction with respect to the cell, i.e. parallel to the cover 2 and to the bottom plate 3.

Substantially all of the particles 7 are here concentrated on the first electrode 4a (wide electrode) and the second electrode 4b is completely clear.

Thus, the particles 7 mask the first electrode 4a, the reflecting face of which is covered. As a result, the cell 1 has an emissive behavior, no longer reflecting the infrared waves it can receive from the outside, but absorbing them at the level of particles 7.

Conversely, in Figure 3, when the generator 5 reverses the voltages between the two electrodes 4a and 4b, all the particles 7 concentrate on the second electrodes 4b, leaving the first electrode 4a completely clear. Since the first electrode 4a is reflecting for infrared waves, the cell 1 is then in a reflecting mode. It reflects substantially all the infrared waves which reach it from the outside.

It should be noted that, for a given cell, the most reflecting state for the infrared waves (electrode 4a totally clear) and the most absorbing state for the infrared waves - so-called emissive state - (electrode 4a totally covered) will depend on the relative surface areas of the two electrodes. It is thus particularly advantageous that there is a large difference between the surface areas of the two electrodes so that the reflecting or absorbing states of the cell are very pronounced.

Concretely, a direct voltage will be applied for moving the particles from one electrode to another. The voltage is cut off so as to stop the movement of the particles. Depending on how long the direct voltage is applied, a greater or lesser quantity of particles will group together on the wide electrodes or on the narrow electrodes. The state of the cell can thus be substantially continuously controlled between the emissive mode thereof and the reflecting mode thereof. Advantageously, a low frequency (10 Hz) alternating voltage is applied for homogeneously dispersing the particles within the cell. Such dispersion will be carried out before a new direct voltage is applied in one direction or the other.

Advantageously, the electrodes 4a and 4b (and more particularly the first electrode 4a) cover at least 90% of the surface area of the bottom plate. The goal is to give the cell a significant reflecting capacity when it is in its reflecting state. It is thus necessary that the greater part of the surface area of the bottom plate 3 is reflecting for infrared waves (due to the first electrode 4a).

Figures 1 to 3 are schematic figures showing more clearly the functioning of the cell according to the invention.

Concretely, the electrodes 4a and 4b have a special shape providing the cell with maximum infrared reflectivity in the reflecting mode and also a homogeneous distribution of the particles, a guarantee of maximum infrared absorption, in the emissive mode.

Figure 4 shows, in front view, the bottom plate 3 of a cell 1 including a first exemplary embodiment of the electrodes 4a and 4b. Said figure can be studied in parallel with Figure 5 which shows the associated cell 1, in a section along the plane of which the line AA is shown in Figure 4.

As can be seen in Figure 4, the electrodes 4a and 4b consist of parallel strips which are arranged in an alternating manner. The first electrode 4a includes wide strips Bi and the second electrode 4b includes narrow strips bi, two consecutive wide strips B1 and B2 being separated from each other by a narrow strip b1.

All the wide strips Bi are electrically connected to one another by a first small bar 8a.

All the narrow strips bi are electrically connected to one another by a second small bar 8b.

The first small bar 8a is electrically connected to a first connection track 9a.

The second small bar 8b is electrically connected to a second connection track 9b.

Thus, when the cell 1 is in the reflecting state, all the particles 7 are grouped on the narrow strips bi. The wide strips Bi are then clear and the infrared-reflecting surface area is maximum.

When, conversely, cell 1 is in the emissive state, all particles 7 are grouped on the wide strips Bi. The surface area of the narrow strips bi is much smaller than the surface area of wide strips Bi and the absorption of infrared waves by the particles is maximum.

Of course, the widths of the wide strips and of the narrow strips, as well as the width of the spaces separating these, can be modified. What is important is to always have at the cell a large difference of surface area between the wide and narrow strips while covering a maximum of the surface area of the bottom plate 3.

It was thus possible to test wide strips, the width of which varied between 200 micrometers and 500 micrometers, associated with 20 micrometers wide narrow strips.

The space between the wide strips and narrow strips could be varied between 110 micrometers and 20 micrometers.

Other shapes are possible for the first electrode 4a and the second electrode 4b.

