US009261411B2

(12) **United States Patent**
Oulachgar et al.

(10) **Patent No.: US 9,261,411 B2**
(45) **Date of Patent: Feb. 16, 2016**

(54) UNCOOLED MICROBOLOMETER DETECTOR AND ARRAY FOR TERAHERTZ DETECTION

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 484 days.

(21) Appl. No.: **13/720,317**

(22) Filed: **Dec. 19, 2012**

(65) **Prior Publication Data**

US 2014/0166882 A1 Jun. 19, 2014

(51) **Int. Cl.**
G01J 5/20 (2006.01)
G01N 21/35 (2014.01)
G01J 5/08 (2006.01)

(52) **U.S. Cl.**
CPC . ***G01J 5/20*** (2013.01); ***G01J 5/0834*** (2013.01)

(58) **Field of Classification Search**
USPC 250/338.4, 338.1, 349
See application file for complete search history.

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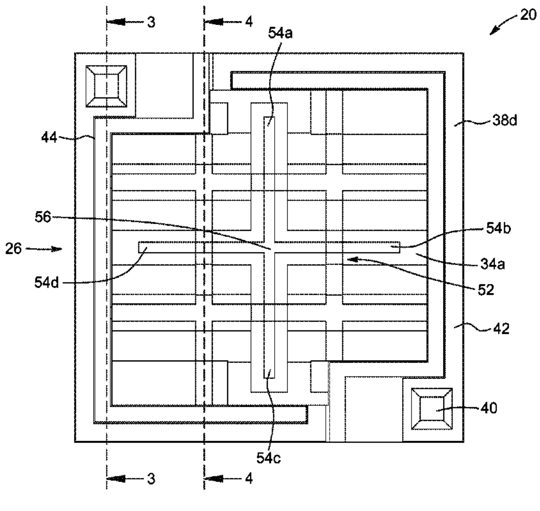
(57) ABSTRACT

An uncooled microbolometer detector that includes a substrate, a platform held above the substrate by a support structure, at least one thermistor provided on the platform, and an optical absorber. The optical absorber includes at least one electrically conductive layer extending on the platform over and in thermal contact with the at least one thermistor and patterned to form a resonant structure defining an absorption spectrum of the uncooled microbolometer detector. The optical absorber is exposed to electromagnetic radiation and absorbs the electromagnetic radiation according to the absorption spectrum. A microbolometer array including a plurality of uncooled microbolometer detectors arranged in a two-dimensional array is also provided. Advantageously, these embodiments allow extending the absorption spectrum of conventional infrared uncooled microbolometer detectors to the terahertz region of the electromagnetic spectrum.

