



**PCT**

**(10) International Publication Number**  
**WO 2009/002411 A1**

**(43) International Publication Date**  
**31 December 2008 (31.12.2008)**

- (51) **International Patent Classification:**  
**G01J 5/40** (2006.01)

(21) **International Application Number:**  
PCT/US2008/007472

(22) **International Filing Date:** 16 June 2008 (16.06.2008)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**  
11/766,430 21 June 2007 (21.06.2007) US

(71) **Applicant (for all designated States except US):** **LUCENT TECHNOLOGIES INC.** [US/US]; 600-700 Mountain Avenue, Murray Hill, NJ 07974-0636 (US).

(72) **Inventors; and**

(75) **Inventors/Applicants (for US only):** **AKSYUK, Vladimir, Anatolyevich** [RU/US]; 585 Trinity Place, Unit N, Westfield, NJ 07090 (US). **BOLLE, Cristian, A.** [AR/US]; 708 Foothill Road, Bridgewater, NJ 08807 (US). **JONES, Christopher, D W** [CA/US]; 52 Cooper Lane, Millington, NJ 07946 (US). **PARDO, Flavio** [AR/US]; 12 Ethan Drive, New Providence, NJ 07974 (US). **RYF, Roland** [SZ/US]; 2 Dolan Avenue, Aberdeen, NJ 07747 (US). **SIMON, Maria, Elina** [AR/US]; 12 Ethan Drive, New Providence, NJ 07974 (US).

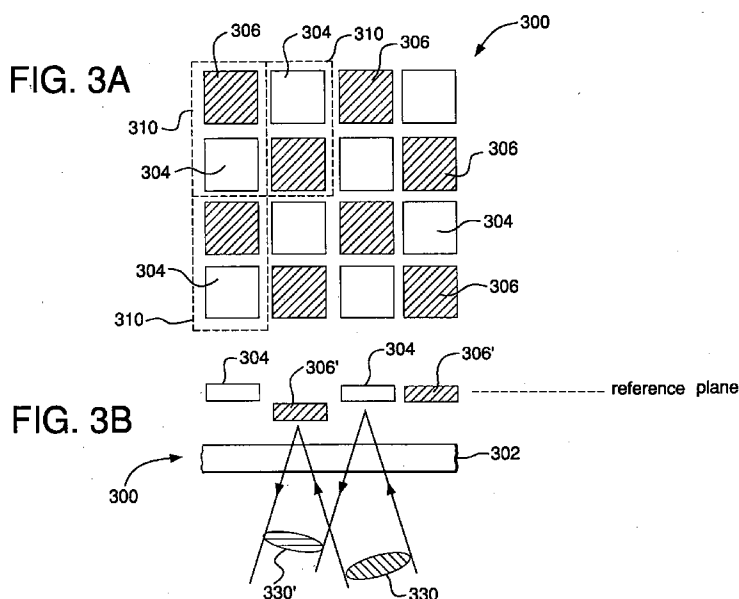
(74) **Common Representative:** **LUCENT TECHNOLOGIES INC.**; Docket Administrator - Room 2f-192, 600-700 Mountain Avenue, Murray Hill, NJ 07974-0636 (US).

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

(84) **Designated States (unless otherwise indicated, for every kind of regional protection available):** ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL,

[Continued on next page]

**(54) Title:** INFRARED IMAGING APPARATUS WITH THERMALLY DISPLACABLE DETECTOR IPIXEL ARRAY AND OPTICAL INTERROGATION SYSTEM



**(57) Abstract:** A representative embodiment of the invention provides an infrared (IR) imaging system (300) adapted to (i) convert an IR image of an object into mechanical displacements of a plurality of movable plates (304,306), (ii) use the mechanical displacements to impart a corresponding spatial phase modulation pattern onto a beam of visible light, and (iii) apply spatial filtering to convert the spatial phase modulation pattern into a visible image of the object.



NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG,  
CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

— *before the expiration of the time limit for amending the  
claims and to be republished in the event of receipt of  
amendments*

**Published:**

— *with international search report*

INFRARED IMAGING APPARATUS WITH THERMALLY DISPLACABLE DETECTOR IPIXEL ARRAY  
AND OPTICAL INTERROGATION SYSTEM

**INFRARED IMAGING APPARATUS**

CROSS-REFERENCE TO RELATED APPLICATIONS

The subject matter of this application is related to that of U.S. Patent Application No. 11/766,414, entitled "Detector of Infrared Radiation Having a Bi-Material Transducer" by Vladimir Aksyuk, Cristian Bolle, Christopher Jones, Flavio Pardo, Roland Ryf, and Maria Elina Simon (Docket No.: Aksyuk 50-30-6-27-17-18), which is being filed on the same date as the present U.S. Patent Application.

This application is also related to U.S. Patent Application No. 11/713,207, filed March 2, 2007, and entitled "Direct Optical Image Projectors." The two above-identified U.S. Patent Applications are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to detectors of infrared radiation and infrared imaging systems.

Description of the Related Art

Infrared (IR) detectors are classified into two categories: photonic and thermal. In a photonic IR detector, infrared photons are absorbed to excite electronic transitions and/or generate photocurrent within an IR absorber, usually a semiconductor material having an appropriate bandgap. The excitation changes material properties of the IR absorber such as, for example, electrical conductivity. This change is measured to quantify the amount of absorbed IR radiation. Photonic IR detectors usually operate at very low temperatures, e.g., about 78 K, to suppress thermally induced electronic transitions and/or thermal "dark" current in the absorber. As such, photonic IR detectors utilize cryostats and/or complex cooling systems, which make these detectors heavy, bulky, and relatively expensive.

In a thermal IR detector, the energy of absorbed infrared photons is converted into heat, which causes a temperature increase within the detector. This temperature increase is converted into a mechanical or electrical response, which is measured to

quantify the amount of absorbed IR radiation. A sensor employed in a thermal IR detector typically has (i) a resistive bolometer, whose electrical resistance changes with temperature, (ii) a pyroelectric material, which exhibits a spontaneous electric polarization change with temperature, (iii) a thermocouple, whose voltage depends on  
5 the thermocouple's temperature differential, and/or (iv) a bi-material (also referred to as bimorph) cantilever, whose shape is sensitive to temperature changes.

Unlike photonic IR detectors, thermal IR detectors typically (i) do not use cooling and (ii) can operate at temperatures normally present in the environment, e.g., about 300 K. As a result, thermal IR detectors can be light, compact, and relatively  
10 inexpensive. Accordingly, thermal IR detectors and infrared imaging systems employing those detectors are being actively developed.

#### SUMMARY OF THE INVENTION

A representative embodiment of the invention provides an infrared (IR) imaging system adapted to (i) convert an IR image of an object into mechanical  
15 displacements of a plurality of movable plates, (ii) use the mechanical displacements to impart a corresponding spatial phase modulation pattern onto a beam of visible light, and (iii) apply spatial filtering to convert the spatial phase modulation pattern into a visible image of the object.

According to one embodiment, an apparatus of the invention has an array of  
20 radiation-absorbing regions supported over a substrate and having first and second pluralities of radiation-absorbing regions. For each radiation-absorbing region of the first plurality, the region's position with respect to the substrate is responsive to an amount of radiation incident on the region. The apparatus further includes an array of reflecting regions, each reflecting region corresponding to one of the radiation-  
25 absorbing regions and adapted to reflect a respective portion of an interrogating beam of light to form a respective portion of a reflected beam. The array of reflecting regions is adapted to impart onto the reflected beam a spatial phase modulation pattern that corresponds to a spatial intensity pattern of the radiation incident on the array of radiation-absorbing regions.