Figure 6a thus shows wide strips Bi and narrow strips bi each including an alternation of slots Ci/ci and tabs Li/li. Every tab li of a narrow strip bi is housed in a slot Ci of a wide strip Bi. In parallel, every tab Li of a wide strip Bi is housed in a slot ci of a narrow strip bi.

In the embodiment shown in Figure 6a, the slots and tabs have rectangular shapes.

The result of such embodiment is a greater covering of the surface of the bottom plate. Such variant further reduces the accumulation of particles.

Figure 6b shows another embodiment which is similar to the embodiment shown in Figure 6a, but for which the slots CI/ci and tabs Li/li have triangular shapes.

Figure 7 shows a device 10 for controlling the infrared reflectivity which uses a plurality of cells 1 assembled on a common support 11, e.g. a fabric or a rigid plate borne by a structure.

All the cells 1 have a structure of the previously described type. However, every cell 1 can be controlled individually by a control means 12 provided with means enabling same, by addressing, to apply a particular voltage to every cell 1 so as to endow same with a particular emissive or reflecting state.

Such state will be defined by a calculation means incorporated in the control means 12 and which will be associated e.g. with a camera means enabling it to determine the infrared emission or absorption characteristics of the support surrounding the structure bearing the device. Patent EP2992292 e.g., which describes such a device, can be consulted.

It thus becomes possible to endow the device 10 with a particular infrared signature which varies from cell to cell.

As an example, Figure 7 shows cells 1a, 1b, 1c having different emissive or reflecting states.

Figure 8 shows a cell 1, the bottom plate 3 of which is transparent in the visible range. The bottom plate is positioned on three cells K1, K2 and K3 containing cholesteric liquid crystals, making it possible to obtain a coloration which is: blue for K1, green for K2, and red for K3, respectively. Every cell K1, K2 and K3 can be controlled individually by a control means with a more or less intense dosage of each color.

Cells for obtaining colors with a more or less strong intensity level are known, e.g. from patent EP3213146.

The stack of cells 1, K1, K2 and K3 is fastened onto a structure S to be camouflaged.

Due to the invention, it becomes possible to combine the masking in the visible range provided by the cells K1, K2 and K3 with an infrared masking provided by the cell 1.

It is of course also possible to associate the cells 1 with a support, the camouflage pattern of which is fixed.

Patentkrav

1. Styreanordning for infrarød reflektivitet omfattende minst én celle (1) som danner et hus omfattende et øvre dekke (2) som er transparent i det synlige området, en bunnplate (3) og minst to elektroder (4a, 4b) som kan forbindes til en elektrisk generator (5), hvor huset inneholder et fluid (6) som er transparent i det synlige området og er fylt med partikler (7),
hvori det øvre dekket (2) og fluidet (6) er transparente i bølgelengdeområdet fra 2,5 mikrometer til 20 mikrometer;
hvori elektrodene (4a, 4b) bæres av bunnplaten og er reflekterende i det infrarøde området;
hvori elektrodene (4a, 4b) er usymmetriske, idet en første elektrode (4a) har et første overflateareal, og en andre elektrode (4b) har et andre overflateareal, hvor det første overflatearealet er større enn det andre overflatearealet; og
hvori partiklene (7) har nanometrisk partikkelstørrelse og omfatter minst ett materiale som kan lades elektrisk, og således har et zetapotensial ulikt null, idet partikkelstørrelsen er valgt for å tilveiebringe infrarød absorpsjon i bølgelengdeområdet fra 2,5 mikrometer til 20 mikrometer.

2. Styreanordning for infrarød reflektivitet ifølge krav 1, karakterisert ved at elektrodene (4a, 4b) dekker minst 90 % av bunnplatens (3) overflateareal.

3. Styreanordning for infrarød reflektivitet ifølge ett av kravene 1 eller 2, karakterisert ved at det første overflatearealet er minst ti ganger større enn det andre overflatearealet.

4. Styreanordning for infrarød reflektivitet ifølge ett av kravene 1 til 3, karakterisert ved at elektrodene (4a, 4b) er transparente i det synlige området.