13 Claims, 19 Drawing Sheets



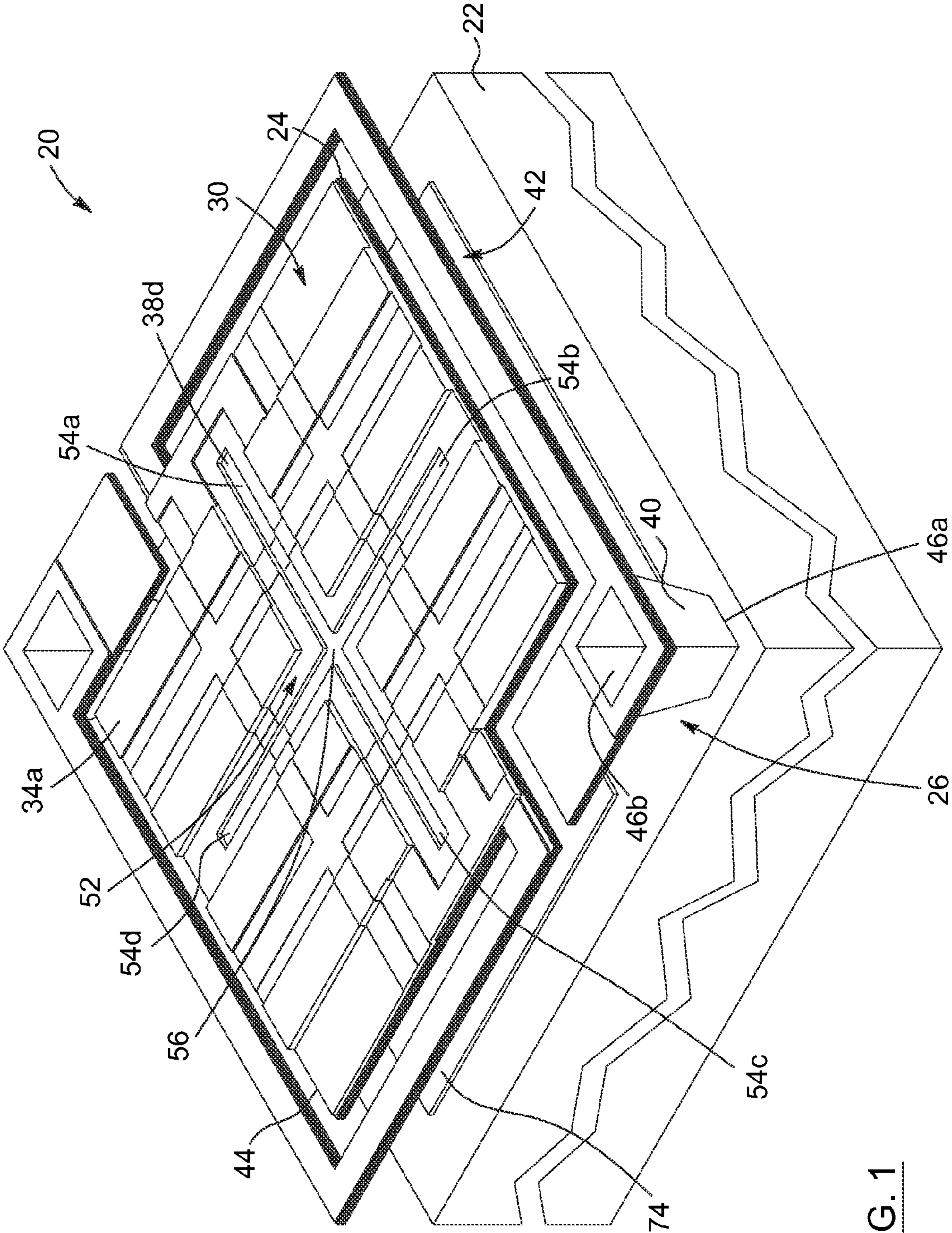


FIG. 1

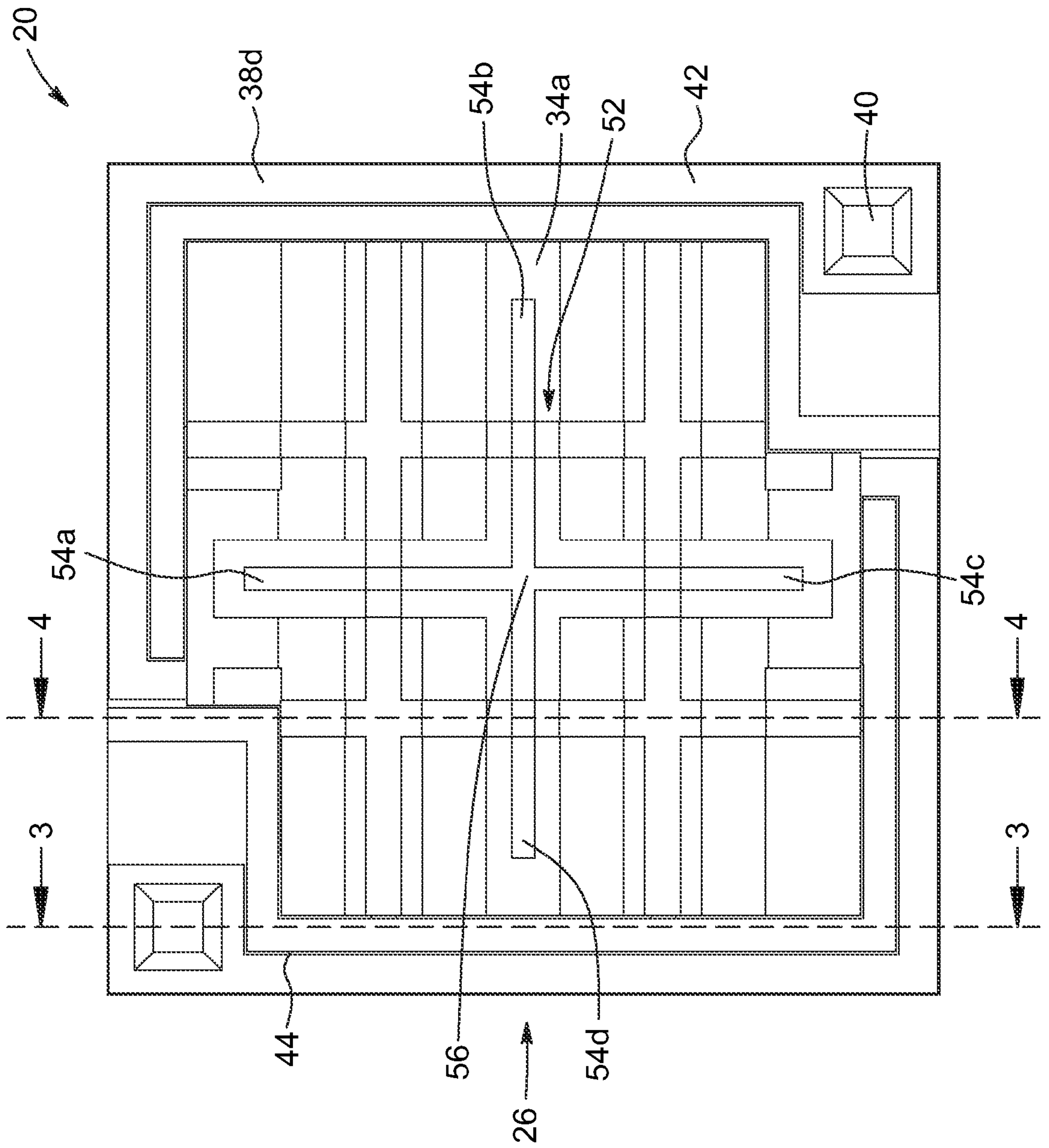


FIG. 2

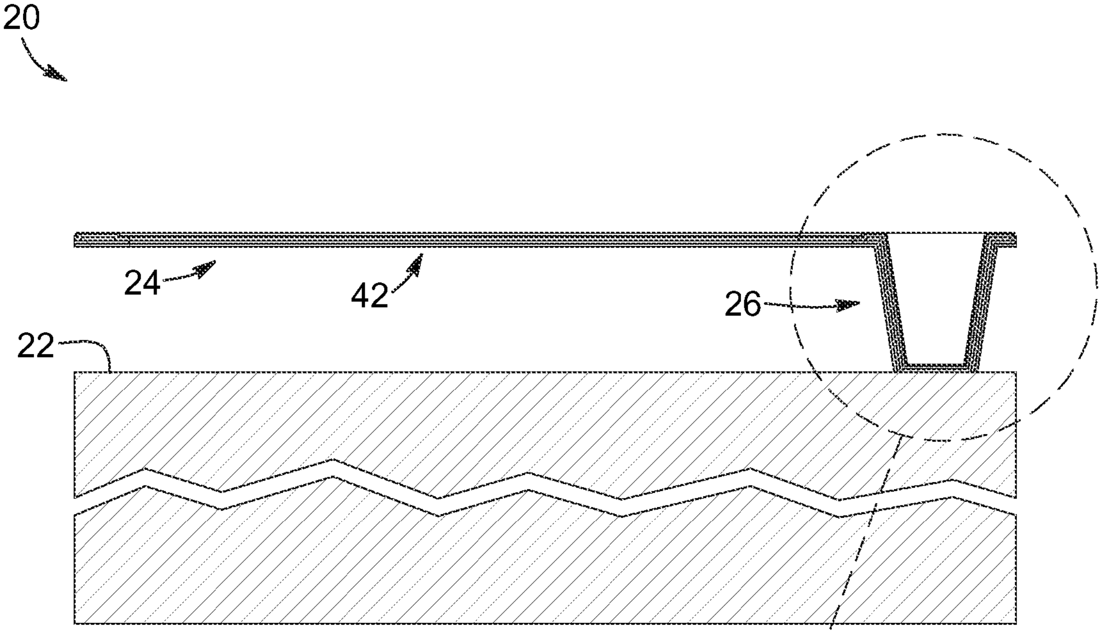


FIG. 3

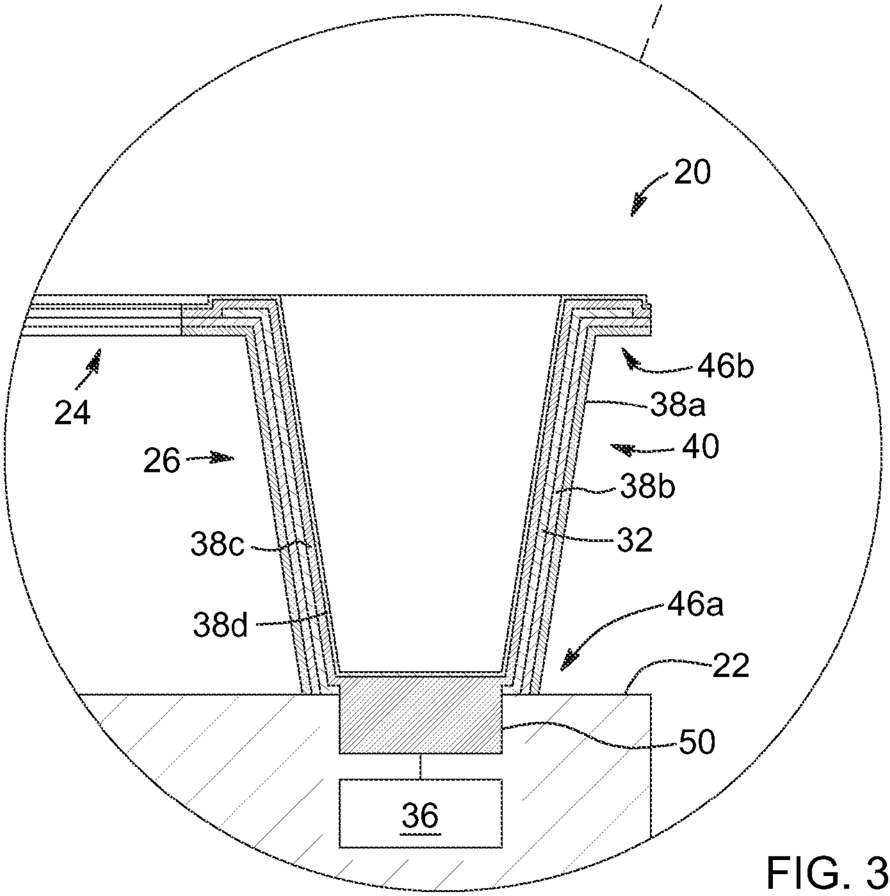


FIG. 3A

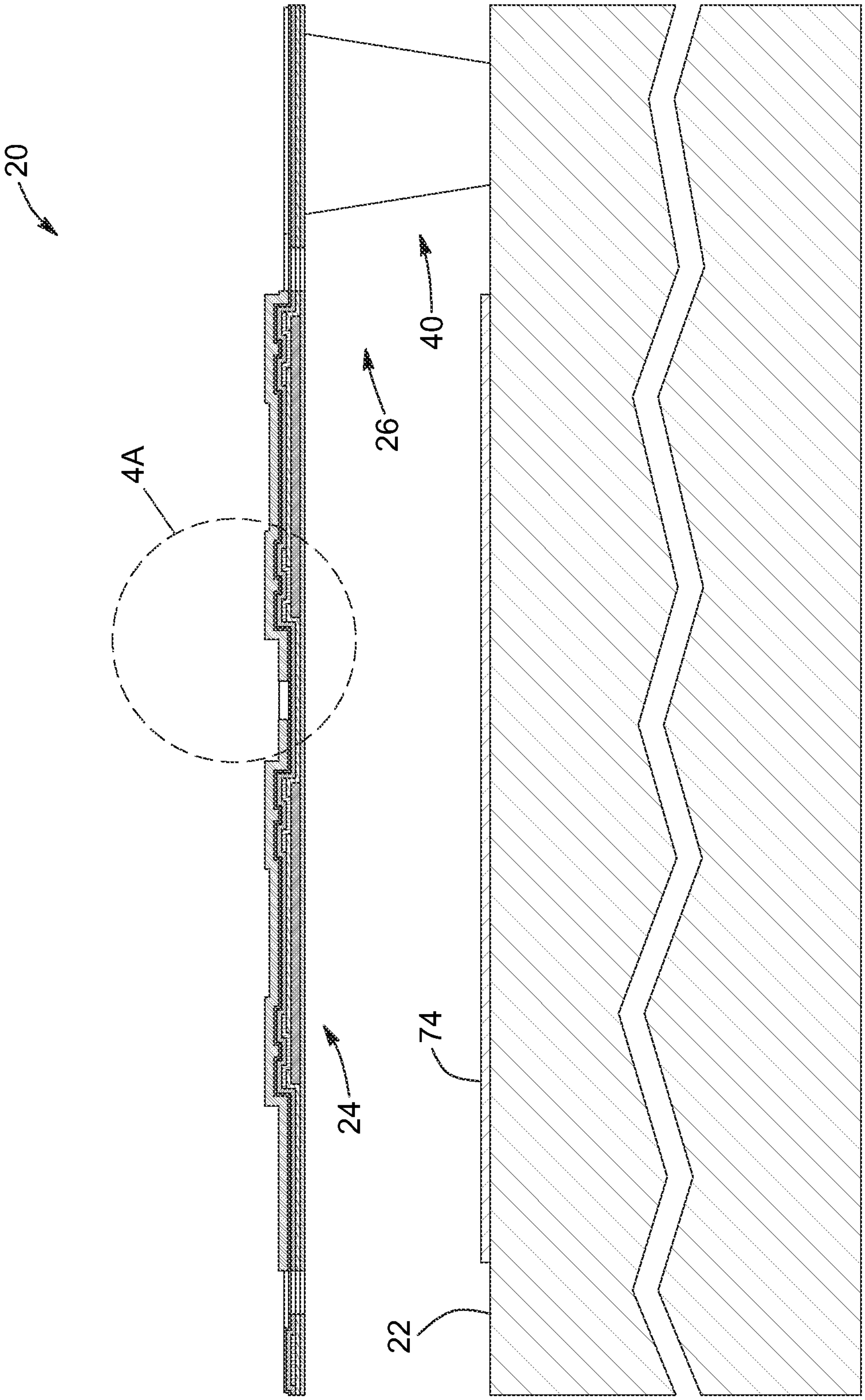


FIG. 4

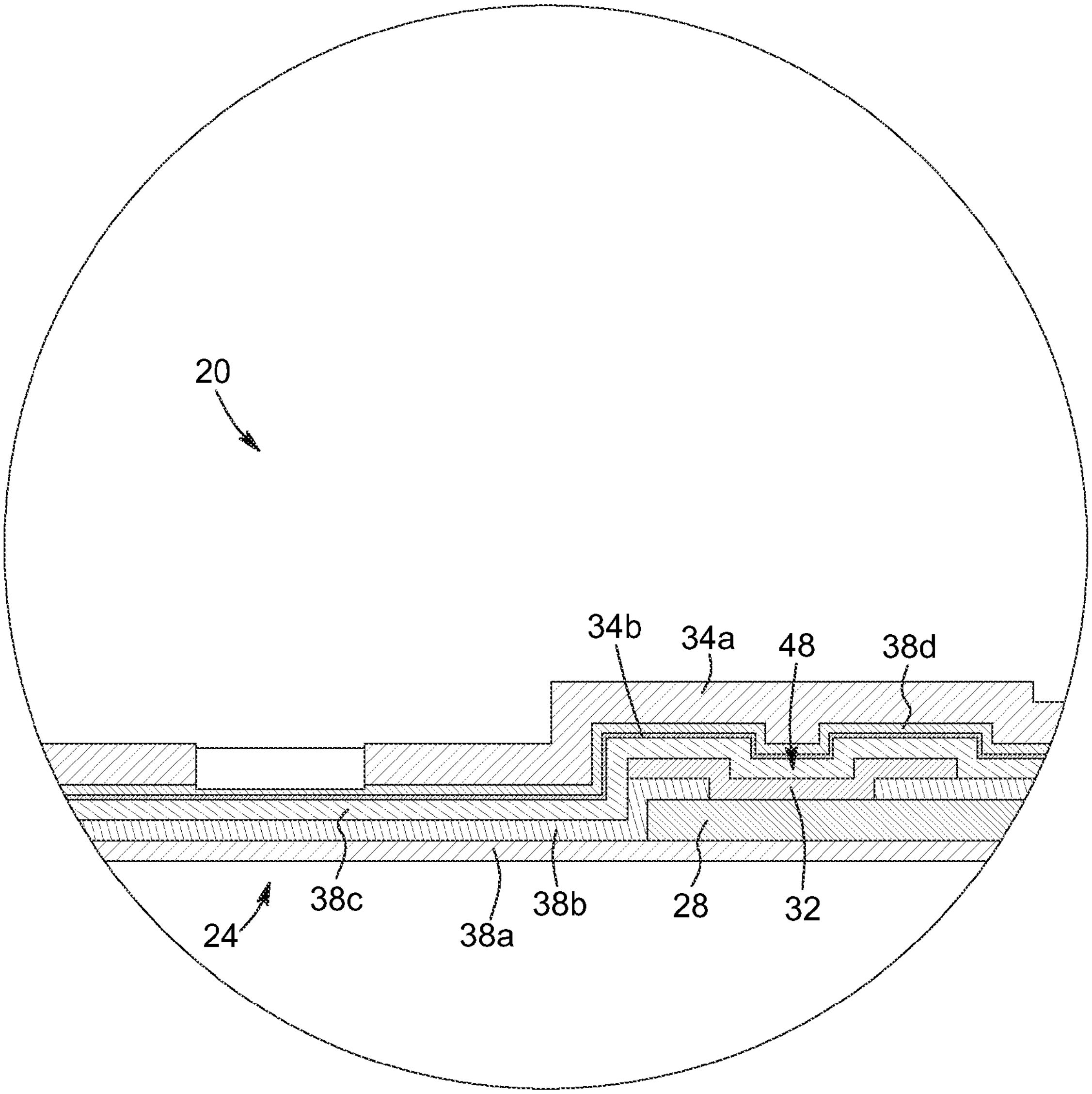
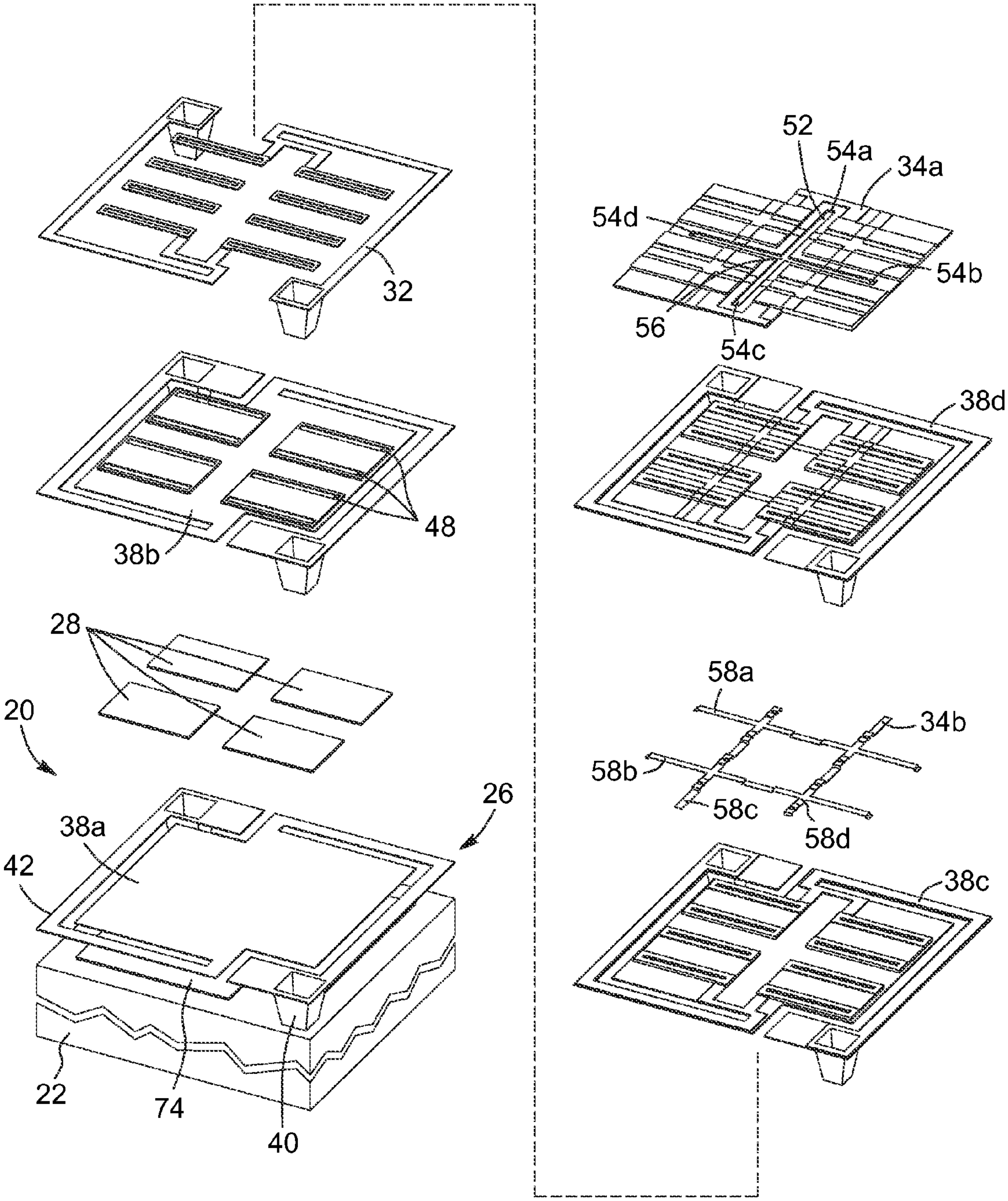


FIG. 4A



32
48
38b
28
20
26
38a
42
22
74
40
52
54a
34a
54d
54b
56
54c
38d
58a
34b
58b
58c
58d
38c