According to another embodiment, a method of the invention for detecting radiation includes the step of receiving radiation using an array of radiation-absorbing regions. The array of radiation-absorbing regions is supported over a substrate and comprises first and second pluralities of radiation-absorbing regions. For each  
5 radiation-absorbing region of the first plurality, the region's position with respect to the substrate is responsive to an amount of radiation incident on the region. The method further includes the step of reflecting an interrogating beam of light using an array of reflecting regions to form a reflected beam having a spatial phase modulation pattern that corresponds to a spatial intensity pattern of the radiation incident on the  
10 array of radiation-absorbing regions. Each reflecting region corresponds to a radiation-absorbing region and is adapted to reflect a respective portion of the interrogating beam to form a respective portion of the reflected beam.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects, features, and benefits of the present invention will become more  
15 fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which:

Fig. 1 illustrates a method of optically interrogating an IR detector according to one embodiment of the invention;

Fig. 2 illustrates a method of optically interrogating an IR detector according to  
20 another embodiment of the invention;

Figs. 3A-B show top and side views, respectively, of an IR detector array according to one embodiment of the invention;

Fig. 4 shows a representative optical arrangement for converting a phase modulation pattern into a viewable visible image;

25 Figs. 5A-B show two representative intensity patterns formed at a focal plane of a lens in the optical arrangement of Fig. 4;

Fig. 6 shows an IR imaging system according to one embodiment of the invention;

Fig. 7 shows a three-dimensional perspective view of a pixel that can be used in the IR detector array of the system shown in Fig. 6 according to one embodiment of the invention;

Fig. 8 shows a three-dimensional perspective view of a pixel that can be used  
5 in the IR detector array of the system shown in Fig. 6 according to another embodiment of the invention;

Fig. 9 shows a three-dimensional perspective view of an array that has a plurality of pixels shown in Fig. 8 according to one embodiment of the invention;

Fig. 10 shows a three-dimensional perspective view of a pixel that can be used  
10 in the IR detector array of the system shown in Fig. 6 according to yet another embodiment of the invention;

Fig. 11 shows a three-dimensional perspective view of a pixel that can be used in the IR detector array of the system shown in Fig. 6 according to yet another embodiment of the invention;

Fig. 12 shows a three-dimensional perspective view of a pixel that can be used  
15 in the IR detector array of the system shown in Fig. 6 according to yet another embodiment of the invention;

Fig. 13 shows a three-dimensional perspective view of a pixel that can be used in the IR detector array of the system shown in Fig. 6 according to yet another  
20 embodiment of the invention;

Fig. 14 shows a top view of a pixel that can be used in the IR detector array of the system shown in Fig. 6 according to yet another embodiment of the invention;

Fig. 15 shows a top view of an array that has a plurality of pixels shown in Fig. 14 according to one embodiment of the invention;

Fig. 16 shows a three-dimensional perspective view of a pixel that can be used  
25 in the IR detector array of the system shown in Fig. 6 according to yet another embodiment of the invention;

Figs. 17A-B show cross-sectional views of a plate that can be used in the IR detector array of the system shown in Fig. 6 according to further embodiments of the  
30 invention;

Figs. 18A-B show three-dimensional perspective views of two respective detectors that can be used in the pixel shown in Fig. 16 according to another embodiment of the invention; and

Fig. 19 shows a side cross-sectional view of an IR detector according to another embodiment of the invention.

### DETAILED DESCRIPTION

The operating principles of an infrared (IR) detector having a bi-material cantilever is described, e.g., in an article by S.R. Hunter, R.A. Amantea, L.A. Goodman, et al., entitled "High Sensitivity Uncooled Microcantilever Infrared Imaging Arrays," published in Proceedings of SPIE, 2003, v. 5074, pp. 469-480, the teachings of which are incorporated herein by reference. Briefly, the detector typically has (1) an IR-radiation absorbing area, (2) a bi-material element, and (3) a thermal isolator. The IR-radiation absorbing area converts the impinging IR radiation into heat, while the thermal isolator prevents the heat from being shunted to the substrate.

The two materials forming the bi-material element are selected to have a large difference in their thermal-expansion coefficients. As the temperature of the bi-material element increases due to the IR heating, the material having the larger thermal-expansion coefficient attempts to expand a greater amount than the adjacent material having the smaller thermal-expansion coefficient. Because the two materials are formed so that they adhere to one another in the bi-material element, they are forced to expand by equal amounts, causing a tensile stress to build up in one material and a compressive stress to build up in the other. The resulting stress gradient across the bi-material element bends it, thereby causing the bi-material element to move with respect to the substrate. The resulting mechanical displacement of a selected portion of the bi-material element or of a structure attached to the bi-material element can be measured and used to quantify the amount of absorbed IR radiation.

Representative pairs of materials that can be used to form a bi-material element include, but are not limited to, a low thermal-expansion material, such as silicon oxide whose composition can be expressed as  $\text{SiO}_x$  (having a thermal-expansion coefficient "tec" of about 0.5 ppm/K), silicon nitride whose composition can be expressed as

SiN<sub>x</sub> (tec ~1 ppm/K), and silicon carbide whose composition can be expressed as SiC<sub>x</sub> (tec ~4 ppm/K), silicon (tec ~2.5 ppm/K), and a high thermal expansion material, such as gold (tec ~14.2 ppm/K), nickel (tec ~13.4 ppm/K), silver (tec ~18.9 ppm/K), aluminum (tec ~23 ppm/K). To maximize the mechanical displacement, it is  
5 preferred to have a relatively large thermal-expansion coefficient differential between the two materials. One skilled in the art will appreciate that the Young's modulus of the materials also affects the amount of displacement.

Fig. 1 illustrates a method of optically interrogating an IR detector **100** according to one embodiment of the invention. More specifically, Fig. 1 shows a  
10 cross-sectional side view of detector **100** together with two optical beams, an IR beam **120**, the intensity of which is being detected, and an interrogating (e.g., visible) beam **130**. In a typical implementation, detector **100** is a MEMS device.

Detector **100** has a substrate **102** that is substantially transparent to interrogating beam **130**. A plate **110** is movably mounted on substrate **102** using an  
15 anchor (support post) **104**, a thermal isolator **106**, and a bi-material transducer **108**. Plate **110** has a reflective layer that reflects interrogating beam **130** as well as an IR-absorbing layer that absorbs IR beam **120** and converts its energy into heat. These two layers can be separate and distinct from each other, or a single layer in the plate structure can perform the functions of both layers either with or without utilizing the  
20 mechanical layer to perform these functions. The absorbed IR energy increases the temperature of the plate and, due to good thermal contact between the plate and bi-material transducer **108**, the temperature of the bi-material transducer as well. Isolator **106** has relatively low thermal conductivity and, as such, prevents the heat from sinking, through anchor **104**, into substrate **102**. The IR-induced temperature increase  
25 in plate **110** and bi-material transducer **108** causes a stress gradient to build across the bi-material transducer, which bends the bi-material transducer and moves the plate with respect to substrate **102**. The motion direction depends on the bi-material layer arrangement in transducer **108** and can be toward substrate **102** or away from the substrate. The motion and/or displacement of plate **110** imparts a phase shift onto



reflected beam **130'**, which phase shift is detected and used to quantify the intensity of IR beam **120**.