5. Styreanordning for infrarød reflektivitet ifølge ett av kravene 1 til 4, karakterisert ved at elektrodene (4a, 4b) er dannet av parallelle strimler (Bi, bi) anordnet på en vekslende måte, idet den første elektroden (4a) innbefatter brede strimler (Bi) og den andre elektroden (4b) innbefatter smale strimler (bi), og to påfølgende brede strimler er adskilt fra hverandre av en smal strimmel.

6. Styreanordning for infrarød reflektivitet ifølge krav 5, karakterisert ved at strimlene (Bi, bi) innbefatter en veksling av spor og fliker.

7. Styreanordning for infrarød reflektivitet ifølge krav 6, karakterisert ved at sporene og flikene har rektangulære former.

8. Styreanordning for infrarød reflektivitet ifølge krav 6, karakterisert ved at sporene og flikene har trekantede former.

9. Styreanordning for infrarød reflektivitet ifølge ett av kravene 1 til 8, karakterisert ved at materialet som kan lades er et metalloksid dopet med et metall, idet materialet har en partikkelstørrelse som inngår mellom 40 og 80 nanometer.

10. Styreanordning for infrarød reflektivitet ifølge krav 9, karakterisert ved at materialet som kan lades er valgt blant følgende materialer: aluminiumdopet sinkoksid (Al: ZnO), galliumdopet sinkoksid (Ga: ZnO), indiumdopet sinkoksid (In: ZnO), niobdopet titandioksid (Nb: TiO2), tinndopet indiumoksid (ITO).

11. Styreanordning for infrarød reflektivitet ifølge krav 10, karakterisert ved at materialet er til stede i fluidet (6) i en konsentrasjon på 10 til 60 milligram per milliliter.

[Fig. 1]

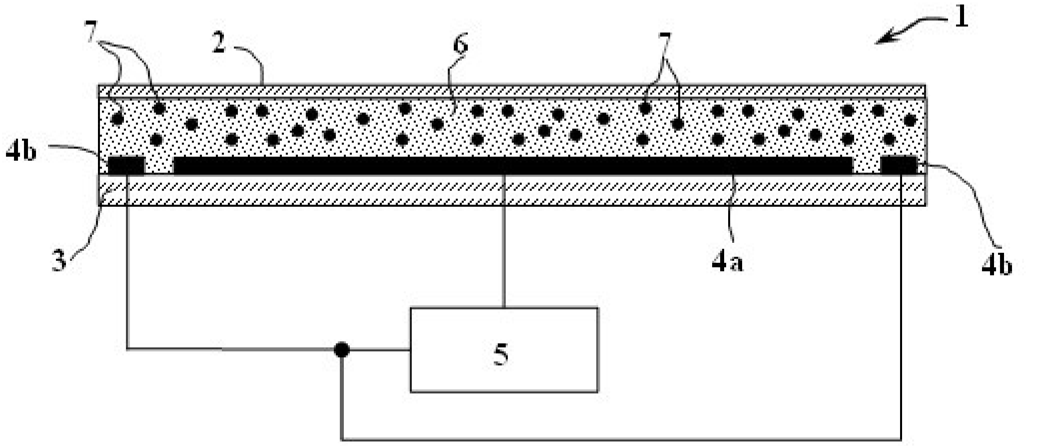

Fig. 1

[Fig. 2]

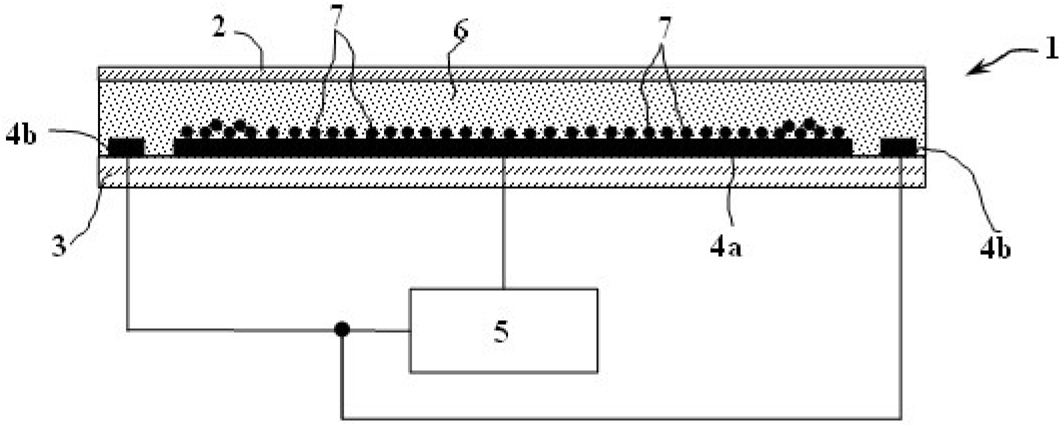

Fig. 2

[Fig. 3]