FIG. 5

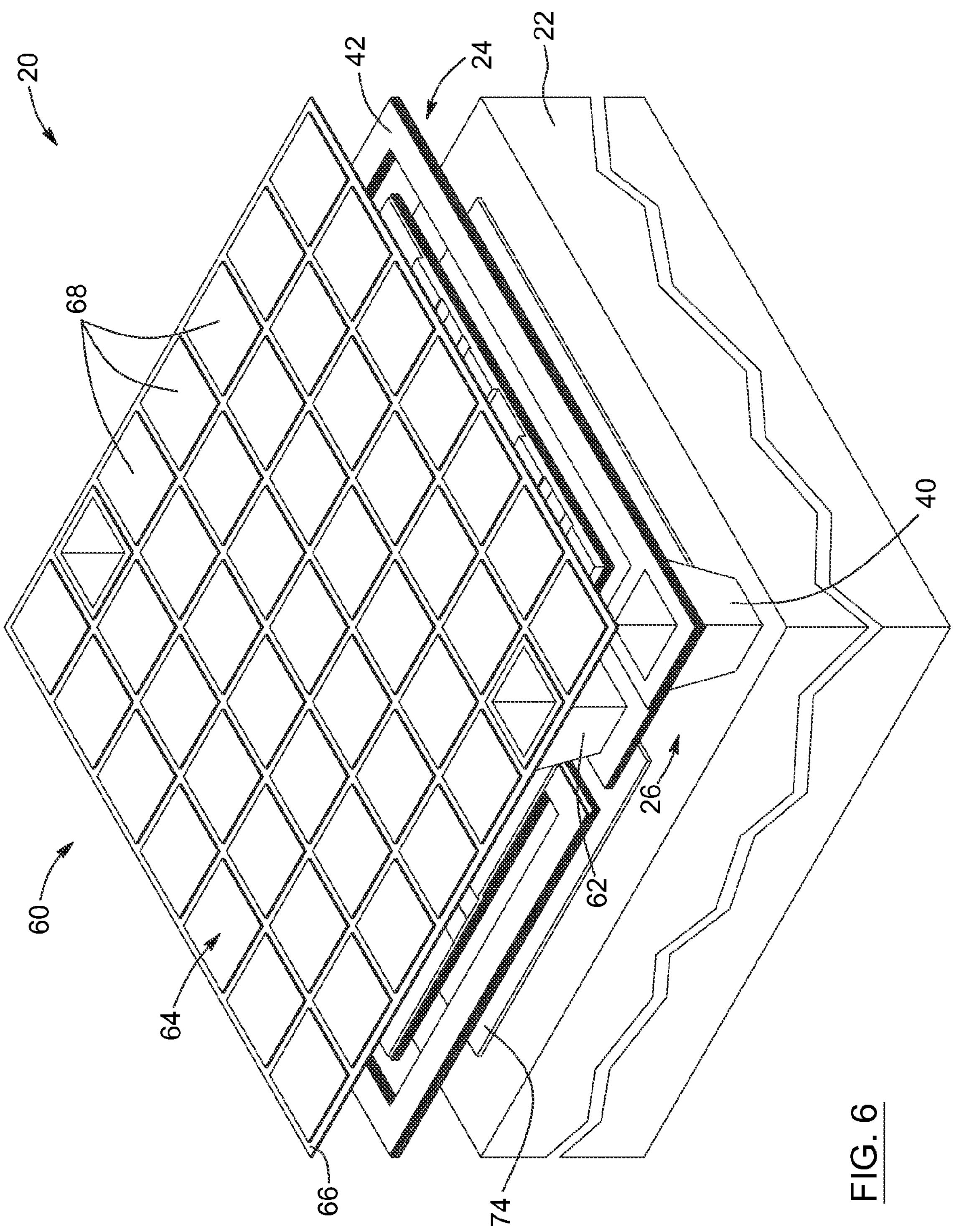


FIG. 6

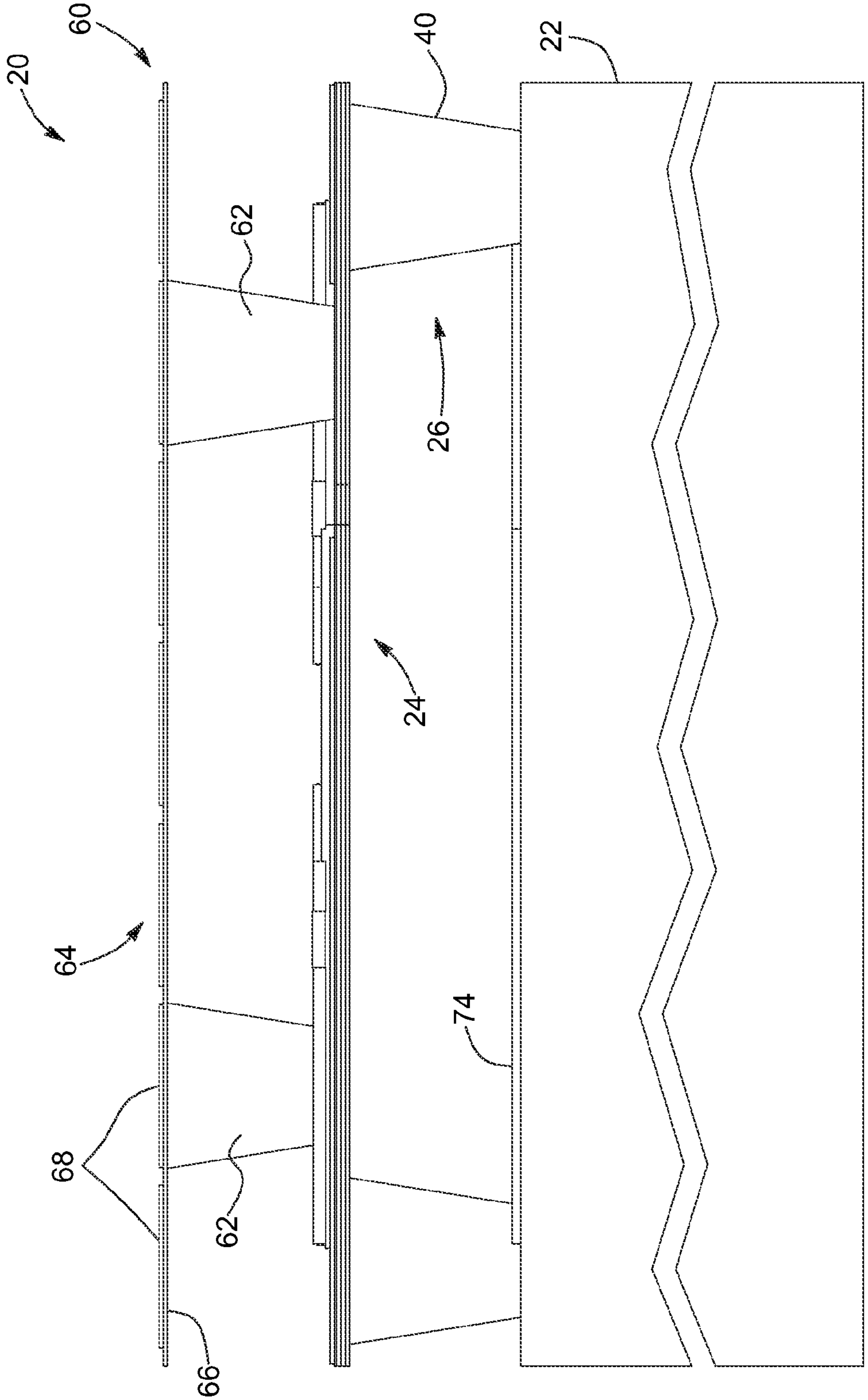


FIG. 7

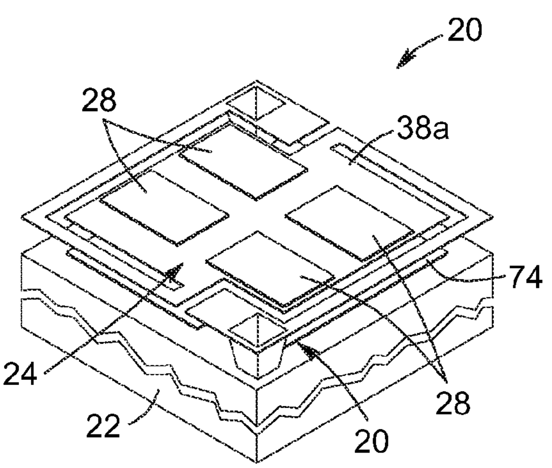


FIG. 8A

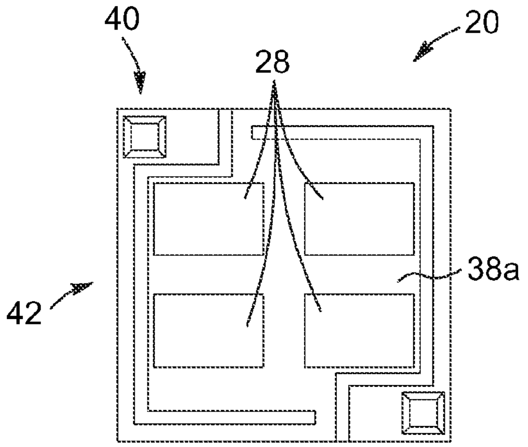


FIG. 8B

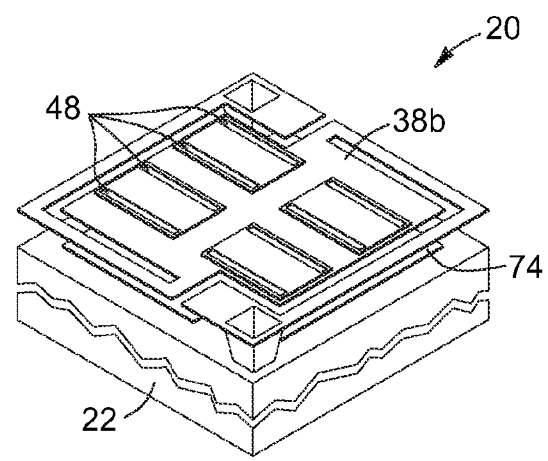


FIG. 8C

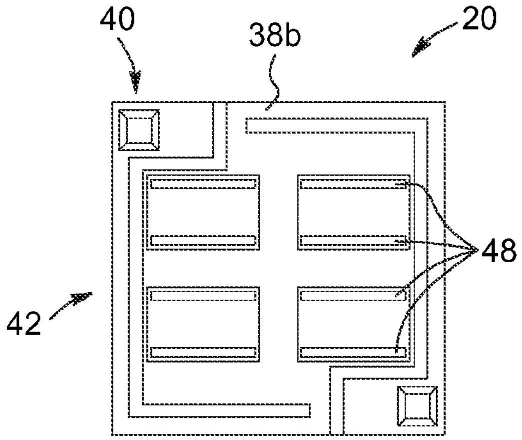


FIG. 8D

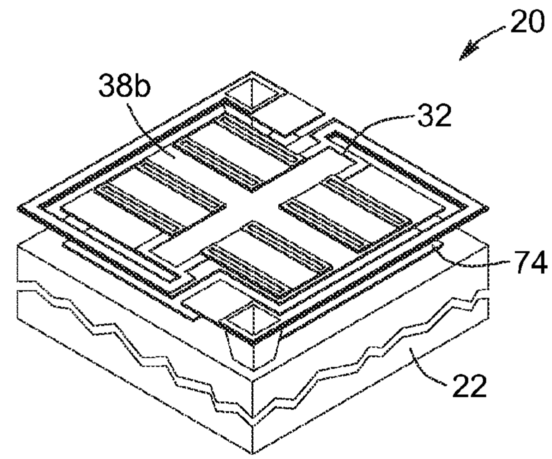


FIG. 8E

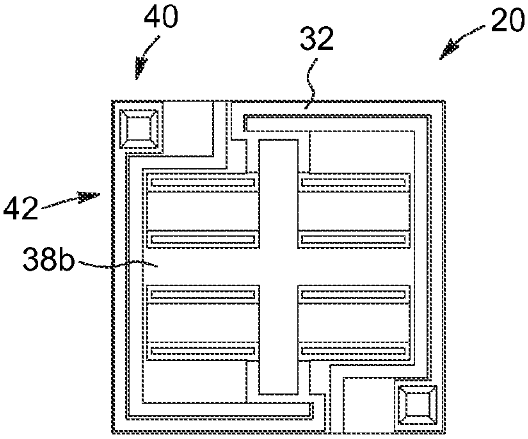


FIG. 8F

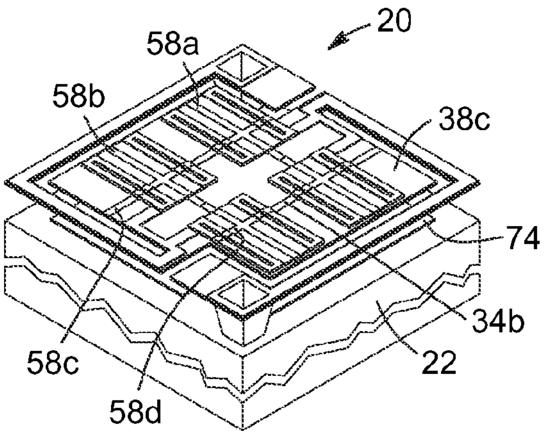


FIG. 8G

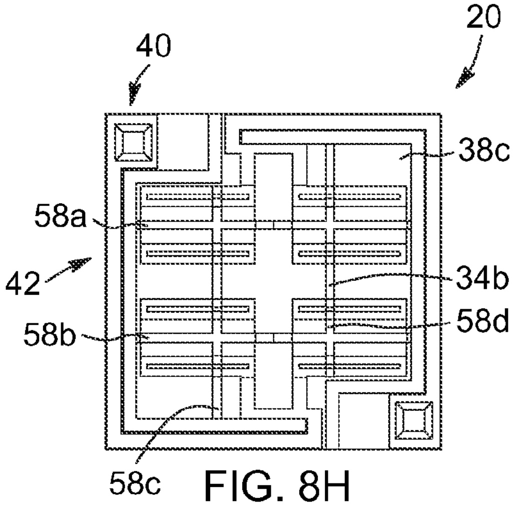