Fig. 2 illustrates a method of optically interrogating an IR detector **200** according to another embodiment of the invention. Detector **200** is generally similar to detector **100** (Fig. 1), and analogous elements of the two detectors are designated with labels having the same last two digits. One difference between detectors **100** and **200** is that, in the latter, IR beam **220**, the intensity of which is being detected, is directed toward the underside of plate **210** through (e.g., silicon) substrate **202** that is substantially transparent to the IR light. A temperature increase caused by the absorption of beam **220** causes bi-material transducer **208** to bend and move plate **210** with respect to substrate **202**. The motion and/or displacement of plate **210** imparts a phase shift onto reflected beam **230'**, which phase shift is detected and used to quantify the intensity of IR beam **220**.

Figs. 3A-B show top and side views, respectively, of an IR detector array **300** according to one embodiment of the invention. Array **300** is a MEMS device that has a plurality of pixels **310**, each having two IR detectors, a detector **304** and a detector **306**. One skilled in the art will appreciate that, the pixel arrangement shown in Fig. 3 is exemplary and that other pixel arrangements and pixel/detector shapes can also be used without departing from the principles of the invention. In one embodiment, each detector **306** is an IR detector that is generally analogous to detector **100** of Fig. 1, and each detector **304** has a fixed plate that does not move with respect to substrate **302**. In another embodiment, each of detectors **304** and **306** is analogous to detector **100**, with one difference between detectors **304** and **306** being that, in response to IR-induced heating, their plates move in opposite directions. For example, the plates in detectors **304** are adapted to move away from substrate **302**, while the plates in detectors **306** are adapted to move toward the substrate.

If an IR image is projected onto array **300**, then the intensity distribution within the image is converted into plate displacements with respect to their respective reference positions. Generally, the greater the IR intensity received by a detector, the greater the plate displacement in that detector. Fig. 3B illustrates a response of array

300 to an exemplary IR image projected onto the array, wherein the IR image has a single bright spot. Consequently, the plate of only one detector (i.e., detector 306' which receives the bright spot) is displaced from the reference plane level, while the plates of all other detectors remain substantially unperturbed. If array 300 having the  
5 plate-displacement pattern shown in Fig. 3B is interrogated by a planar-wave visible beam 330, then a reflected beam 330' will no longer be a planar wave, but rather, it will have a phase-front distortion introduced by the plate displacement in detector 306'. In general, an arbitrary IR image projected onto array 300 will cause the array to act as a spatial phase modulator that imprints onto interrogating visible beam 330 a  
10 spatial phase modulation pattern corresponding to the IR image.

A method and system for converting a spatial phase modulation pattern into a viewable visible image is described, e.g., in the above-cited U.S. Patent Application No. 11/713,207. The reader is therefore referred to the '207 application for a detailed description of that method/system. For the sake of convenience, a brief description of  
15 a representative optical arrangement that can be used to implement an embodiment of the conversion method disclosed in the '207 application is given below.

Fig. 4 shows an optical arrangement 400 for converting a spatial phase modulation pattern into a viewable visible image. Arrangement 400 has a spatial phase modulator 430 that imprints a spatial phase modulation pattern onto a planar-wave beam 422 that is produced using a laser 410 and a collimating lens 420. The  
20 resulting spatially phase-modulated beam 432 passes through a lens 440 that forms at its focal plane an intensity pattern, wherein the spatial phase modulation pattern of beam 432 and the formed intensity pattern are related by spatial Fourier transformation.

25 Figs. 5A-B show two representative intensity patterns formed at the focal plane of lens 440. More specifically, axes  $x$  and  $y$  in each of Figs. 5A-B represent the coordinates within the focal plane of lens 440, and the axis orthogonal to the  $xy$  plane represents light intensity. Fig. 5A shows an intensity pattern 510 that is produced when beam 432 is a planar wave, thus corresponding to a situation when all plates are  
30 parallel to the substrate and positioned at the same offset distance. Pattern 510 has a

single peak, generally referred to as a zero-order peak. Fig. 5B shows an intensity pattern **520** that is produced when beam **432** has a periodic phase-modulation pattern produced when spatial phase modulator **430** is illuminated by a uniform IR beam. As evident in Fig. 5B, pattern **520** has multiple peaks in addition to the zero-order peak.

5 These additional peaks are generally referred to as side peaks.

Referring back to Fig. 4, a spatial filter **450** placed at a focal plane of lens **440** has one or more openings configured to transmit light corresponding to the respective areas around one or more selected side peaks. At the same time, spatial filter **450** rejects (blocks) light corresponding to the zero-order peak and the remaining side  
10 peaks. The resulting spatially filtered beam is collimated by a lens **460** to produce a collimated beam **462**. If spatial phase modulator **430** is not illuminated uniformly by IR light, then the effect is to broaden the side peaks. As explained in more detail in the '207 application, beam **462** is an intensity-modulated beam having a spatial intensity distribution related to the phase modulation pattern of beam **432**. At an  
15 image plane **470**, this spatial intensity distribution creates a visible image that can be viewed as known in the art, e.g., using an eyepiece **480**.

Fig. 6 shows an IR imaging system **600** according to one embodiment of the invention. System **600** has an IR detector array **630** that is analogous to IR detector array **300** of Fig. 3. In one embodiment, array **630** has 1024x1024 pixels, each  
20 analogous to pixel **310** of array **300** (Fig. 3).

Array **630** divides system **600** into two optical sections, an IR section **602** and a visible section **604**. Section **602** has an IR lens assembly **608** that receives an IR beam **606** from an object (not shown in Fig. 6) and projects a corresponding image of the object onto array **630**. Pixels of array **630** transform the received IR radiation into  
25 plate displacements as described above.

Section **604** is designed to optically interrogate array **630** to transform plate displacements into a corresponding visible image in a manner generally analogous to that of optical arrangement **400** of Fig. 4. However, optical arrangement **400** differs from section **604** of system **600** in that the latter utilizes a so-called folded optical  
30 configuration, in which some optical elements are traversed by light more than one

time. As a result, section **604** can generally have fewer optical elements and be more compact than optical arrangement **400**.

Section **604** has a laser **610** that generates an appropriately polarized visible beam **612** and directs that beam, via an optical beam redirector **614**, toward array **630**.

5 In one embodiment, optical beam redirector **614** is a polarization beam splitter that is oriented with respect to the polarization of optical beam **612** so as to redirect substantially all light of that beam towards array **630**. In this embodiment, section **604** also has a quarter-wave plate (not explicitly shown in Fig. 6). The quarter wave plate is a birefringent plate that is located between polarization beam splitter **614** and array  
10 **630**. The birefringent plate produces a retardation of about one quarter of a wavelength between two orthogonal linear polarization components of an optical beam transmitted normally therethrough. By traversing the birefringent plate two times, the light directed to and reflected from array **630** acquires a polarization that causes polarization beam splitter **614** to transmit (without redirecting) the reflected  
15 light, as opposed to redirecting it back toward laser **610**.

A lens **620** located between splitter **614** and array **630** is traversed by the light two times and, as such, performs at least two functions. For the light traveling toward array **630**, lens **620** acts as a collimating lens similar to lens **420** (see Fig. 4). For the light reflected by array **630**, lens **620** acts as a focusing lens similar to lens **440** (see  
20 Fig. 4).