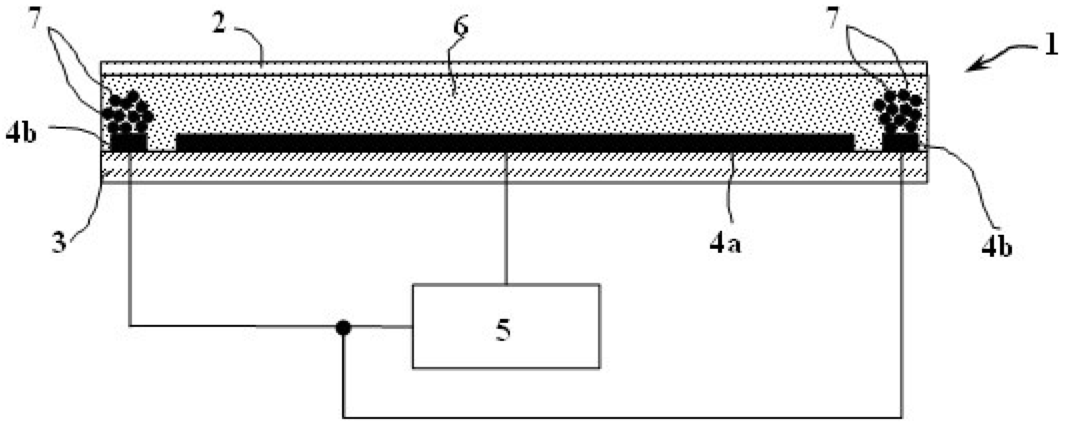

Fig. 3

[Fig. 4]

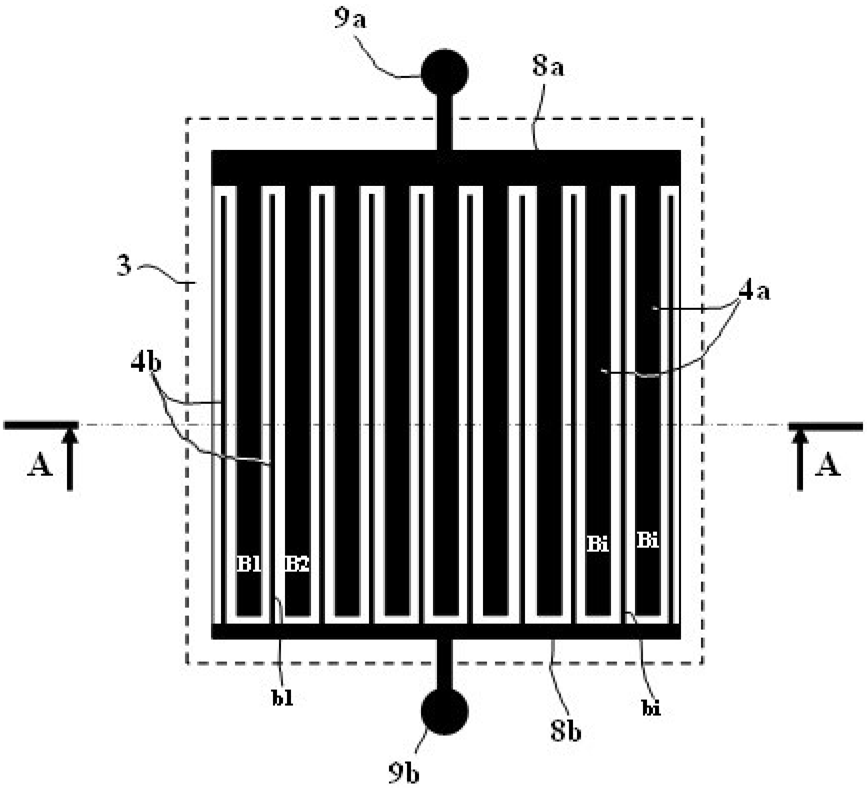

Fig. 4

[Fig. 5]