FIG. 8H

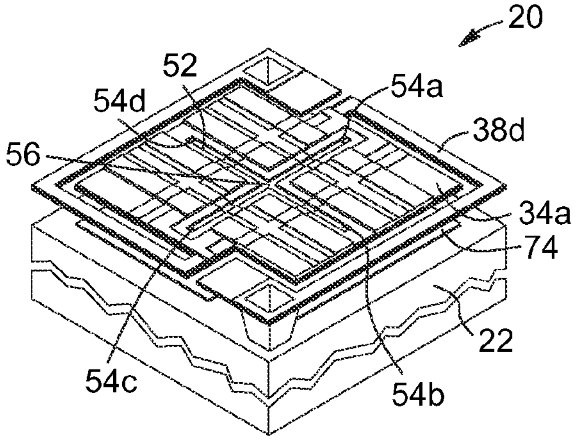


FIG. 8I

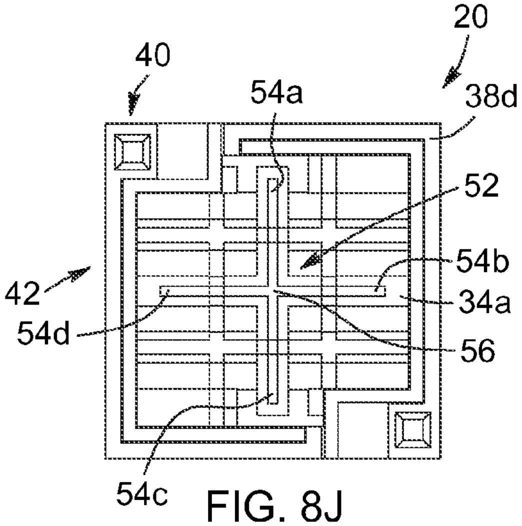


FIG. 8J

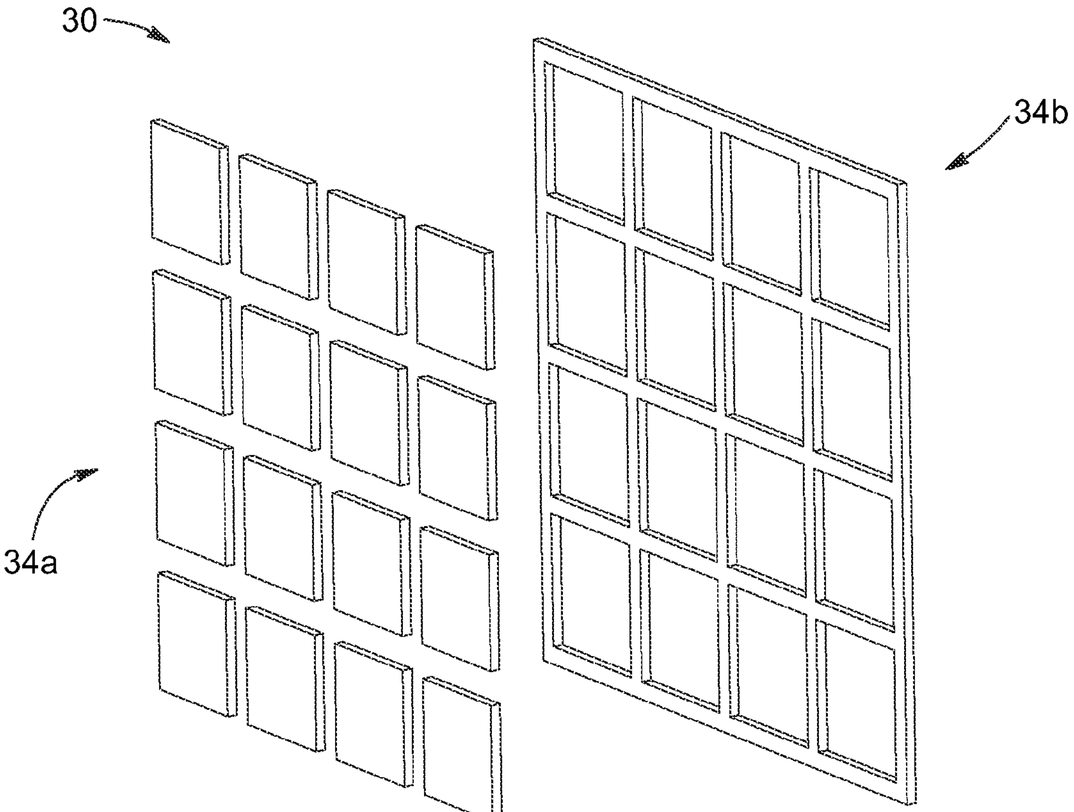


FIG. 9A

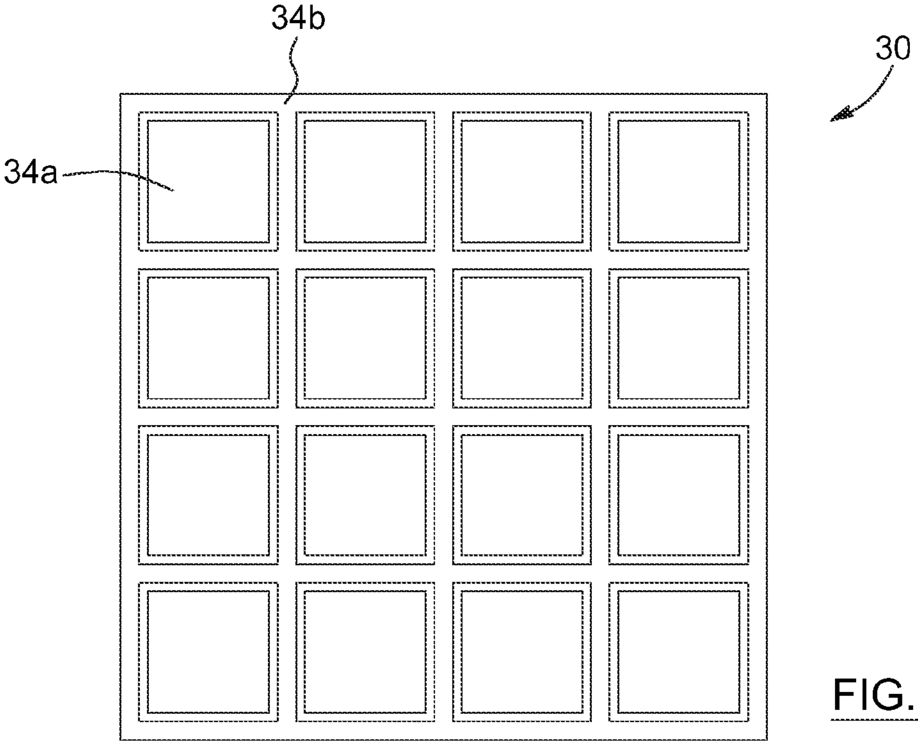


FIG. 9B

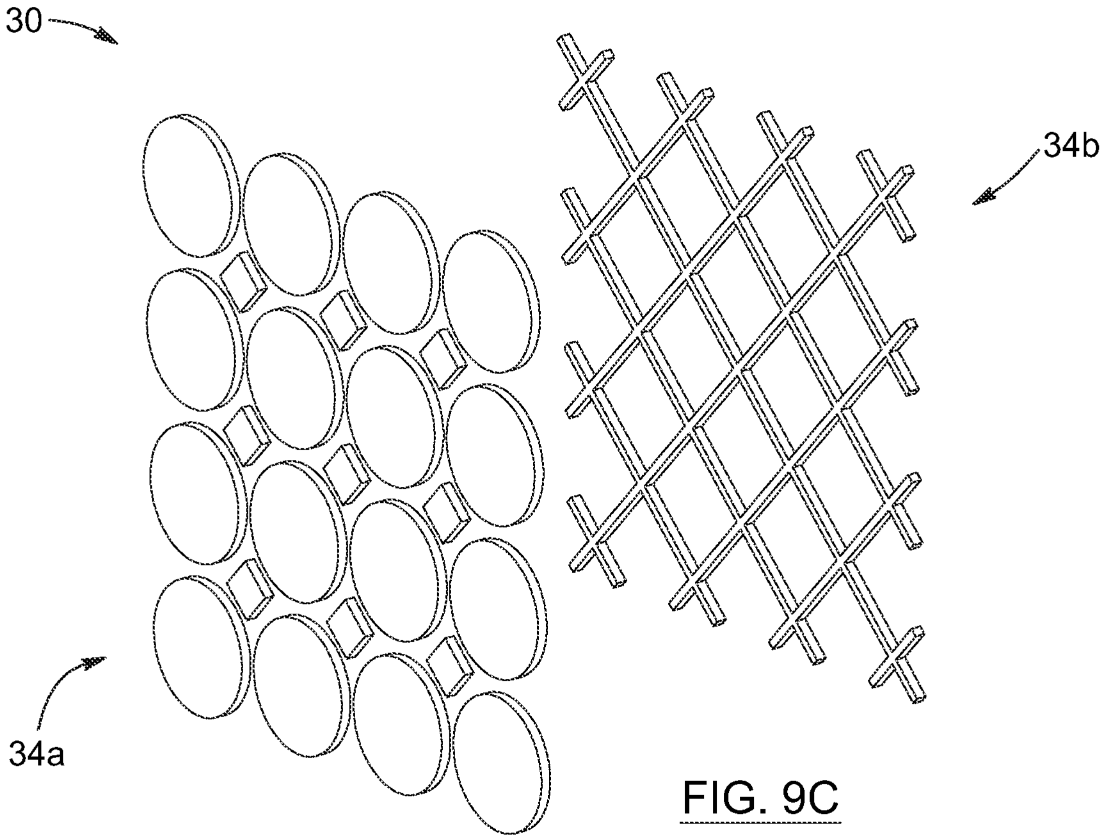


FIG. 9C

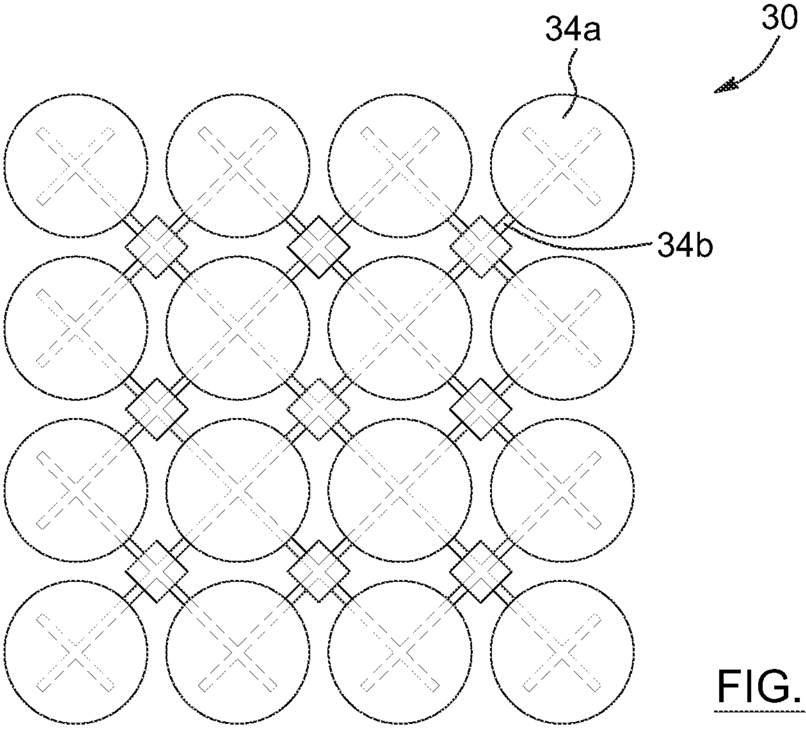


FIG. 9D

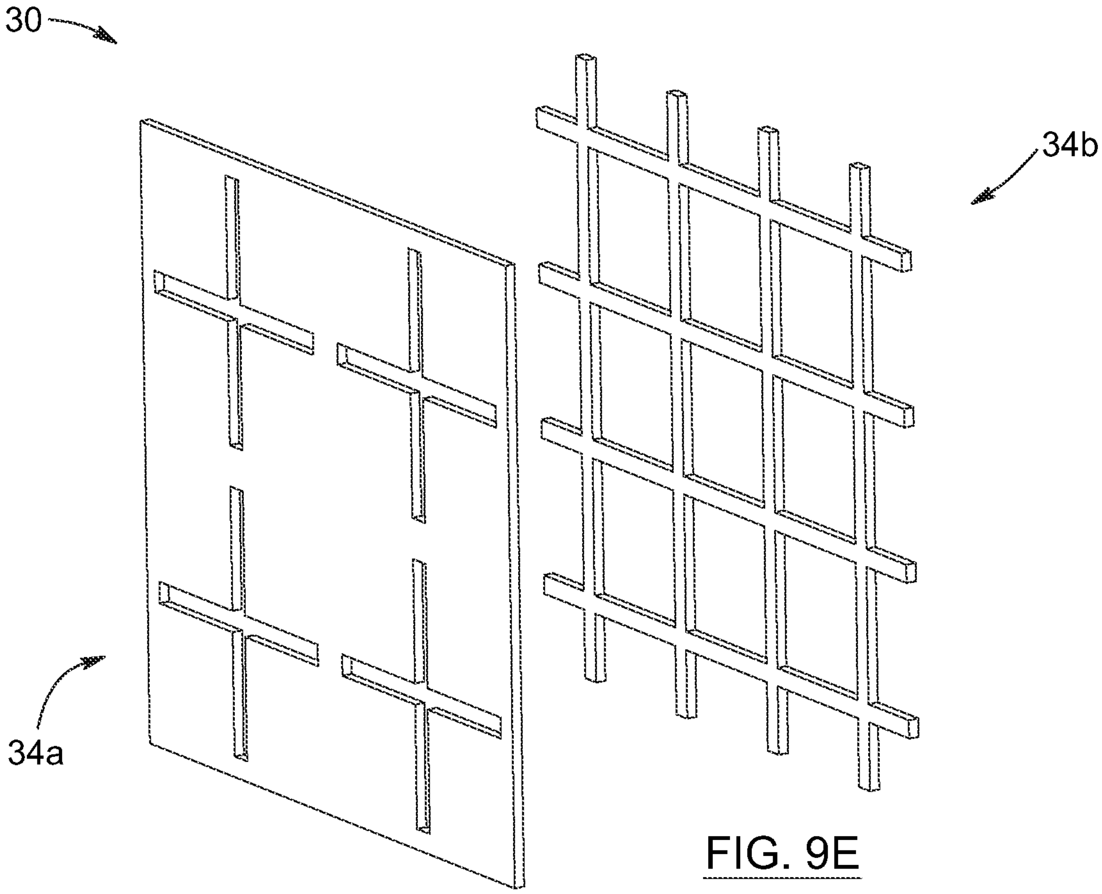
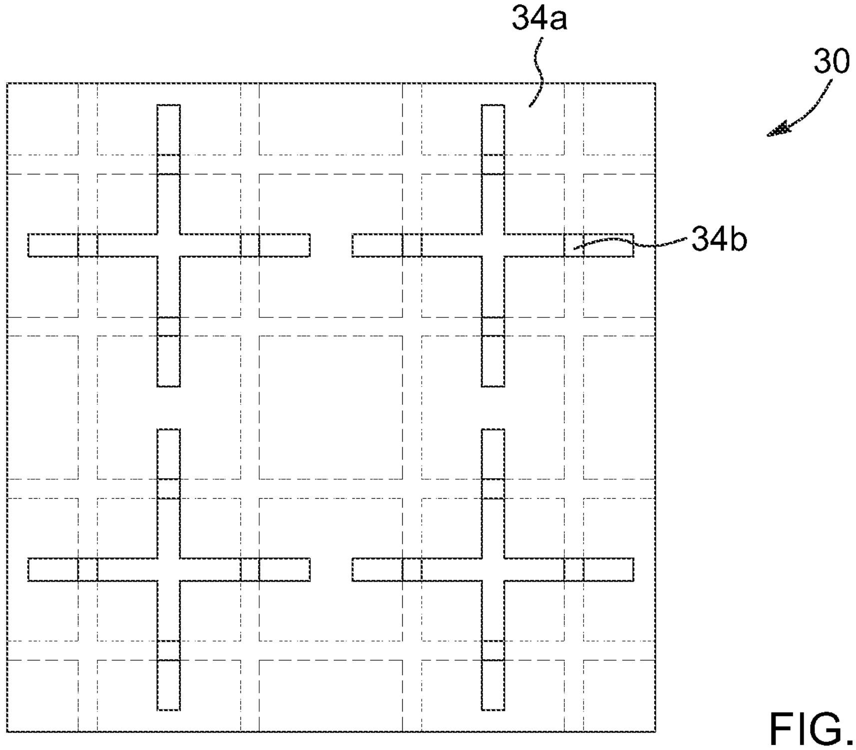


FIG. 9E



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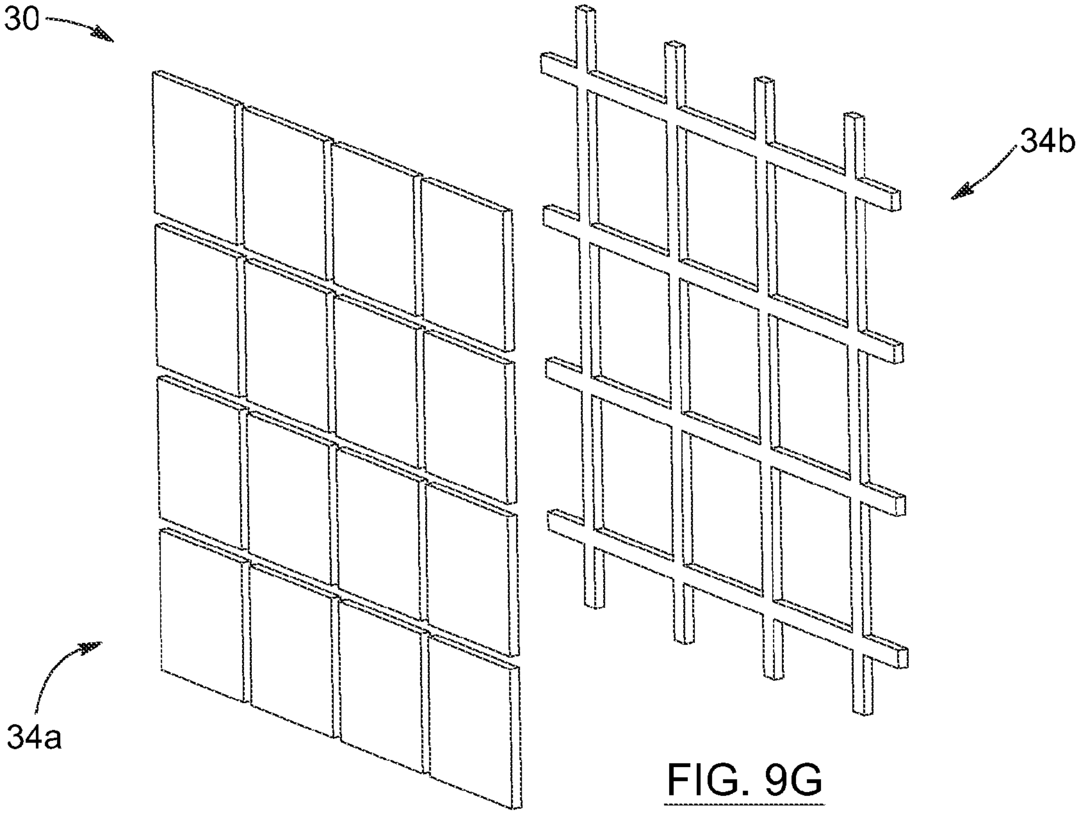