Plate displacements in array **630** induced by the received IR image imprint a corresponding spatial phase modulation pattern onto the reflected visible beam (see also Fig. 3). Lens **620** forms at its focal plane an intensity pattern corresponding to the spatial phase modulation pattern of the reflected visible beam in a manner similar  
25 to that of lens **440** of arrangement **400** (see Figs. 4 and 5A-B). A spatial filter **650** that is generally analogous to spatial filter **450** (Fig. 4) transmits light corresponding to one or more selected side peaks, while rejecting light corresponding to the zero-order peak and the remaining side peaks. A lens **660** receives the resulting spatially filtered beam and forms a visible image on an optional screen **670**, which image can be viewed, e.g.,  
30 through an eyepiece **680**. One skilled in the art will appreciate that the visible image

formed on screen **670** is a representation, in visible light, of the IR image projected by the optical assembly of section **602** onto array **630**. System **600** therefore advantageously converts an IR image that cannot be observed by a naked human eye into a corresponding visible-light image that is readily observable.

5            Fig. 7 shows a three-dimensional perspective view of a pixel **700** that can be used in array **630** according to one embodiment of the invention. Pixel **700** has two bi-material plates **710a-b** mounted on a substrate **702**. Each plate **710** has at least two layers, a top (e.g., gold) layer **714** having a relatively large thermal-expansion coefficient and a bottom (e.g., hydrogenated SiC) layer **712** having a relatively small  
10 thermal-expansion coefficient. Each plate **710** can also have additional layers (not explicitly shown), e.g., an IR-absorbing layer and a reflective layer for reflecting the interrogating visible light.

Plate **710a** is mounted on substrate **702** using a support post **720a** that has a large thermal conductance (obtained either through proper geometry or material  
15 selection, or both). As such, plate **710a** is in substantial thermal equilibrium (has the same temperature as) substrate **702**. In contrast, plate **710b** is mounted on substrate **702** using a support post **720b** that is made to have a low thermal conductance (similarly obtained either through proper geometry or material selection, or both) and, as such, acting as a thermal isolator. As a result, any IR radiation absorbed by plate  
20 **710b** causes a temperature increase in that plate relative to plate **710a** and substrate **702**. This temperature increase will generally cause plate **710b** to curl and deflect its unattached edge toward substrate **702** as indicated in Fig. 7. Differential displacement of plates **710a-b** with respect to one another can be used to imprint a spatial phase modulation pattern onto an interrogating visible beam, which can then be used, e.g., in  
25 system **600**, to visualize the corresponding IR image projected onto an IR detector array having pixel **700**.

Fig. 8 shows a three-dimensional perspective view of a pixel **800** that can be used in array **630** according to another embodiment of the invention. Pixel **800** has an IR detector **820b** that is generally similar to detector **100** (Fig. 1) or **200** (Fig. 2).  
30 More specifically, detector **820b** has a plate **810b** that is movably mounted on a

substrate **802** using an anchor **804b**, a thermal isolator **806**, and a bi-material transducer **808b**. Anchor **804b** is attached to substrate **802**. Bi-material transducer **808b** has a shape of a flattened rod or a plank that is oriented generally parallel to substrate **802**. Isolator **806**, which is located between anchor **804b** and bi-material transducer **808b**, has relatively low thermal conductivity and, as such, prevents the heat generated by IR absorption in plate **810b** from sinking, through the bi-material transducer, into the anchor and substrate **802**. The IR-induced temperature increase in plate **810b** and bi-material transducer **808b** causes the transducer to deform and move the plate with respect to substrate **802**.

Pixel **800** further has an IR detector **820a** that is generally similar to detector **820b**, and analogous elements of the two detectors have labels having the same last two digits. However, one difference between detectors **820b** and **820a** is that the latter has a thermal link **812** instead of thermal isolator **806**. Link **812** has relatively large thermal conductivity and keeps plate **810a** and bi-material transducer **808a** in substantial thermal equilibrium with anchor **804a** and substrate **802**. Similar to the differential displacement of plates **710a-b** in pixel **700**, differential displacement of plates **810a-b** in pixel **800** can be used to imprint a phase modulation pattern onto an interrogating visible beam.

Fig. 9 shows a three-dimensional perspective view of an array **900** that has a plurality of pixels **800** according to one embodiment of the invention. In array **900**, each support structure for a plate **810** has respective anchor **804**, thermal isolator **806** or thermal link **812**, and bi-material transducer **808**. Each such support structure is fitted into a space created by a corresponding gap between two other plates **810** and a cutout in a third plate **810**. As a result, different pixels **800** mesh together to create a two-dimensional array of pixels that are analogous to pixels **310** of Fig. 3.

Fig. 10 shows a three-dimensional perspective view of a pixel **1000** that can be used in array **630** according to yet another embodiment of the invention. Pixel **1000** has two IR absorbing plates: a fixed plate **1010a** and a movable plate **1010b**. Fixed plate **1010a** is fixedly suspended over a substrate **1002** by being attached to anchors **1004a** and **1004b**. Movable plate **1010b** is movably suspended over substrate **1002**

using anchors **1004b-c**, four bi-material transducers **1008a-d**, and two thermal isolators **1006a-b** that form two suspension arms **1022a-b** for the movable plate.

Each of bi-material transducers **1008a-d** is a rod that is oriented substantially parallel to substrate **1002**. Two bi-material transducers **1008** belonging to the same suspension arm **1022** are also substantially parallel to one another. One advantageous characteristic of suspension arms **1022** resulting from this transducer arrangement is that the arms can compensate for ambient temperature variations. More specifically, movable plate **1010b** does not move with respect to substrate **1002** if there is an ambient temperature change for entire pixel **1000** (i.e., the temperature remains uniform). However, if there is a temperature difference between plate **1010b** and substrate **1002**, then arms **1022a-b** do move plate **1010b** from its reference position corresponding to uniform temperature.

First, suppose that pixel **1000** is in thermal equilibrium. Then, four bi-material transducers **1008a-d** have the same temperature and, thus, substantially the same shape corresponding to that temperature. Suppose that the temperature is such that transducer **1008a** is curled up, i.e., the end of transducer **1008a** that is attached to thermal isolator **1006a** is at a larger offset distance from substrate **1002** than the end attached to anchor **1004b**. Then, transducer **1008b**, by virtue of having the same shape as transducer **1008a**, will compensate for the curvature of the latter and have its end attached to plate **1010b** positioned at the same offset distance from substrate **1002** as the end of transducer **1008a** attached to anchor **1004b**. Similarly, transducer **1008c** will compensate for the curvature of transducer **1008d** and have its end attached to plate **1010b** positioned at the same offset distance from substrate **1002** as the end of transducer **1008d** attached to anchor **1004c**. Due to this compensation, plate **1010b** will remain in the same (reference) position regardless of ambient temperature variations. Rather, the effect of ambient temperature variations will be motion of isolators **1006a-b** up and down with respect to substrate **1002**, while plate **1010b** remains substantially stationary.

Next, suppose that the temperature of plate **1010b** is higher than that of plate **1010a**. This temperature differential can result, e.g., from IR absorption and the fact

that isolators **1006** inhibit heat dissipation from plate **1010b** into the substrate. In this case, bi-material transducers **1008a-b** will have different shapes. More specifically, transducer **1008b** will have a shape corresponding to the temperature of plate **1010b** while transducer **1008a** will have a (different) shape corresponding to the temperature of substrate **1002** and plate **1010a**. For the same reasons, bi-material transducers **1008c-d** will also have different shapes. Due to these shape differences, plate **1010b** will become displaced with respect to its reference position corresponding to a thermal equilibrium state of pixel **1000**. Similar to the differential displacement of plates **810a-b** in pixel **800**, differential displacement of plates **1010a-b** in pixel **1000** can be used to imprint a spatial phase modulation pattern onto an interrogating visible beam.