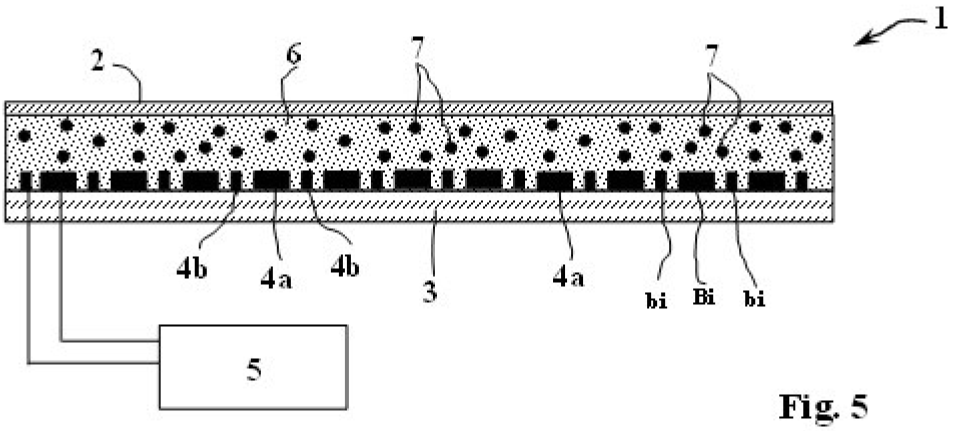

Fig. 5

[Fig. 6a]

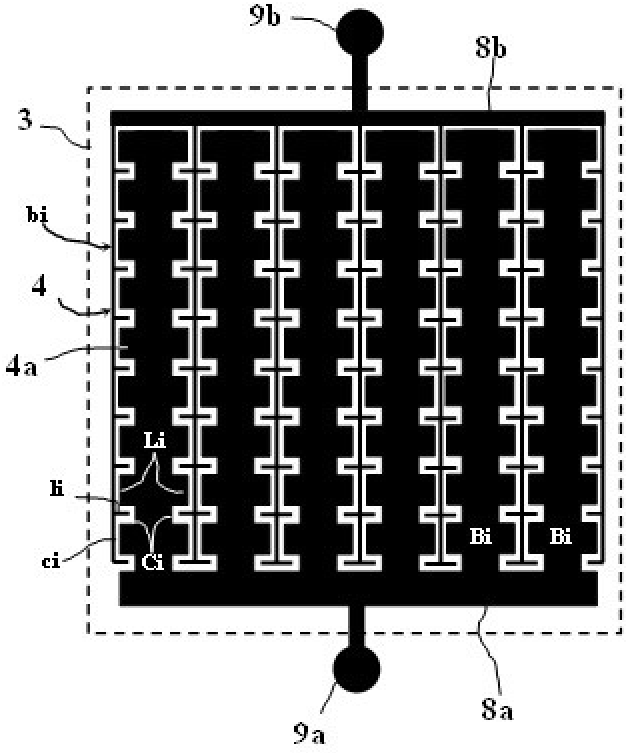

Fig. 6a

[Fig. 6b]