FIG. 9G

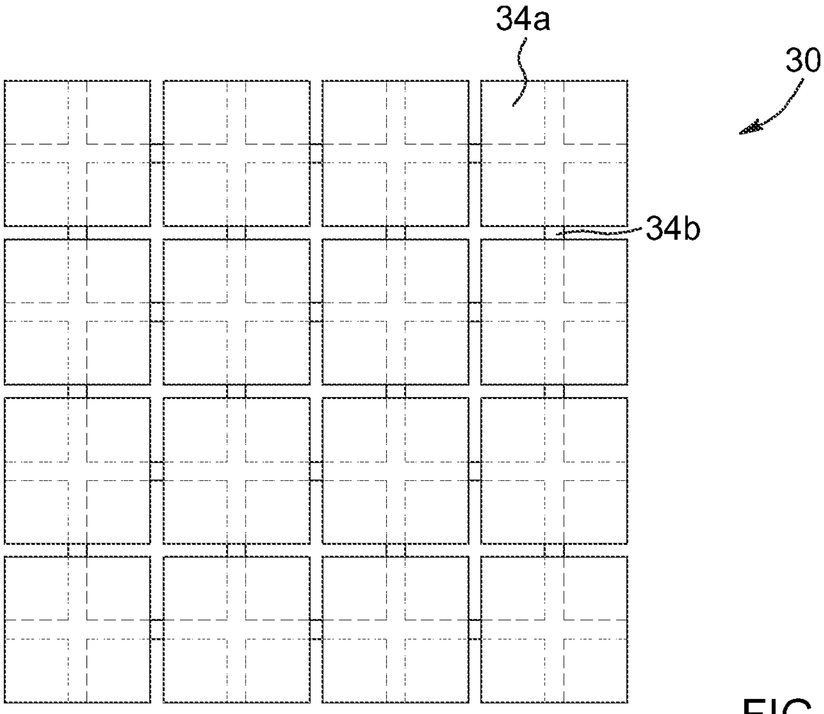

FIG. 9H

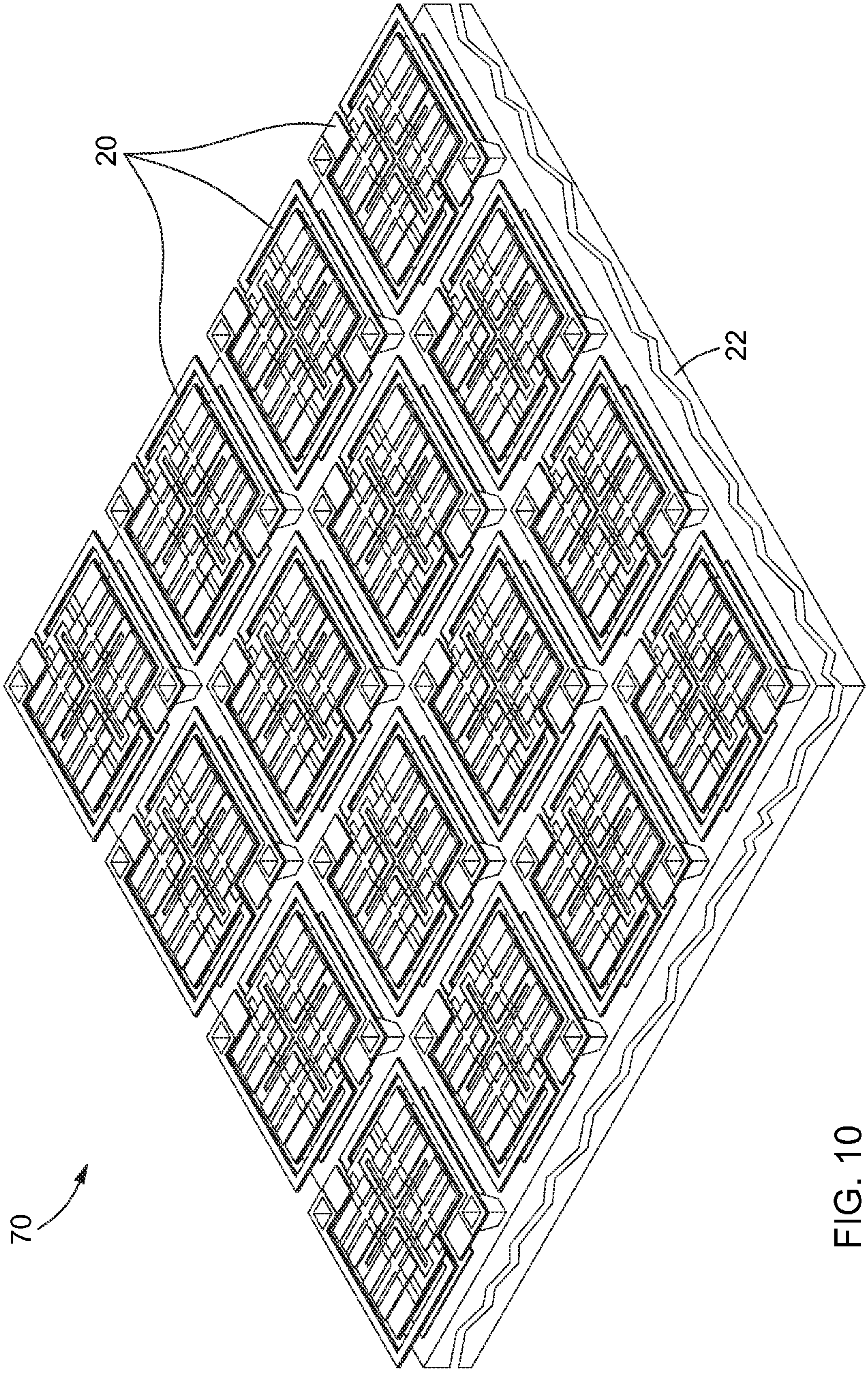

FIG. 10

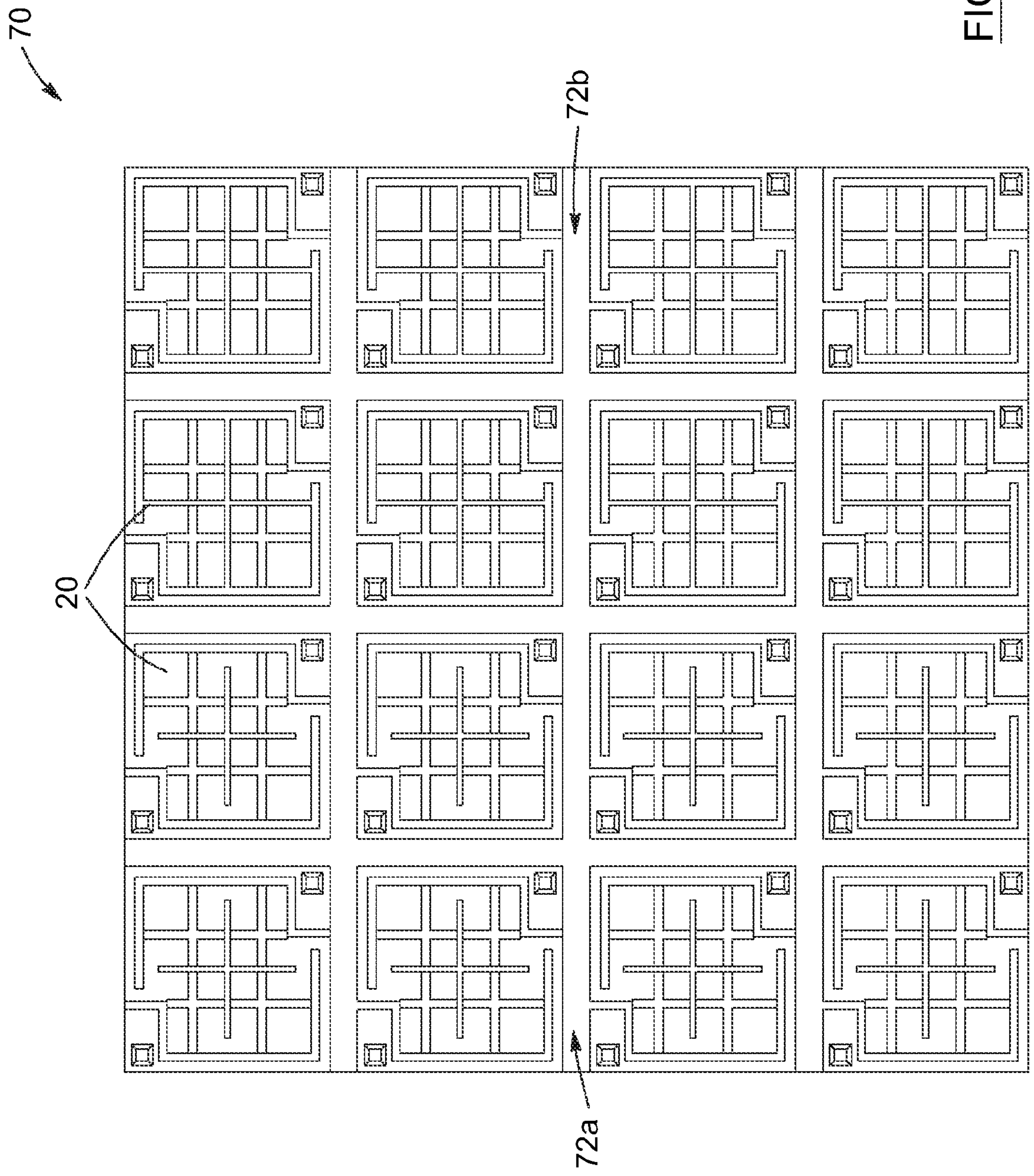

FIG. 11A

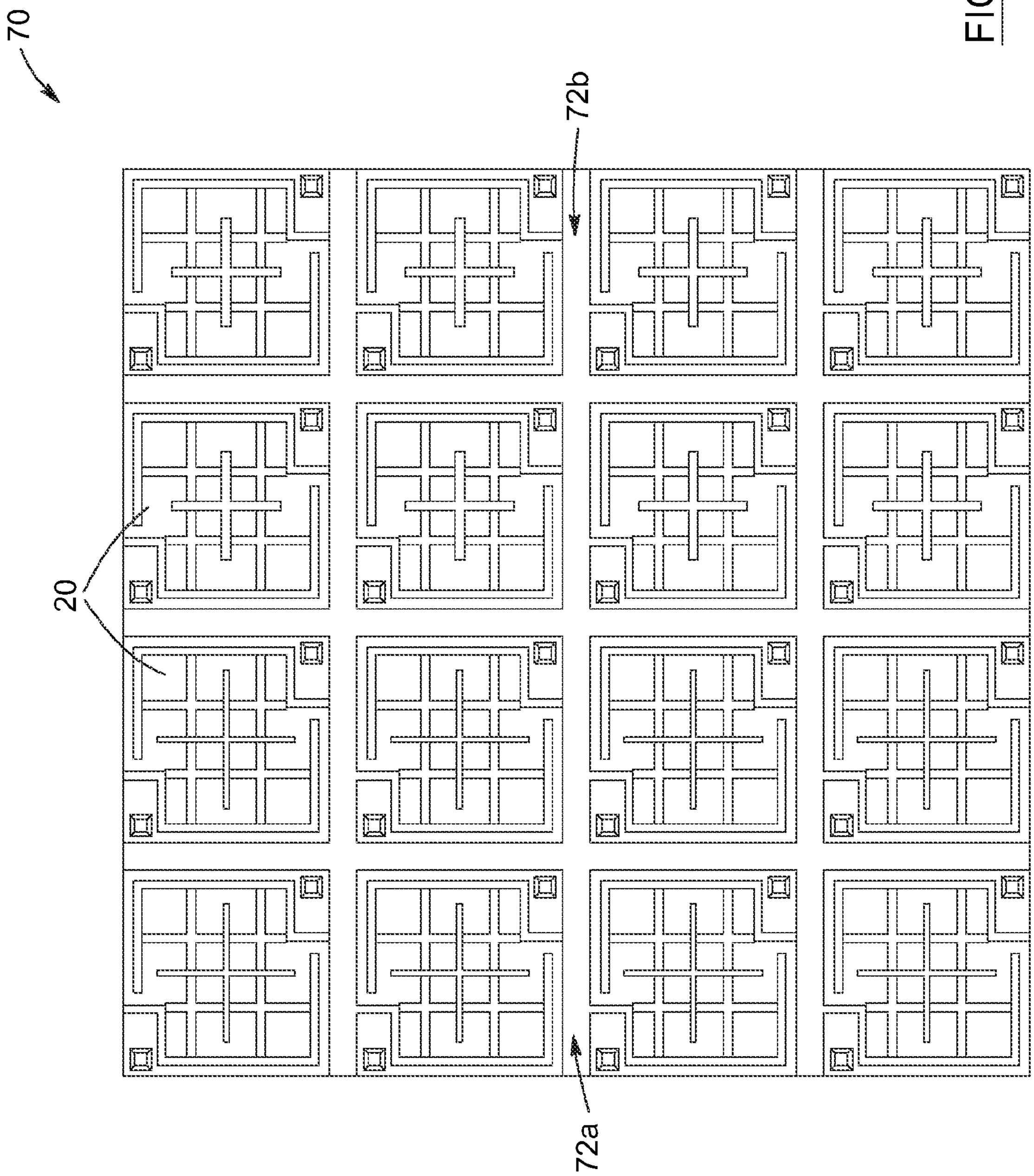

FIG. 11B

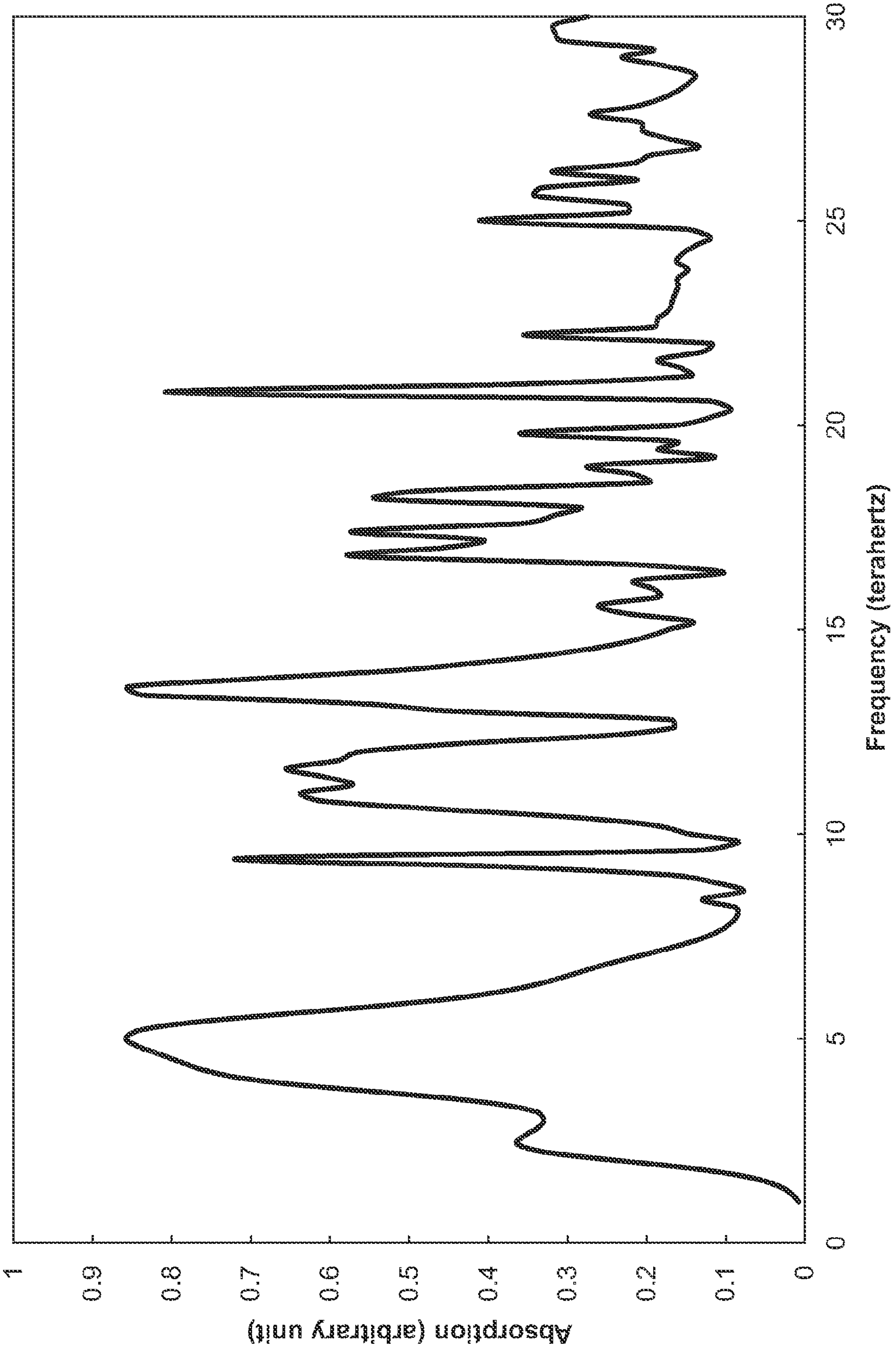
Absorption (arbitrary unit)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Frequency (terahertz)
0
5
10
15
20
25
30