Fig. 11 shows a three-dimensional perspective view of a pixel **1100** that can be used in array **630** according to yet another embodiment of the invention. Pixel **1100** has two IR absorbing plates **1110a-b**. Plate **1110a** is suspended over a substrate **1102** using anchors **1104a-b**, four bi-material transducers **1108d-g**, and two thermal links **1112a-b** that together form two suspension arms **1122** for this plate. Plate **1110b** is similarly suspended over substrate **1102** using anchors **1104b-c**, four bi-material transducers **1108a-d**, and two thermal isolators **1106a-b** that form two suspension arms **1124**. Note that suspension arms **1122a** and **1124a** share anchor **1104b** and transducer **1108d**, which advantageously results in surface area savings and a corresponding increase in the fill factor. Similar to suspension arms **1022** of pixel **1000** (Fig. 10), suspension arms **1122** and **1124** of pixel **1100** can compensate for ambient temperature variations. In addition, the substantially identical mechanical structure of the suspension arms **1122** and **1124** enables plates **1110a-b** to match each other very well in terms of the residual tilt arising from manufacturing tolerances.

Due to the presence of respective thermal links **1112a-b** between transducers **1108d-e** and transducers **1108f-g**, respectively, plate **1110a** is in substantial thermal equilibrium with substrate **1102** and, in that respect, is analogous to fixed plate **1010a** of pixel **1000** (see Fig. 10). In contrast, due to the presence of respective thermal isolators **1106a-b** between transducers **1108c-d** and transducers **1108a-b**,



respectively, plate **1110b** is thermally isolated from substrate **1102** and, similar to plate **1010b** (Fig. 10), is susceptible to an IR-induced temperature increase relative to the substrate. This temperature increase will cause a displacement of plate **1110b** with respect to its reference position. Similar to the differential displacement of plates **1010a-b** in pixel **1000**, differential displacement of plates **1110a-b** in pixel **1100** can be used to imprint a phase modulation pattern onto an interrogating visible beam.

Fig. 12 shows a three-dimensional perspective view of a pixel **1200** that can be used in array **630** according to yet another embodiment of the invention. Pixel **1200** has two IR-absorbing plates **1210a-b**. Plate **1210a** is suspended over a substrate **1202** using an anchor **1204a**, three bi-material transducers **1208a-c**, and a thermal link **1212** that form a suspension arm **1224** for that plate. When undeformed, transducers **1208a-c** lie within a plane that is parallel to substrate **1202**. Transducers **1208a-c** are parallel to one another, with the transducer that is attached to anchor **1204a** (i.e., transducer **1208b**) located between the two transducers that are directly attached to plate **1210a** (i.e., transducers **1208a,c**). This transducer arrangement advantageously creates a good balance (in terms of sideways tilting) for plate **1210a** with just one suspension arm.

Plate **1210b** is similarly suspended over substrate **1202** using an anchor **1204b**, three bi-material transducers **1208d-f**, and a thermal isolator **1206** that form a suspension arm **1222**. Similar to suspension arms **1122** and **1124** of pixel **1100** (Fig. 11), suspension arms **1222** and **1224** of pixel **1200** compensate for ambient temperature variations. In addition, the fact that a single suspension arm is used for each of plates **1210a-b** can advantageously be used to achieve a relatively high IR fill factor in an array having a plurality of pixels **1200** because having a single suspension arm per plate saves surface area in the array and enables a corresponding increase in the surface area that can be taken up by the IR-absorbing plates.

Fig. 13 shows a three-dimensional perspective view of a pixel **1300** that can be used in array **630** according to yet another embodiment of the invention. Pixel **1300** is similar to pixel **1000** (Fig. 10) in that it has a fixed IR-absorbing plate **1310a** and a movable IR-absorbing plate **1310b**. However, unlike plates **1010a-b** of pixel **1000**,

which have approximately equal areas, plates **1310a-b** of pixel **1300** have areas that differ by a relatively large factor. For example, in various embodiments of pixel **1300**, the area of plate **1310b** can be greater than the area of plate **1310a** by a factor of about 2, about 10, or about 50. One reason for this area difference is that, although  
5 fixed plate **1310a** absorbs IR radiation, it does not convert the absorbed radiation into mechanical displacement. In contrast, movable plate **1310b** does convert the absorbed IR radiation into mechanical displacement. To increase the sensitivity of pixel **1300** to IR radiation, it is therefore advantageous to harvest most of the IR radiation impinging upon the pixel with movable plate **1310b**.

10 Fixed plate **1310a** is rigidly suspended over a substrate **1302** by being attached to an anchor **1304a** (partially hidden from view in Fig. 13). Movable plate **1310b** is movably suspended over substrate **1302** using anchors **1304a-b**, four bi-material transducers **1308**, and two thermal isolators **1306** that form two suspension arms **1322** for the movable plate. Similar to suspension arms **1022** of pixel **1000** (Fig. 10),  
15 suspension arms **1322** of pixel **1300** compensate for ambient temperature variations.

Although plates **1310a-b** have the IR-absorbing areas that differ in size, these plates have visible-light reflecting areas that have substantially the same size. This characteristic is achieved by mounting on each of plates **1310a-b** a respective reflector **1316** (shown semitransparent in Fig. 13 for clarity) that is adapted to reflect the  
20 interrogating light. More specifically, reflector **1316a** is mounted on fixed plate **1310a** using a support post **1314a** attached to the fixed plate. Note that the area of reflector **1316a** is greater than the area of fixed plate **1310a**, and reflector **1316a** overhangs a portion of movable plate **1310b**. Similarly, reflector **1316b** is mounted on movable plate **1310b** using a support post **1314b** attached to the movable plate.  
25 The area of reflector **1316b** is smaller than the area of movable plate **1310b**. In one embodiment, one or both of reflectors **1316a-b** may overhang at least part of at least one of suspension arms **1322** to increase the relative fill factor of the reflectors.

Fig. 14 shows a top view of a pixel **1400** that can be used in array **630** according to yet another embodiment of the invention. Pixel **1400** has a movable  
30 plate **1410** shaped similar to a double-bladed kayak paddle. More specifically, plate

**1410** comprises two blades (plates) **1418a-b** connected by a shaft **1420**. Plate **1410** is suspended over the substrate using a suspension arm **1422** formed by an anchor **1404**, three bi-material transducers **1408a-c**, and a thermal isolator **1406**. One end of bi-material transducer **1408a** is attached to anchor **1404**, and the other end of that bi-material transducer is attached to isolator **1406**. Each of bi-material transducers **1408b-c** is attached between plate **1418a** and isolator **1406**.

Due to the presence of isolator **1406**, the IR radiation absorbed by plate **1410** causes a temperature increase in the plate and transducers **1408b-c** relative to the substrate. If the material having the larger thermal-expansion coefficient is physically on top of the material having the smaller thermal-expansion coefficient, then the temperature increase causes transducers **1408b-c** to curl down and deflect plate **1418a** toward the substrate. In addition to the deflection, plate **1418a** also becomes tilted with respect to the substrate because of the curled shape (in the "hot" state) of transducers **1408b-c**. This tilt is such that an edge **1428** of plate **1418a** is closer to the substrate than an opposite edge **1430** of that plate. The tilting of plate **1418a** pivots shaft **1420**, which tilts and moves plate **1418b** away from the substrate. Thus, due to IR-induced heating, plates **1418a-b** move in opposite directions, one toward the substrate and the other away from the substrate. This response of plate **1410** increases the magnitude of differential displacement of plates **1418a-b** per unit IR energy, e.g., compared to that of plates **1218a-b** (Fig. 12). This enhanced differential displacement can advantageously be used to achieve for pixel **1400** a relatively high sensitivity to IR radiation.