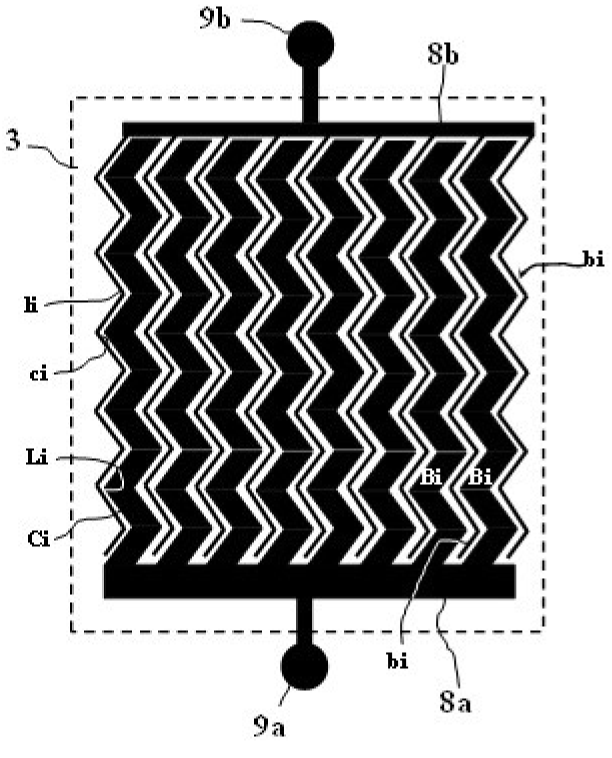

Fig. 6b

[Fig. 7]

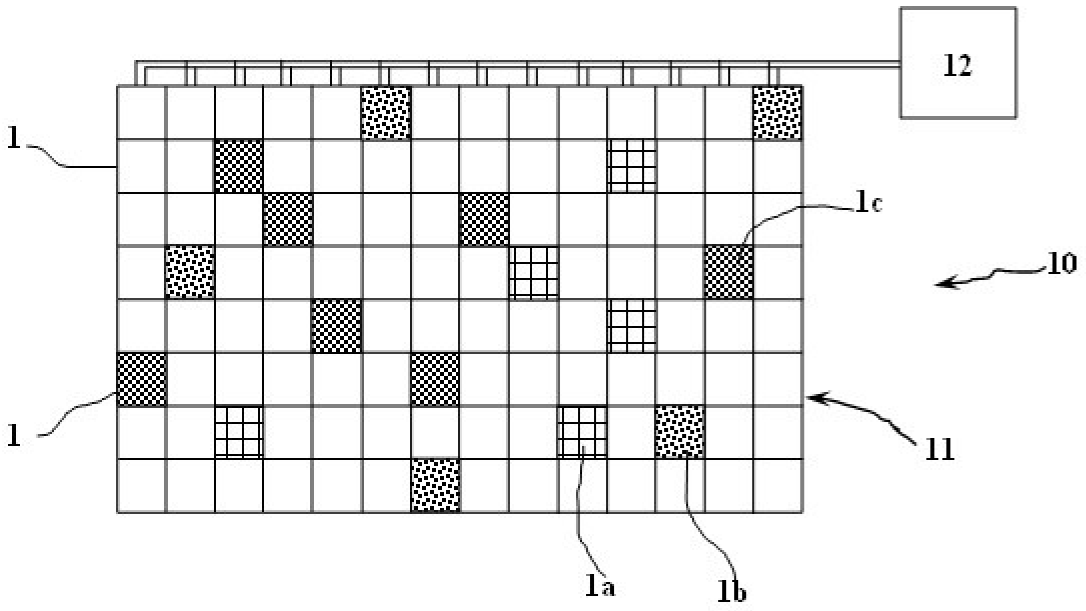

Fig. 7

[Fig. 8]

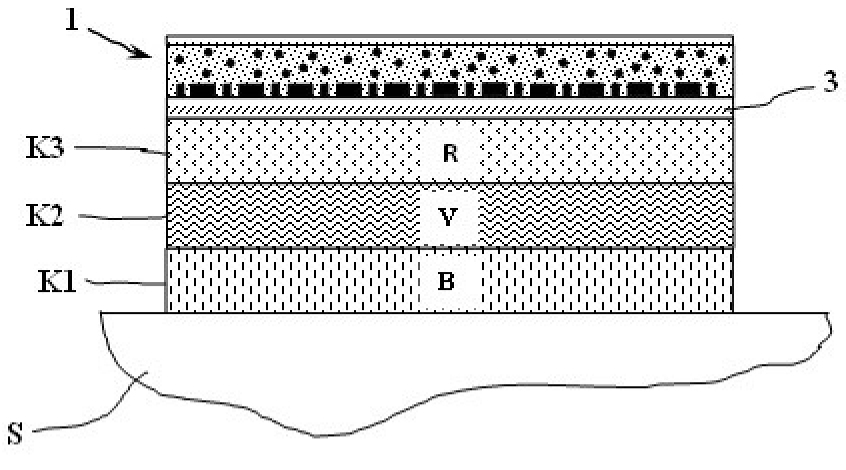

Fig. 8