FIG. 12A

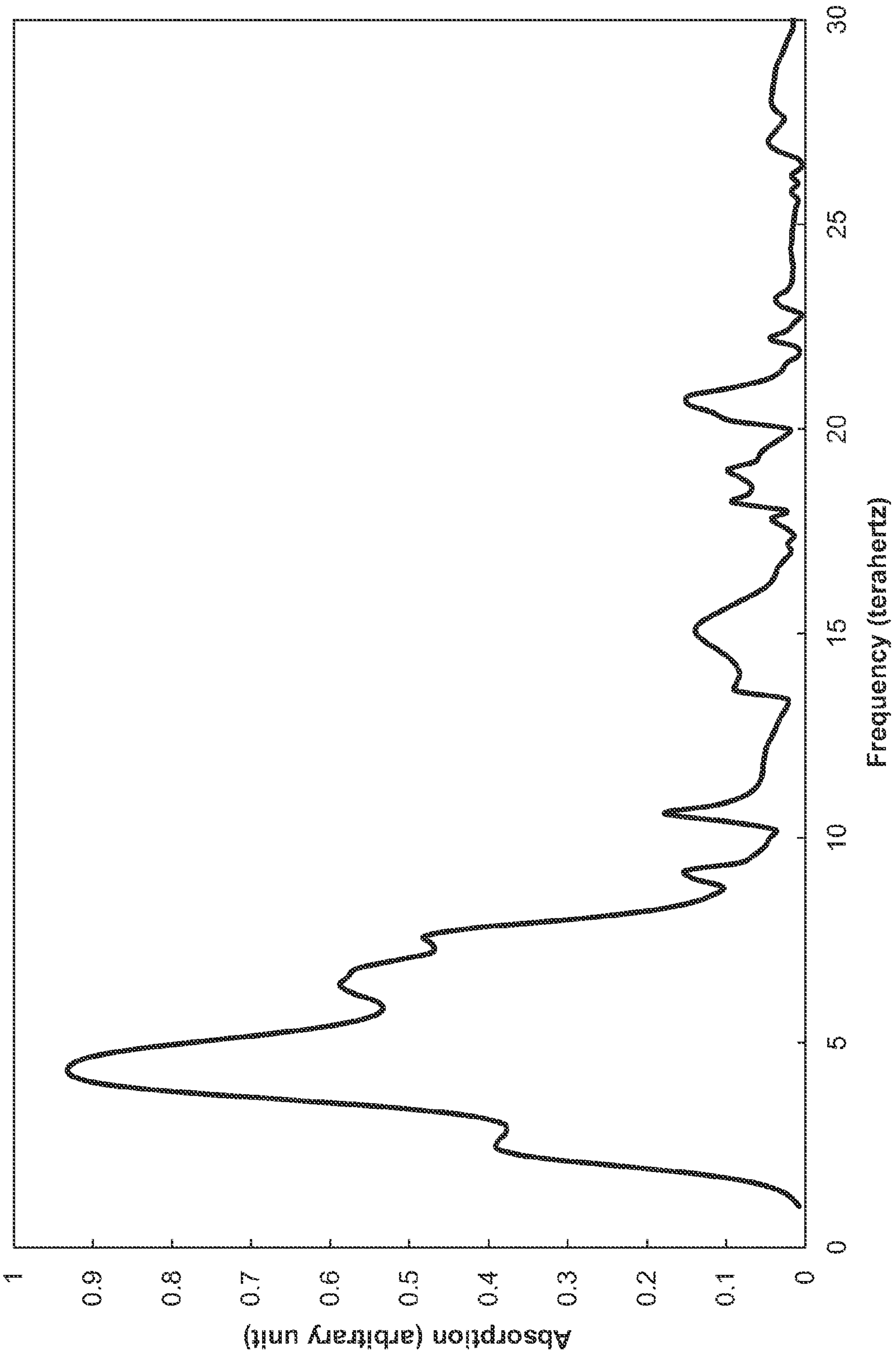
Absorption (arbitrary unit)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
Frequency (terahertz)

FIG. 12B

UNCOOLED MICROBOLOMETER DETECTOR AND ARRAY FOR TERAHERTZ DETECTION

FIELD OF THE INVENTION

The present invention relates to the field of uncooled microbolometer detectors, and more particularly concerns an uncooled microbolometer detector suitable for absorption and detection of terahertz radiation, and an array including a plurality of the same.

BACKGROUND OF THE INVENTION

Thermal detectors operate by absorbing energy from electromagnetic radiation incident thereonto and by converting the heat thus generated into an electrical signal representative of the amount of absorbed radiation. Perhaps the most prominent type of thermal detectors currently available is uncooled microbolometer detectors, usually shortened as microbolometers. A microbolometer is typically based on a suspended platform or bridge structure having a low thermal mass and on which is disposed a material having a temperature-dependent electrical resistance. The platform is generally held above and thermally insulated from a substrate by a support structure, and is provided with a thermistor, which is the resistive element whose electrical resistance changes in response to temperature variations caused by the absorbed radiation. The thermistor may, for example, be composed of a material having a high temperature coefficient of resistance (TCR) such as vanadium oxide and amorphous silicon.

Microbolometers are capable of operating at room temperature. Because they do not require cryogenic cooling, may be integrated within compact and robust devices that are often less expensive and more reliable than those based on cooled detectors.

Arrays of uncooled microbolometer detectors may be fabricated on a substrate using common integrated circuit fabrication techniques. Such arrays are often referred to as focal plane arrays (FPAs). In most current applications, arrays of uncooled microbolometers are used to sense radiation in the infrared portion of the electromagnetic spectrum, usually in the mid-wave infrared, encompassing wavelengths of between about 3 and 5 μm (micrometers), or in the long-wave infrared, encompassing wavelengths of between about 8 and 14 μm.

Such arrays are often integrated in uncooled thermal cameras for sensing incoming infrared radiation from a target scene. Each microbolometer detector of the array absorbs some infrared radiation resulting in a corresponding change in the microbolometer detector temperature, which produces a corresponding change in electrical resistance. A two-dimensional pixelated thermal image representative of the infrared radiation incident from the scene can be generated by converting the changes in electrical resistance of each microbolometer detector of the array into an electrical signal that can be displayed on a screen or stored for later viewing or processing. By way of example, state-of-the-art arrays of infrared uncooled microbolometer detectors now include 1024 by 768 pixel arrays with a 17-μm pixel pitch.

In the last decade, there has been a growing interest toward extending uncooled microbolometer spectroscopy and sensing applications beyond the traditional infrared range, namely in the far-infrared and terahertz (or sub-millimeter) spectral regions. As known in the art, these regions of the electromagnetic spectrum have long been relatively unused for industrial and technological purposes due to the lack of efficient techniques for detection and generation of radiation in this frequency range.

In this context, extending the absorption spectrum of uncooled microbolometers beyond 30 μm is not straightforward, since the materials used to fabricate the detectors absorb predominantly in the infrared, and because the pitch of terahertz-sensitive pixels is typically larger than that of infrared-sensitive pixels to avoid diffraction effects. In addition, to maximize radiation absorption in the desired spectral band, conventional infrared microbolometer detectors generally include a reflector deposited on the underlying substrate to form a quarter-wavelength Fabry-Perot optical resonant cavity with the suspended platform. However, forming such a quarter-wavelength resonant cavity is generally not practical from the point of view of surface micromachining techniques used in the microfabrication of uncooled microbolometer detecting electromagnetic radiation at wavelengths longer than 10 μm.

Therefore, there remains a need in the art for an uncooled microbolometer detector capable of absorbing electromagnetic radiation in the terahertz and far-infrared regions, while retaining at least some of the advantages of infrared detector technology in terms of cost, reliability, ease of fabrication, and maturity of the field.

SUMMARY OF THE INVENTION

According to an aspect of the invention, there is provided an uncooled microbolometer detector. The uncooled microbolometer includes:

a substrate;

a platform held above the substrate by a support structure;

at least one thermistor provided on the platform; and

an optical absorber including at least one electrically conductive layer extending on the platform over and in thermal contact with the at least one thermistor and patterned to form a resonant structure defining an absorption spectrum of the uncooled microbolometer detector, the optical absorber being exposed to electromagnetic radiation and absorbing the electromagnetic radiation according to the absorption spectrum.

In some embodiments, the at least one electrically conductive layer includes a first electrically conductive layer patterned to form a capacitive structure and a second electrically conductive layer patterned to form an inductive structure. In such embodiments, the absorption spectrum of the uncooled microbolometer detector can be controlled by adjusting the geometric properties of the pattern defined in the electrically conductive layers and the materials composing the same.

In some embodiments, the optical absorber is preferably configured to absorb the electromagnetic radiation in a wavelength range from about 30 to 3000 micrometers, corresponding to the terahertz region of the electromagnetic spectrum.

In some embodiments, the uncooled microbolometer detector further includes a spectral filter supported above the platform in a spaced relationship therewith. In such embodiments, the spectral filter is configured to pre-filter the electromagnetic radiation before the electromagnetic radiation impinges onto the optical absorber. In some embodiments, the spectral filter comprises a low-pass filter, preferably a capacitive structure, which prevents electromagnetic radiation with frequencies above a certain cutoff frequency from reaching the optical absorber.

According to another aspect of the invention, there is provided a microbolometer array including a plurality of uncooled microbolometer detectors as described above, wherein the plurality of uncooled microbolometer detectors is arranged in a two-dimensional array.

In some embodiments, the plurality of uncooled microbolometer detectors is divided in a number of subsets of uncooled microbolometer detectors, the absorption spectrum of the uncooled microbolometer detectors of each subset being different from one another.

Other features and advantages of the present invention will be better understood upon reading of preferred embodiments thereof with reference to the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic perspective view of an uncooled microbolometer detector in accordance with an embodiment of the invention.

FIG. **2** is a top plan view of the uncooled microbolometer detector shown in FIG. **1**.

FIG. **3** is a cross-sectional view of the uncooled microbolometer detector shown in FIG. **1**, taken along section line **3**. FIG. **3**A is an enlargement of portion **3**A of FIG. **3**.

FIG. **4** is a cross-sectional view of the uncooled microbolometer detector shown in FIG. **1**, taken along section line **4**. FIG. **4**A is an enlargement of portion **4**A of FIG. **4**.

FIG. **5** is a partially exploded perspective view of the uncooled microbolometer detector shown in FIG. **1**.

FIG. **6** is a schematic perspective view of an uncooled microbolometer detector including a spectral filter supported above the platform, in accordance with an embodiment of the invention.

FIG. **7** is a side elevation view of the uncooled microbolometer detector shown in FIG. **6**.

FIGS. **8**A, **8**C, **8**E, **8**G and **8**I are schematic perspective views of the uncooled microbolometer detector shown in FIG. **1**, wherein one or more overlying components of the uncooled microbolometer detector are removed therefrom in order to better illustrate the underlying components. FIGS. **8**B, **8**D, **8**F, **8**H and **8**J are top plan views of FIGS. **8**A, **8**C, **8**E, **8**G and **8**I, respectively.

FIGS. **9**A to **9**H are schematic perspective (FIGS. **9**A, **9**C, **9**E and **9**G) and top plan (FIGS. **9**B, **9**D, **9**F and **9**H) views of various capacitive and inductive structures that can be patterned in the first and second electrically conductive layer of the optical absorber of the uncooled microbolometer detector in accordance with embodiments of the invention.

FIG. **10** is a schematic perspective view of a microbolometer array including a plurality of uncooled microbolometer detectors arranged in a two-dimensional array, in accordance with an embodiment of the invention.

FIGS. **11**A and **11**B are schematic top views of a microbolometer array in accordance with another embodiment of the invention, wherein the plurality of uncooled microbolometer detectors is divided in a number of subsets of uncooled microbolometer detectors, the absorption spectrum of the uncooled microbolometer detectors of each subset being different from one another.

FIGS. **12**A and **12**B are theoretical absorption spectra plotted as a function of frequency in the terahertz region for the uncooled microbolometer detector shown in FIG. **1** (FIG. **12**A without a spectral filter) and in FIG. **6** (FIG. **12**B with a spectral filter).

DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

In the following description, similar features in the drawings have been given similar reference numerals and in order to weigh down the figures, some elements may not be referred to on some figures if they were already identified in preceding figures. It should also be understood herein that the elements of the drawings are not necessarily drawn to scale and that the emphasis is instead being placed upon clearly illustrating the elements and structures of the present embodiments.

Embodiments of the present invention generally relate to an uncooled microbolometer detector including an optical absorber extending on a suspended platform structure and having an absorption spectrum that defines the absorption spectrum of the overall detector. The optical absorber may advantageously be optimized for detecting radiation in the terahertz (THz) region of the electromagnetic spectrum, while being disposed on a platform structure that is similar to that of conventional uncooled infrared microbolometer detectors.

Embodiments of the present invention also relate to an array including a plurality of such uncooled microbolometer detectors.

Uncooled Microbolometer Detector

According to an aspect of the invention, there is provided an uncooled microbolometer detector, an embodiment of which is shown in FIGS. **1** to **5** and **8**. It is to be noted that, for the sake of simplicity, the expression "uncooled microbolometer detector" may in some instances be shortened to "uncooled microbolometer", "microbolometer detector" or simply "microbolometer".

Broadly described, the uncooled microbolometer detector **20** includes a substrate **22**, a platform **24** held above the substrate **22** by a support structure **26**, at least one thermistor **28** provided on the platform **24** and an optical absorber **30**. Optionally, the microbolometer detector **20** may include an electrically conductive path **32** electrically connecting each thermistor **28** to electrical traces patterned on the substrate **22**. The optical absorber **30** includes at least one electrically conductive layer **34***a* and **34***b* extending on the platform **24** over and in thermal contact with the at least one thermistor **28**. The electrically conductive layers **34***a* and **34***b* are patterned, preferably according to the geometry of the platform **24**, to form a resonant structure defining an absorption spectrum of the uncooled microbolometer detector **20**, the optical absorber **30** being exposed to electromagnetic radiation and absorbing the electromagnetic radiation according to the absorption spectrum. As further explained below, adjusting the number, pattern geometry and materials properties of the electrically conductive layers **34***a* and **34***b* allows tailoring the profile and spectral position of the absorption spectrum of the uncooled microbolometer detector **20** so as to absorb at specific wavelengths of radiation, for example in the terahertz region.

Throughout the present description, the term "microbolometer" is understood to refer to an uncooled thermal radiation detector that operates by absorbing incident electromagnetic radiation and converting the absorbed radiation into heat. The microbolometer generally includes at least one thermistor, which is a resistive element whose electrical resistance changes in response to temperature variations caused by the absorbed radiation. This physical property is used to measure the energy or power carried by the radiation incident on the microbolometer. The microbolometer is generally thermally insulated from the substrate or surroundings to allow the absorbed incident radiation to generate a temperature change in the thermistor while being substantially unaffected by the temperature of the substrate. Microbolometers are generally fabricated on the substrate using integrated circuit fabrication techniques and have applications, among other fields, in night vision, thermal imaging, remote sensing, spectroscopy, and radiation detection.

As used herein, the term "uncooled" is intended to refer to microbolometer detectors that operate at or near ambient temperature, without any type of cryogenic cooling system.

As for most commonly known microbolometer structures, the microbolometer detector according to embodiments of the invention may be fabricated using conventional surface micromachining and photolithographic techniques. For example, in some embodiments, the microbolometer detector may be fabricated using a monolithic integration approach, wherein the substrate of the microbolometer detector, preferably provided with an electrical readout integrated circuitry (ROIC), is pre-manufactured using standard complementary metal-oxide-semiconductor (CMOS) processes. More particularly, it is an advantage of embodiments of the present invention to provide uncooled microbolometer detectors whose absorption spectrum selectively absorbs radiation having wavelengths longer than the wavelengths of infrared radiation but whose fabrication process is carried out using techniques similar to those of common use for manufacturing infrared microbolometers.

In such embodiments, the platform, the support, the thermistors and the optical absorber of the uncooled microbolometer detector may successively be deposited and patterned on the substrate using common thin-film deposition techniques paired with selective photoresist and sacrificial layer etching processes. However, it will be understood that the uncooled microbolometer detector according to embodiments of the invention may be fabricated using other manufacturing techniques, for example bulk micromachining, without departing from the scope of the invention.

In this regard, FIGS. **8**A to **8**J illustrate an embodiment of the uncooled microbolometer detector **20** wherein one or more overlying components thereof are removed in order to better illustrate the underlying components. It will be noted that FIGS. **8**A to **8**J may correspond to the uncooled microbolometer detector **20** at different steps of the fabrication process thereof.

Substrate

Still referring to FIGS. **1** to **5** and **8**, the uncooled microbolometer detector **20** first includes a substrate **22**. The substrate **22** may be made of silicon (Si), silicon carbide (SiC), gallium arsenide (GaAs), germanium (Ge) or any other suitable substrate material that may, but need not, support integration of semiconductor devices.