Fig. 15 shows a top view of an array **1500** that has a plurality of pixels **1400** according to one embodiment of the invention. In particular, Fig. 15 shows one representative way of arranging pixels **1400** to continuously fill a plane. One skilled in the art will appreciate that other arrangements of pixels **1400** can also be used to continuously fill a plane.

Fig. 16 shows a top view of a pixel **1600** that can be used in array **630** according to yet another embodiment of the invention. Pixel **1600** has two IR-absorbing plates **1610a-b**. Plate **1610a** is suspended over a substrate **1602** using two

anchors **1604a-b**, four bi-material transducers **1608a-d**, and two thermal isolators **1606a-b** that form two suspension arms for that plate. Plate **1610b** is similarly suspended over substrate **1602** using two anchors **1604c-d**, four bi-material transducers **1608e-h**, and two thermal isolators **1606c-d** that also form two suspension arm. However, one difference between plates **1610a-b** is that plate **1610b** is attached to its suspension arms via two respective shafts **1620a-b**. Similar to shaft **1420** in pixel **1400**, shaft **1620** in pixel **1600** causes plate **1610b** to move in the opposite direction than that of plate **1610a**. More specifically, if the layer structure of bi-material transducers **1608** is such that, upon heating, plate **1610a** moves toward substrate **1602**, then, upon similar heating, plate **1610b** moves away from the substrate. This response of plates **1610a-b** makes the magnitude of their differential displacement per unit IR energy to be relatively high, which advantageously translates into relatively high sensitivity to IR radiation for pixel **1600**.

Figs. 17A-B show cross-sectional views of a plate **1710** that can be used as plate **1610** according to further embodiments of the invention. Plate **1710** has a base layer **1702**, which itself can contain several sub-layers. One function of base layer **1702** is to provide mechanical support for a relatively thin metal layer **1704**, the exterior side of which can be used as a reflecting region for the interrogating light (see, e.g., Fig. 2). Another function of base layer **1702** is to serve as an IR-absorbing region for plate **1710**.

In one embodiment illustrated by Fig. 17A, the thickness of base layer **1702** is chosen so as to create a resonator for the IR radiation. More specifically, an IR beam **1720** (for illustration purposes shown as propagating at angle to the normal of plate **1710**) impinging upon an air/dielectric interface **1706** is partially reflected from that interface as beam **1722** and partially transmitted as beam **1724**. Beam **1724** is then reflected from a metal/dielectric interface **1708** as beam **1726**. Beam **1726** is then partially reflected from interface **1706** as beam **1728** and partially transmitted as beam **1730**. If the thickness of base layer **1702** is chosen so that beams **1722** and **1730** interfere destructively, then the IR beam becomes substantially trapped between interfaces **1706** and **1708**, while making multiple trips through the base layer.

Because base layer **1702** absorbs a fraction of the IR radiation during each pass, the cumulative IR absorption in the base layer can be made relatively large, e.g., about 60%, which advantageously increases the sensitivity of the corresponding IR detector.

In another embodiment illustrated by Fig. 17B, the thickness of base layer **1702** and the thickness of air gap **G** between the base layer and a substrate **1712** are chosen so as to create a resonator for the IR radiation. More specifically, an IR beam **1740** (for illustration purposes shown as propagating at angle to the normal of plate **1710**) impinging upon a substrate/air interface **1756** is partially reflected from that interface as beam **1742** and partially transmitted as beam **1744**. Beam **1744** is then reflected from interface **1708** as beam **1746**. If the cumulative thickness of base layer **1702** and the air gap is chosen so that beams **1742** and **1746** interfere destructively, then the IR beam becomes substantially trapped between interfaces **1708** and **1756**, while making multiple trips through the base layer, which increases the amount of absorbed IR radiation.

Figs. 18A-B show three-dimensional perspective views of two respective detectors **1800a-b** that can be used in pixel **1600** according to another embodiment of the invention. More specifically, detector **1800a** can be used in place of the detector having plate **1610a**, and detector **1800b** can be used in place of the detector having plate **1610b**. To form a pixel, detectors **1800a-b** can be positioned so that plates **1810a-b** of those detectors are oriented with respect to each other similar to plates **1610a-b** in pixel **1600**.

Each plate **1810** has two respective layers **1812** and **1814** separated by a mesh-like structure **1816**. The extra layer (i.e., layer **1814**) in plate **1810** can be used to improve IR absorption as follows. The materials of and the separation between layer **1812** and substrate **1802** can be chosen, as known in the art, to create a resonator for the IR light. More specifically, a metal layer similar to layer **1704** (see Figs. 17A-B) can be deposited over layer **1812** and the distance between layer **1812** and substrate **1802** be chosen so that an IR beam becomes substantially trapped between them, e.g., as illustrated in Fig. 17B. The intensity distribution of the trapped IR light is not uniform, but rather, has peaks and valleys similar to those of a standing wave. If the

height of structure **1816** is such that layer **1814** is placed at a peak of the intensity distribution, then layer **1814** can absorb IR radiation very effectively, thereby increasing the overall IR absorption in plate **1810**.

Structure **1816** is designed so that, in addition to placing layer **1814** at the prescribed location, it provides good thermal contact between layers **1812** and **1814**. Similarly, shafts **1820a-b** that are analogous to shafts **1620a-b** (Fig. 16) have a bi-layer structure to provide good thermal contact between plate **1810b** and bi-material transducers of the respective suspension arms. Alternative designs for shafts **1820a-b** include increasing the width of the shafts compared to those shown in Fig. 18 and/or using materials having relatively high heat conductance to provide good heat flow to the transducers.

Fig. 19 shows a side cross-sectional view of a detector **1900** according to another embodiment of the invention. Detector **1900** is generally analogous to, e.g., detector **1800**, except that detector **1900** is designed for electrical readout. More specifically, (1) a movable plate **1910** that is supported on a substrate **1902** by a suspension arm **1922** and (2) an electrode **1926** deposited on the substrate form a capacitor that can be used, as known in the art, to implement electrical sensing of the plate's position. A representative description of such electrical sensing can be found, e.g., in the above-cited article by S.R. Hunter, R.A. Amantea, L.A. Goodman, et al.

Although many detectors, pixels, and arrays of the invention have been described in reference to optical sensing of plate displacements, in certain embodiments, they can be adapted for electrical readout. For example, pixels **800**, **1000**, **1100**, **1200**, **1400**, and **1600** can include electrodes deposited on the substrate under the respective plates to form capacitors that are similar to the capacitor formed by plate **1910** and electrode **1926**.

Detectors, pixels, arrays, and MEMS devices of the invention can be fabricated, e.g., as described in commonly owned U.S. Patent Nos. 6,850,354 and 6,924,581 using layered wafers, the teachings of which patents are incorporated herein by reference. Additional layers of material may be deposited onto a wafer using, e.g., chemical vapor deposition. Various parts of the devices may be mapped onto the

corresponding layers using lithography. Additional description of various fabrication steps may be found, e.g., in U.S. Patent Nos. 6,201,631, 5,629,790, and 5,501,893, the teachings of all of which are incorporated herein by reference. Representative fabrication-process flows can be found, e.g., in U.S. Patent Nos. 6,667,823, 6,876,484, 5 6,980,339, 6,995,895, and 7,099,063 and U.S. Patent Application No. 11/095,071 (filed on 03/31/2005), the teachings of all of which are incorporated herein by reference.