As mentioned above, the substrate **22** may be provided with an electrical readout integrated circuitry **36** (see, e.g., FIG. **3**A), which may be embodied, for example, by one or more CMOS circuitry layers formed on or in the substrate **22** according to conventional CMOS processes. Alternatively, the electrical readout integrated circuitry **36** may be provided external to the substrate **22**. Moreover, the substrate **22** may be a multilayered structure made of several dielectric, semiconductor and metallic layers including, but not limited to, a radiation reflecting layer, one or more protective dielectric layers, and electrical contacts for electrical connection with the electrical readout integrated circuitry **36**.

Platform and Support Structure

As illustrated in FIGS. **1** to **5** and **8**, the uncooled microbolometer detector **20** also includes a platform **24** held above the substrate **22** by a support structure **26**.

As used herein, the term "platform" generally refers to a substantially planar and rigid structure or membrane supported by the support structure and generally having greater horizontal dimensions than vertical thickness. In this regard, it will be readily understood that throughout the present description, the terms "vertical" and "vertically" refer to a direction perpendicular to a plane parallel to the conventional plane or surface of the substrate. Likewise, the terms "horizontal" and "horizontally" are used to refer to directions lying in a plane which is perpendicular to the vertical direction as just defined. Both terms are not meant to refer to a particular orientation of the uncooled microbolometer detector.

The platform **24** preferably provides thermal isolation to each thermistor **28** by minimizing heat transfer through thermal conduction. The platform **24** may be shaped as a substantially rectangular single or multilayer thin film, which preferably includes electrically insulating and low-stress materials. Suitable materials for inclusion in the platform **24** include, without limitation, silicon nitride and silicon dioxide. In some embodiments, the platform **24** may have horizontal dimensions selected between about 10 and 1000 μm, and it may have a vertical thickness selected in the range of about 0.1 to 1 μm.

The platform **24** may generally be formed on top of a sacrificial layer (not shown), which may be deposited on the substrate **22** during the fabrication process of the uncooled microbolometer detector **20** and be subsequently patterned, selectively etched and sacrificially removed, for example in an oxygen plasma.

As best seen in FIG. **4**A, in the illustrated embodiment the platform **24** preferably includes four vertically stacked dielectric layers **38*a*** to **38*d***. These four dielectric layers **38*a*** to **38*d*** provide mechanical rigidity and a physical separation between the at least one thermistor **28**, the electrically conductive path **32**, and each electrically conductive layer **34*a*** and **34*b*** of the optical absorber **30**, each of which will be described in further detail hereinbelow. However, it will be understood that depending on the intended application of the uncooled microbolometer detector **20**, the platform **24** may take a variety of shapes, dimensions and configurations without departing from the scope of the invention.

It is to be noted that, in contrast to common uncooled infrared microbolometer detectors whose absorption waveband is determined essentially by the infrared absorption properties of the material making up the platform (e.g. silicon nitride), in embodiments of the invention, the absorption spectrum of the microbolometer detector **20** is defined by that of the optical absorber **30**, as described hereinbelow. As a result, the platform **24** is primarily intended for supporting and providing thermal isolation to the one or more thermistors **28**, and need not, but could, be made of an optically absorbing material optimized for absorption in a specific wavelength range of interest.

The term "support structure" as used herein refers broadly to a structure that holds and mechanically supports the platform of the uncooled microbolometer detector in a spaced relationship above the substrate.

It may be advantageous for the support structure **26** to provide enough mechanical rigidity and strength for maintaining the platform **24** of the microbolometer detector **20** at a height of between about 1 and 10 μm from the substrate **22**. It will also be understood that, in addition to providing mechanical support and thermal isolation, the support structure **26** may also provide electrical connection of each thermistor **28** and to the substrate **22**, as discussed hereinbelow.

Referring more particularly to FIGS. **3** and **3**A, the support structure **26** generally includes posts **40** and arms **42**. As used herein, the term "post" refers generally to a structural element of the support structure that extends mainly vertically along a height thereof from the substrate. In particular, the height of each post essentially defines the spacing between the platform and the substrate. In contrast, the term "support arm" refers broadly to a structural element of the support structure that extends mainly horizontally.

As for the platform **24**, the support structure **26** is preferably made of a low-stress and self-supporting material, for example silicon nitride or silicon dioxide, which may be provided in the form of one or more thin-film layers, and having for example a thickness of about 0.1 to 1 μm. The support structure **26** is generally fabricated concurrently with the platform **24**, such that the support structure **26** and platform **24** may share one or more material layers. As better illustrated in FIG. **3**A, the four dielectric layers **38***a* to **38***d* of the platform **24** extends outwardly and downwardly therefrom to form the outermost layers **38***a* and **38***b* and innermost layers **38***c* and **38***d* of the posts **40** and support arms **42** that sandwich a portion of the electrically conductive path **32** that provides an electrical link between each thermistor **28** and the substrate **22**.

In the illustrated embodiment, the support structure **26** is generally disposed along an outer perimeter **44** of the platform **24**. The support structure **26** includes two posts **40** connected to and projecting substantially vertically from the substrate **22**. Each post **40** includes a proximal end **46***a* connected to the substrate **22** and a distal end **46***b* terminating near the outer perimeter of the platform **24** and connected to the support arms **42**.

However, one of ordinary skill in the art will understand that the general configuration and disposition of the support structure **26** should not be construed so as to limit the scope of the present invention. For example, in order to meet the thermal, mechanical and electrical constraints of various applications, each post **40** of the support structure **26** may have a variety of lengths and cross-section shapes and dimensions, which are all considered being within the scope of the present invention. Similarly, the support structure **26** need not be provided outwardly of the platform **24** but may be disposed completely or partially underneath the platform **24**, such as the support structure shown in U.S. patent application Ser. No. 13/632,577 entitled "Microbolometer detector with centrally-located support structure". In arrays of uncooled microbolometer detectors, such configurations may provide a higher fill factor for optical absorption while simultaneously mitigating diffraction effects. In addition, depending on the specific application involved, both single-level and multiple-level platform configurations are possible. Furthermore, the support arms **42** need not be straight, but may also include transverse sections and be arranged according to meandering or serpentine configurations. Such geometric patterns allow increasing the effective length of support arms **42** and hence the thermal isolation they provide to the platform **24** and to the at least one thermistor **28** provided thereon.

Thermistors

Still referring to FIGS. **1** to **5** and **8**, the microbolometer detector **20** also includes at least one thermistor **28** provided on the platform **24**.

As used throughout the present description, the term "thermistor" generally refers to an uncooled thermally sensitive resistor and is meant to encompass any suitable material, structure or device having an electrical resistance that changes as a function of its temperature, preferably in a predictable and controllable manner.

Each thermistor **28** may be made of a material having a high TCR near room temperature, preferably of at least 0.5% per kelvin, including but not limited to a vanadium oxide material, an amorphous silicon material and a titanium oxide material. However, it will be understood that the composition of each thermistor **28** is not limited to those cited above. Any material or combination of materials having a suitable TCR is considered to be encompassed within the scope of the present invention.

In the illustrated embodiment, the uncooled microbolometer detector **20** includes four thermistors **28** disposed between first and second dielectric layers **38***a* and **38***b* of the platform **24**. Moreover, each thermistor **28** is embodied by a thin film element having a substantially rectangular shape with a width, length and thickness which may be selected according to a desired electrical resistance of the corresponding thermistor **28**. Of course, each thermistor **28** may have various shapes and sizes and may be disposed on the platform according to various configurations without departing from the scope of the invention.

The at least one thermistor **28** of the microbolometer detector **20** may be deposited onto the platform **24** using common deposition techniques such as evaporation, sputtering, spin coating or any other appropriate thin-film transfer technique. Likewise, the size, shape and disposition of each thermistor **28** may be subsequently delineated by means of various selective wet and dry etching techniques combined with photolithographic processes.

Electrically Conductive Path

Still referring to FIGS. **1** to **5** and **8**, and as briefly discussed above, the uncooled microbolometer detector **20** preferably includes an electrically conductive path **32** electrically connecting each thermistor **28** provided on the platform **24** to the substrate **22**.

As shown in the illustrated embodiment, the electrically conductive path **32** preferably establishes electrical contact with the thermistors **28** via contact openings **48** (see, e.g., FIGS. **4**A, **5**, **8**C and **8**D) defined in the second dielectric layer **38***b* and extends along the support arms **42** and posts **40** down to the substrate **22**. As mentioned above, the substrate may include an electrical readout integrated circuitry **36** (see, e.g., FIG. **3**A) electrically connected to the electrically conductive path **32**, for example by means of via openings **50** lithographically defined at the bottom of each post **40** during the fabrication process of the uncooled microbolometer detector **20**.

The electrically conductive path **32** may be deposited and delineated using known microfabrication techniques and may be made of any material having a suitable electrical conductivity including, without limitation, gold, aluminum, titanium, copper, silver, tungsten, chrome and vanadium. It will be understood that the width and thickness of the electrically conductive path **32** along the length thereof may be adjusted to procure a thermal conductance and an electrical resistance that optimize the performance of the uncooled microbolometer detector **20**. In the illustrated embodiment (see FIGS. **3**A and **4**A), a third dielectric layer **38***c* of the platform is preferably deposited over the electrically conductive path **32** for protecting the same. It will also be understood that, in embodiments provided with more than one thermistor **28**, it may be possible to adjust the equivalent resistance of the plurality of thermistors **28** by connecting the plurality of thermistors **28** in one of a series, parallel and series-parallel circuit schemes.

Optical Absorber

Referring back to FIGS. **1** to **5** and **8**, the uncooled microbolometer detector **20** also includes an optical absorber **30** exposed to and absorbing electromagnetic radiation incident onto the uncooled microbolometer detector **20**.

As used herein, the term "optical absorber" is intended to refer to a material or structure that can, upon exposure to certain wavelengths of electromagnetic radiation, absorb electromagnetic energy (i.e. photons) from the incident wave and convert the same into thermal energy. The term "optical" used herein refers generally to the electromagnetic spectrum and is not limited to the visible or to another portion of the electromagnetic spectrum.

The optical absorber **30** includes at least one electrically conductive layer **34***a* and **34***b* extending on the platform **24** over and in thermal contact with the thermistors **28**. In the illustrated embodiment, the optical absorber **30** preferably includes first and second electrically conductive layers **34***a* and **34***b*. However, in other embodiments, the optical absorber may alternatively include only one or more than two electrically conductive layers without departing from the scope of the invention, as discussed in further detail below.

As used herein, the term "electrically conductive layer" is intended to refer a layer, a film or a coating applied in any suitable manner so as to extend on the platform over the at least one thermistor, such that each layer includes an electrically conductive material. The one or more electrically conductive layers **34***a* and **34***b* may for instance be a metal, including a metal alloy, a semiconductor material (either doped or undoped), or any appropriate electrically conductive material. It will be understood that by virtue of their inherent electrical conductivity, the electrically conductive layers **34***a* and **34***b* of the optical absorber **30** behave as lossy inductive and capacitive elements that can convert the incident electromagnetic radiation into thermal energy via resonance effect.

As used herein, the term "thermal contact" generally means that heat conduction occurs directly or indirectly between two components, that is, the two components may be in direct contact with each other or may have a sufficiently thermally conducting material provided between them. More specifically, the term "thermal contact" is intended to refer to the fact that when the optical absorber **30** is heated upon absorption of electromagnetic radiation, the heat generated thereby is conducted or transmitted to each thermistor **28**.

It will also be understood that the term "over" in specifying the spatial relationship of the optical absorber **30** relative to the thermistors **28** denotes that the optical absorber **30** is either in direct contact with or separated by one or more intervening layers from the upper surface of the thermistors **28**. For example, in the embodiment of FIGS. **1** to **5** and **8**, the optical absorber **30** and the four thermistors **28** are separated from each other by the second dielectric layer **38***b*, the electrically conductive path **32** and the third dielectric layer **38***c*.

The electrically conductive layers **34***a* and **34***b* are patterned to form a resonant structure defining an absorption spectrum of the uncooled microbolometer detector **20** such that upon exposure to electromagnetic radiation, the optical absorber **30** absorbs the electromagnetic radiation according to the absorption spectrum.

As used herein, the term "pattern" is intended to refer to a geometric arrangement or configuration of one or more features formed, inscribed or otherwise defined in each electrically conductive layer **34***a* and **34***b*. The features may be lines, squares, circles, grids, crosses or any other shapes, or combinations thereof (see FIGS. **9**A to **9**H). The features may be delineated in the electrically conductive layers **34***a* and **34***b* by any appropriate etching, patterning or deposition processes, or combinations thereof. Moreover, it will be understood that the term "pattern" may, but need not, be a regular or predictable arrangement but may include irregular arrangements as long as the resulting pattern form a resonant structure that define the absorption spectrum of the uncooled microbolometer detector **20**.

As used herein, the term "resonant structure" is intended to refer to a structure which provides resonance conditions for the absorption of electromagnetic radiation in one or more wavelength bands. In other words, the resonant structure is designed in a manner such that electromagnetic radiation within one or more specific wavelength bands is selectively absorbed while any electromagnetic radiation of wavelength out of the one or more bands is reflected by or transmitted through the resonant structure.

The resonant structure has an absorption spectrum that defines the absorption spectrum of the uncooled microbolometer detector as a whole. Throughout the present description, the term "absorption spectrum" is intended to refer to a spectrum of electromagnetic energy over a range of wavelengths whose intensity at each wavelength corresponds to a measure of the fraction of electromagnetic radiation that is absorbed by the optical absorber of the uncooled microbolometer detector. The absorption spectrum may include one or more absorption bands within which electromagnetic radiation is predominantly absorbed. Each absorption band may exhibit one or more absorption peaks, each peak corresponding to a resonance wavelength of the resonant structure. In embodiments of the invention, the absorption spectrum generally depends on the geometry of the pattern forming the resonant structure and on the materials properties, the spacing of the electrically conductive layers, and also on the height of the Fabry-Perot cavity formed between the platform and the substrate of the uncooled microbolometer detector.

Referring to FIGS. **1** to **5** and **8**, in some embodiments, the geometric and material parameters of the optical absorber **30** may be optimized for detecting radiation in the terahertz region of the electromagnetic spectrum, while advantageously being provided on a microbolometer detector **20** having a substrate **22**, a platform **24**, a support structure **26** and thermistors **28** that are similar to those of conventional infrared microbolometer detectors. As used herein the term "terahertz radiation" refers to electromagnetic radiation having wavelengths in a range between about 30 μm and 3000 μm, corresponding to frequencies ranging from approximately 0.1 THz to 10 THz.

However, while particularly useful for terahertz applications, one of ordinary skill in the art will understand that embodiments of the invention could additionally or alternatively be used in other regions of the electromagnetic spectrum, for example in the infrared and visible regions, without departing from the scope of the invention. It will be understood that as the wavelength of the electromagnetic radiation detected by the microbolometer detector decreases, the characteristic size of the geometrical parameters of the optical absorber decreases accordingly. In particular, the design of the optical absorber is generally limited mainly by the minimum critical dimension of the pattern that can be defined on the electrically conductive layers by the fabrication process of the microbolometer detector.

In some embodiments, the pattern defined by each of the electrically conductive layers **34***a* and **34***b* of the optical absorber **30** may preferably be selected so as to form either a capacitive structure or an inductive structure. For example, in the illustrated embodiment, the first electrically conductive layer **34***a* is patterned to form a capacitive structure and the second electrically conductive layer **34***b* is patterned to form an inductive structure.

As known in the art, the characterization of such structures as inductive or capacitive may be derived from the lumped circuit elements comprising an equivalent circuit for approximating their spectral characteristics (e.g. reflection, transmission and absorption) to electromagnetic radiation incident thereonto. More particularly, a capacitive structure generally behaves as a low-pass filter and may be constructed using an array or grid of patch elements, while an inductive structure generally behaves as a high-pass filter and may be constructed using an array or grid of aperture or slot elements. Referring to FIGS. **9**A to **9**H, there are shown examples of capacitive and inductive structures that can be patterned into the first and second electrically conductive layers **34***a* and **34***b*, respectively. However, it is to be understood that these exemplary capacitive and inductive structures are given for purposes of illustration only and are not to be construed as limiting the scope of the invention.

Referring back to FIGS. **1** to **5** and **8**, the capacitive and inductive structures are preferably stacked one over the other in order to form a capacitive-inductive resonant circuit defining the resonant structure of the optical absorber **30**. In such embodiments, the absorption spectrum of the optical absorber **30** generally depends on the geometry and composition of the capacitive and inductive structures, that is, of the first and second electrically conductive layers **34***a* and **34***b*. By adjusting these parameters, it is possible to tailor the peak position, peak value, width and shape of the absorption spectrum of the optical absorber **30**, and thus of the uncooled microbolometer detector **20** as a whole. In the illustrated embodiment, the capacitive structure patterned in the first electrically conductive layer **34***a* is disposed over the inductive structure patterned in the second electrically conductive layer **34***b*.

However, in other embodiments, the inductive structure may be disposed over the capacitive structure without departing from the scope of the present invention.

It is also to be noted that while in some embodiments the optical absorber combines individual capacitive and inductive structures respectively formed in two distinct electrically conductive layers, in other embodiments the optical absorber may include more than two electrically conductive layers, each being patterned to a capacitive or and inductive structure. Such multilayer configurations may be useful for providing an uncooled microbolometer detector with a more complex absorption spectrum, for example with a plurality of absorption bands and absorption peaks at specific frequencies of interest.

In other embodiments, the optical absorber may be provided with a single electrically conductive layer patterned into either a capacitive or inductive structure. For example, in one embodiment, the optical absorber may include a single electrically conductive layer patterned to form a capacitive structure. In such an embodiment, the resonant structure of the optical absorber may be formed by combining the capacitive structure patterned in the electrically conductive layer with an inductive structure defined by the Fabry-Perot cavity formed between the platform and a radiation reflecting mirror provided on the substrate of the uncooled microbolometer detector. Alternatively, in other embodiments, the optical absorber may be provided with a single electrically conductive layer into which are patterned both a capacitive and an inductive structure.

Still referring to FIGS. **1** to **5** and **8**, the capacitive structure may preferably include a cross-shaped slot **52** patterned through the first electrically conductive layer **34***a*, while the inductive structure may include inductive elements **58***a* to **58***d* patterned in the second electrically conductive layer **34***b* and electromagnetically coupled to the cross-shaped slot **52**. In the illustrated embodiment, the cross-shaped slot **52** has four arms **54***a* to **54***d* extending outwardly from a center **56** thereof, with adjacent arms **54***a* to **54***d* extending at right angles relative to each other. Furthermore, each inductive element **58***a* to **58***d* is shaped as an elongated electrically conductive segment that extends substantially orthogonally across a corresponding one of the four arms **54***a* to **54***d* of the cross-shaped slot **52**. Furthermore, the optical absorber **30** may, but need not, include an electrically insulating layer **38***d* disposed between the first and second electrically conductive layers **34***a* and **34***b*, for example as an etch stop layer, and corresponding to the fourth dielectric layer **38***d* introduced above.

The cross-shaped slot **52** patterned through the first electrically conductive layer **34***a* and the inductive elements **58***a* to **58***d* patterned in the second electrically conductive layer **34***b* are electromagnetically coupled to each other so as to form the resonant structure of the optical absorber **30** of the uncooled microbolometer detector **20**. The absorption spectrum of the uncooled microbolometer detector **20** will depend on the geometric parameters of the capacitive and inductive structures patterned into the first and second electrically conductive layers **34***a* and **34***b* such as:

- the length and width of the arms **54***a* to **54***d* of the cross-shaped slot **52**;
- the length and width of the inductive elements **58***a* to **58***d* and their position relative to the arms **54***a* to **54***d* of the cross-shaped slot **52**;
- the vertical spacing between the first and second electrically conductive layers **34***a* and **34***b*, which corresponds to the thickness of the fourth dielectric layer **38***d*; and
- the gap between the optical absorber **30** and the radiation reflecting mirror optionally provided on the substrate.

Moreover, the absorption spectrum of the uncooled microbolometer detector **20** will also depend on the material composition of the first and second electrically conductive layers **34***a* and **34***b*, in particular their electrical conductivity, which can be frequency-dependent and influence the value of the complex impedance of each electrically conductive layer **34***a* and **34***b*.

One of ordinary skill in the art will thus recognize that by adjusting these geometrical and material parameters, it may be possible to control the profile (e.g. the shape, width and peak value) and position of the absorption spectrum of the uncooled microbolometer detector **20** so as to absorb specific wavelengths of radiation, for example terahertz radiation.

For example, referring to FIG. **12**A, there is shown a theoretical calculation of the absorption spectrum of the uncooled microbolometer detector shown in FIG. **1** and including a first electrically conductive layer patterned into a cross-shaped capacitive structure and second electrically conductive layer patterned into an inductive structure. As can be seen from the illustrated spectrum, the uncooled microbolometer detector exhibits a main absorption peak near 5 THz.

Radiation Reflecting Mirror

Referring back to FIGS. **1**, **4**, **5** and **8**, and as mentioned above, the uncooled microbolometer detector **20** may include a radiation reflecting mirror **74** provided on the substrate **22** and disposed under the platform **24**. The radiation reflecting mirror **74** has a reflecting surface that faces the underside of the platform **24**. The radiation reflecting mirror **74** may be a thin metal film, for example a thin aluminum film, which can be deposited on the substrate **22** during the fabrication process of the uncooled microbolometer detector **20**.

It will be understood by one of ordinary skill in the art that the radiation reflection mirror **74** provided on the substrate **22** may form a Fabry-Perot cavity with the platform **24** disposed thereabove, which may enhance the absorption of electromagnetic radiation by the optical absorber **30** by modifying the overall impedance of the uncooled microbolometer detector **20**.

More specifically, the radiation reflecting mirror **74** may provide additional absorption by reflecting back into the optical absorber **30** the electromagnetic radiation which the optical absorber **30** is configured to absorb but which has not been absorbed on its first passage therethrough. Preferably, the radiation reflecting mirror **74** extends on the substrate **22** so as to cover most of the area underneath the platform **24** to maximize the back reflection level.

Additionally or alternatively, the radiation reflecting mirror **74** may be configured not to reflect any electromagnetic radiation of wavelength out of the one or more absorption bands of the optical absorber **30**.

For example, in an embodiment of the uncooled microbolometer detector **20** optimized for detecting radiation in the terahertz region of the electromagnetic spectrum, the radiation reflecting mirror **74** may be configured to reflect electromagnetic radiation within one or more specific frequency bands in the terahertz region, while absorbing or transmitting to the substrate **22** the electromagnetic radiation of frequency out of the one or more specific frequency bands, in particular, the infrared radiation.

In order to provide more degrees of freedom to tailor the reflection, transmission and absorption properties of the radiation reflecting mirror **74** in one or more spectral bands of interest, it will be understood that the radiation reflecting mirror **74** may be patterned into specific geometries based on principles similar to those described above in reference to the optical absorber **30** of the uncooled microbolometer detector **20**.

Spectral Filter

Referring now to FIGS. **6** and **7**, in some embodiments, the microbolometer detector **20** may further include a spectral filter **60** supported above the platform **24** in a spaced relationship therewith.

In the illustrated embodiment, the spectral filter **60** is maintained above the platform **24** of the uncooled microbolometer detector **20** by two pillars **62** projecting upwardly from opposite corners of the platform **24**, near the two posts **40** of the support structure **26**. However, other types of support arrangement could be envisioned without departing from the scope of the invention.

As used herein, the term “spectral filter” is intended to refer to any structure that selectively transmits, either totally or partially, spectral components of the electromagnetic radiation incident thereonto. More specifically, the spectral filter **60** of FIGS. **6** and **7** is configured to pre-filter the incident electromagnetic radiation before it reaches the optical absorber **30** by removing therefrom undesirable spectral content, either by reflection or by absorption. Advantageously, the provision of the spectral filter **60** may eliminate the need for a window filter surrounding the uncooled microbolometer detector, thus reducing the cost of the microbolometer detector **20**.

Depending on its intended application, the spectral filter **60** may be embodied by a low-pass filter (e.g. a capacitive filter), a high-pass filter (e.g. an inductive filter) or a bandpass or bandstop filter (e.g. a capacitive-inductive resonant filter). In the embodiment of FIGS. **6** and **7**, the spectral filter **60** operates as a low-pass filter that transmits electromagnetic radiation of frequency lower than a predetermined cutoff frequency. The cut-off frequency will depend on the geometry of the resonant structure and also on the material properties. In such a configuration, the spectral filter **60** may reflect high-frequency radiation (e.g. infrared radiation) and thus may prevent the same from reaching the optical absorber **30**. Advantageously, this may contribute to reduce high frequency noise that would degrade the optical performance of the uncooled microbolometer detector **20**, for example as a result of the diffraction of the incident radiation and of the sensitivity to infrared radiation of some of the materials included in the microbolometer detector **20** (e.g. silicon nitride).

For example, referring now to FIG. **12**B, there is shown a theoretical calculation of the absorption spectrum of the uncooled microbolometer detector shown in FIG. **6**, which differs from the embodiment of FIG. **1** only by the provision of a low-pass capacitive spectral filter supported above the platform. As can be seen from the illustrated spectrum, the uncooled microbolometer detector still exhibits a main absorption peak near 5 THz, but the magnitudes of the satellite peaks above 10 THz are significantly reduced in comparison to the absorption spectrum shown in FIG. **12**A.

More specifically, the spectral filter **60** shown in FIGS. **6** and **7** includes an electrically is conductive layer **64** patterned to form a capacitive filter and deposited on top of a support membrane **66** held above the platform **24** by the two pillars **62**. As for the platform **24** and support structure **26** of the uncooled microbolometer detector **20**, the support membrane **66** and pillars may be made of a low-stress and self-supporting material, for example silicon nitride or silicon dioxide. In the illustrated embodiment, the capacitive filter is a regular array of square patches **68** whose transmission spectrum and cut-off frequency depend on the size, separation and composition of the square patches. Advantageously, and as discussed above in relation with the capacitive structure of the optical absorber, the spectral response of the capacitive filter based on such a square patch array is independent of the polarization of the electromagnetic radiation incident thereonto. However, it will be understood that other embodiments can make use of different configurations for the capacitive filter.

Microbolometer Array

Referring now to FIG. **10**, in accordance with another aspect of the invention, there is provided a microbolometer array **70**. The microbolometer array **70** includes a plurality of uncooled microbolometer detectors **20** such as described above, wherein the plurality of microbolometer detectors **20** is arranged in a two-dimensional array. While FIG. **10** depicts a four by four array for clarity, it will be recognized that in other embodiments, the total number of microbolometer detectors **20** in the array **70** could be higher or lower depending on the intended application. In some embodiments, the microbolometer array **70** may include microbolometer detectors **20** arranged in an array of pixels, wherein the spacing between two nearest-neighbor microbolometer detectors **20** (e.g. the pixel pitch) may be between about 12 and 312 μm.

It will also be understood that in order to meet the constraints of a particular application, the microbolometer array **70** may include identical or different microbolometer detectors **20** without departing from the scope of the present invention. In this regard, referring to FIGS. **11**A and **11**B, the microbolometer detectors **20** may include subsets **72***a* and **72***b* of microbolometer detectors **20**, wherein the absorption spectrum of the uncooled microbolometer detectors of each subset is different from one another.

More specifically, in FIG. **11**A, the optical absorber of one subset **72***a* of microbolometer detectors **20** includes a capacitive structure embodied by a cross-shaped slot patterned through the first electrically conductive layer, wherein the four arms of the slots do not extend outwardly to the peripheral edge of the platform. On the other hand, the optical absorber of the other subset **72***b* of microbolometer detectors **20** includes a capacitive structure embodied by a cross-shaped slot patterned through the first electrically conductive layer, wherein the four arms of the slots extend outwardly to the peripheral edge of the platform. Furthermore, in FIG.

11B, the optical absorbers in the two subsets **72***a* and **72***b* of microbolometer detectors differ in terms of the length and width of the cross-shaped slots patterned through the first electrically conductive layer. It will thus be understood that, in such embodiments, the absorption spectrum of each pixel, row of pixels or cluster of pixels of the array may be optimized independently.

It should be noted that while the microbolometer detectors **20** are arranged to form a two-dimensional array in the embodiments of FIGS. **10** and **11**, they may alternatively be configured as a linear array or be provided at arbitrary locations that do not conform to a specific pattern.

Of course, numerous modifications could be made to the embodiments described above without departing from the scope of the present invention.

The invention claimed is:

1. An uncooled microbolometer detector comprising:

a substrate;

a platform held above the substrate by a support structure;

at least one thermistor provided on the platform; and

an optical absorber extending on the platform over and in thermal contact with the at least one thermistor, the optical absorber comprising a first electrically conductive layer patterned to form a capacitive structure operating as a low-pass spectral filter and a second electrically conductive layer patterned to form an inductive structure operating as a high-pass spectral filter, the capacitive structure and the inductive structure together forming a resonant structure defining an absorption spectrum of the optical absorber, the optical absorber being exposed to electromagnetic radiation and absorbing the electromagnetic radiation according to the absorption spectrum.

2. The uncooled microbolometer detector according to claim **1**, wherein the optical absorber further comprises an electrically insulating layer disposed between the first and second electrically conductive layers.

3. The uncooled microbolometer detector according to claim **1**, wherein:

the capacitive structure comprises a cross-shaped slot patterned through the first electrically conductive layer; and

the inductive structure comprises inductive elements patterned in the second electrically conductive layer, the inductive elements being electromagnetically coupled to the cross-shaped slot.

4. The uncooled microbolometer detector according to claim **3**, wherein the cross-shaped slot has four arms extending outwardly from a center thereof, with adjacent arms extending at right angles relative to each other, and wherein each inductive element extends substantially orthogonally across a corresponding one of the four arms of the cross-shaped slot.

5. The uncooled microbolometer detector according to claim **1**, wherein each of the least one thermistor comprises a thin film of one of vanadium oxide and amorphous silicon.

6. The uncooled microbolometer detector according to claim **1**, wherein the optical absorber is configured to absorb the electromagnetic radiation in a wavelength range of between about 30 and 3000 micrometers.

7. The uncooled microbolometer detector according to claim **1**, wherein the absorption spectrum of the uncooled microbolometer detector comprises a plurality of absorption bands.

8. The uncooled microbolometer detector according to claim **1**, further comprising a radiation reflecting mirror provided on the substrate and disposed under the platform.

9. The uncooled microbolometer detector according to claim **1**, further comprising a spectral filter supported above the platform in a spaced relationship therewith and configured to pre-filter the electromagnetic radiation before the electromagnetic radiation impinges onto the optical absorber.

10. The uncooled microbolometer detector according to claim **9**, wherein the spectral filter comprises a low-pass filter.

11. The uncooled microbolometer detector according to claim **10**, wherein the low-pass filter is a capacitive filter.

12. A microbolometer array comprising a plurality of uncooled microbolometer detectors according to claim **1**, wherein the plurality of microbolometer detectors is arranged in a two-dimensional array.

13. The microbolometer array according to claim **12**, wherein the plurality of uncooled microbolometer detectors is divided in a number of subsets of uncooled microbolometer detectors, the absorption spectrum of the uncooled microbolometer detectors of each subset being different from one another.

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