As used in this specification, the term infrared radiation covers all of the following spectral bands: (1) visible to near IR, wavelengths from about 400 nm to 10 about 1  $\mu\text{m}$ ; (2) short-wave IR, wavelengths from about 1  $\mu\text{m}$  to about 3  $\mu\text{m}$ ; (3) midwave IR, wavelengths from about 3  $\mu\text{m}$  to about 7  $\mu\text{m}$ ; and (4) long-wave IR, wavelengths from about 7  $\mu\text{m}$  to about 14  $\mu\text{m}$ .

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. 15 Various surfaces may be modified, e.g., by metal deposition for enhanced reflectivity, IR absorption, and/or electrical conductivity, or by ion implantation for enhanced mechanical strength. Differently shaped paddles, arms, anchors, plates, shafts, posts, beams, and/or electrodes may be implemented without departing from the scope and principle of the invention. Detectors of the invention can be variously arrayed to form 20 linear or two-dimensional arrays. Devices and systems of the invention can be configured to operate with CW or pulsed light. Interrogating light can be of any suitable wavelength, e.g., from the near-infrared region, and not necessarily limited to the visible spectrum. Devices of the invention can be formed using one, two or more wafers secured together. Although detectors of the invention have been described in 25 reference to IR radiation, they can similarly be configured to detect other radiation types, e.g., visible light, terahertz radiation, or corpuscular radiation. Various modifications of the described embodiments, as well as other embodiments of the invention, which are apparent to persons skilled in the art to which the invention pertains are deemed to lie within the principle and scope of the invention as expressed 30 in the following claims.

It should be understood that the steps of the exemplary methods set forth herein are not necessarily required to be performed in the order described, and the order of the steps of such methods should be understood to be merely exemplary. Likewise, additional steps may be included in such methods, and certain steps may be  
5 omitted or combined, in methods consistent with various embodiments of the present invention.

Reference herein to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment can be included in at least one embodiment. The appearances of the  
10 phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments necessarily mutually exclusive of other embodiments. The same applies to the term "implementation."

Throughout the detailed description, the drawings, which are not to scale, are  
15 illustrative only and are used in order to explain, rather than limit the invention. The use of terms such as height, length, width, top, bottom, is strictly to facilitate the description of the invention and is not intended to limit the invention to a specific orientation. Similarly, while many figures show the different structural layers as horizontal layers, such orientation is for descriptive purpose only and not to be  
20 construed as a limitation.



CLAIMS

What is claimed is:

1. An apparatus, comprising:  
an array of radiation-absorbing regions supported on a substrate and having first and second pluralities of radiation-absorbing regions, wherein, for each radiation-absorbing region of the first plurality, the region's position with respect to the  
5 substrate is responsive to an amount of radiation incident on the region; and  
an array of reflecting regions, each reflecting region being rigidly fixed to one of the radiation-absorbing regions and being adapted to reflect a respective portion of an interrogating beam of light to form a respective portion of a reflected beam, the array of reflecting regions being adapted to impart onto the reflected beam a spatial phase  
10 modulation pattern that corresponds to a spatial intensity pattern of the radiation incident on the array of radiation-absorbing regions.
2. The invention of claim 1, wherein:  
the incident radiation is infrared radiation; and  
the interrogating beam comprises visible light.
- 15 3. The invention of claim 1, further comprising:  
a lens adapted to receive the reflected beam and form at about a focal plane of the lens an intensity pattern corresponding to said reflected beam; and  
a spatial filter adapted to subject the formed intensity pattern to spatial filtering to convert the spatial phase modulation pattern of the reflected beam into a spatial  
20 intensity distribution of a spatially filtered beam.
4. The invention of claim 3, further comprising:  
a lens assembly adapted to project an image of an object to form the incident-radiation intensity pattern on the array of radiation-absorbing regions, wherein the spatial intensity distribution of the spatially filtered beam creates an interrogating-light  
25 representation of the image.
5. The invention of claim 3, wherein:

the formed intensity pattern comprises a plurality of peaks; and  
the spatial filter is adapted to transmit light corresponding to at least one peak and  
to block light corresponding to at least one other peak.

6. The invention of claim 1, wherein:

5 each radiation-absorbing region of the second plurality has a fixed position with  
respect to the substrate independent of the amount of incident radiation.

7. The invention of claim 1, wherein:

for each radiation-absorbing region of the second plurality, the region's position  
with respect to the substrate is responsive to an amount of radiation incident on the  
10 region; and

in response to the incident radiation,

each radiation-absorbing region in the first plurality is adapted to move toward  
the substrate; and

each radiation-absorbing region in the second plurality is adapted to move  
15 away from the substrate.

8. The invention of claim 1, wherein:

each radiation-absorbing region is a surface portion of a plate;

the plates are arranged to form a plurality of pixels, each pixel having a first plate  
corresponding to the first plurality and a second plate corresponding to the second  
20 plurality; and

for each pixel, the surface area of the radiation-absorbing region of the first plate is  
at least two times greater than surface area of the radiation-absorbing region of the  
second plate.

9. The invention of claim 8, wherein:

25 each reflecting region comprises a reflector mounted on a respective plate; and  
in at least one pixel, a reflector mounted on the second plate overhangs the first  
plate.

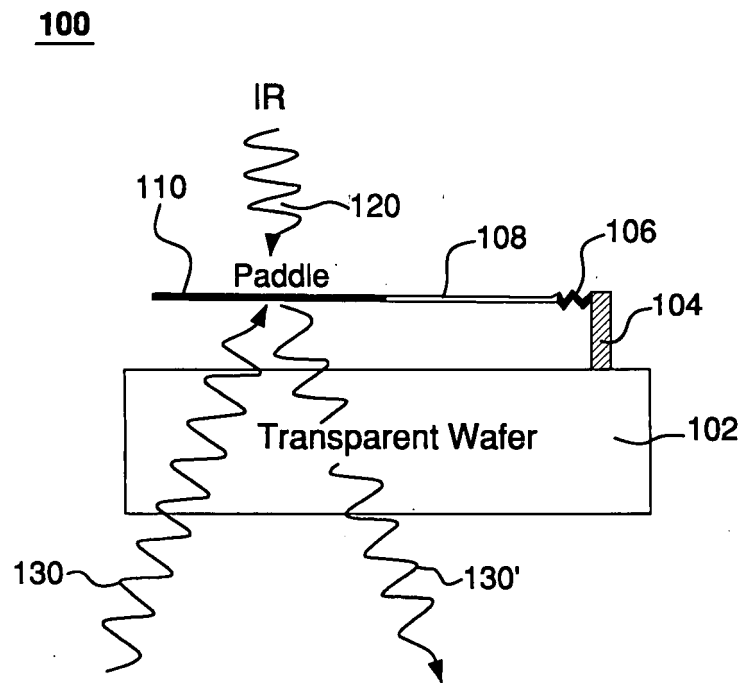
10. A method of detecting radiation, comprising:

receiving radiation using an array of radiation-absorbing regions, wherein:

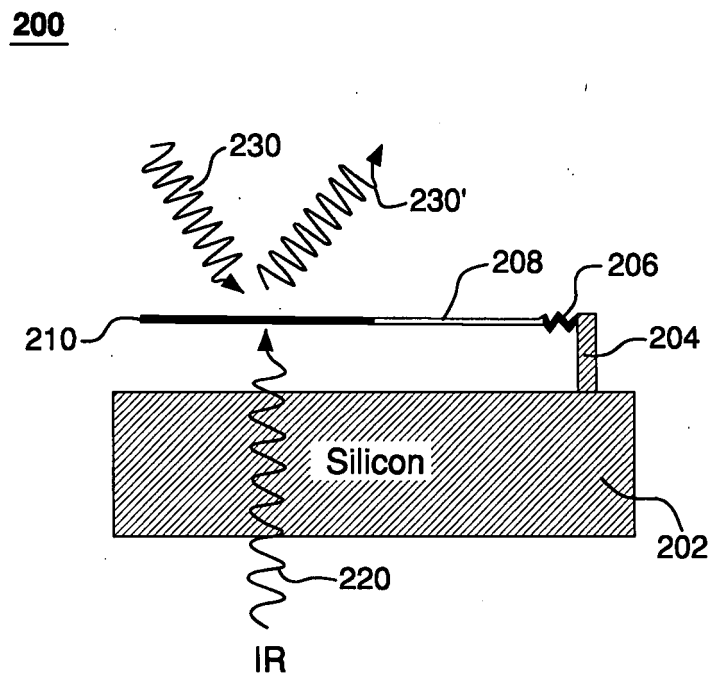
the array of radiation-absorbing regions is supported on a substrate and comprises first and second pluralities of radiation-absorbing regions; and

for each radiation-absorbing region of the first plurality, the region's position  
5 with respect to the substrate is responsive to an amount of radiation incident on the region; and

reflecting an interrogating beam of light using an array of reflecting regions to form a reflected beam having a spatial phase modulation pattern that corresponds to a spatial intensity pattern of the radiation incident on the array of radiation-absorbing  
10 regions, wherein each reflecting region is rigidly fixed to one of the radiation-absorbing regions and is adapted to reflect a respective portion of the interrogating beam to form a respective portion of the reflected beam.



**FIG.1**



**FIG. 2**

FIG. 3A

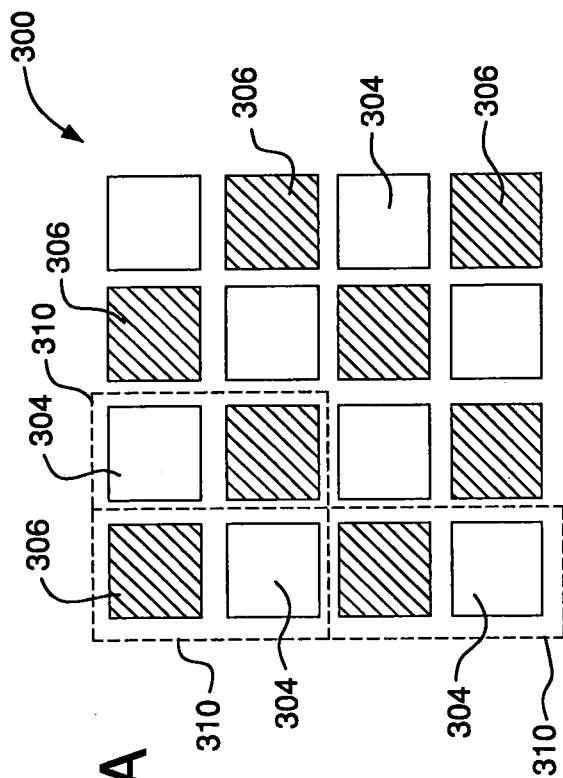
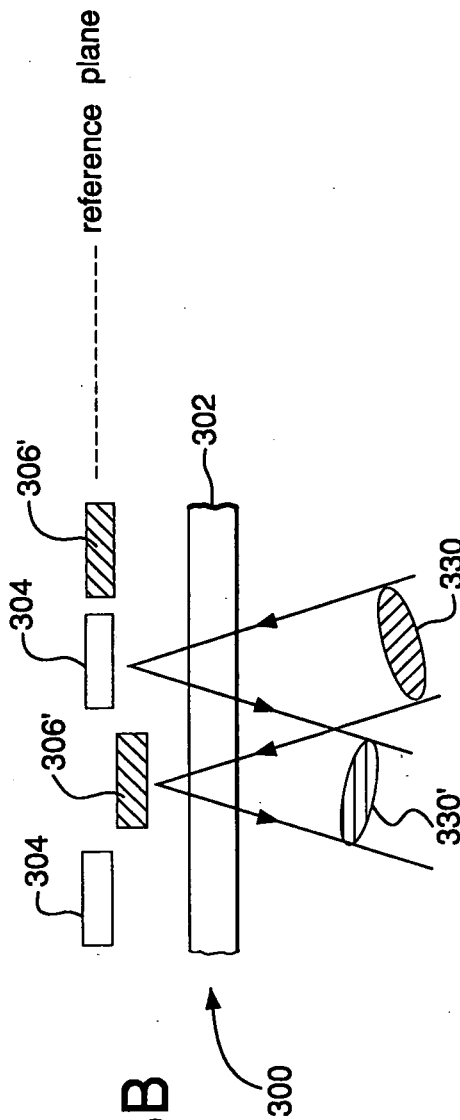


FIG. 3B



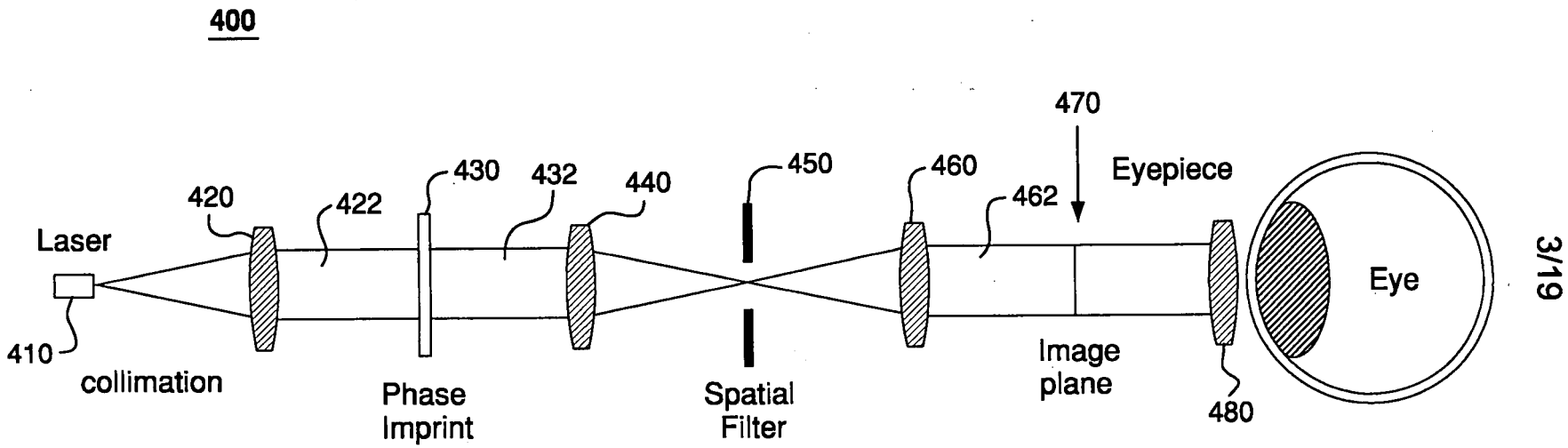


FIG. 4

4/19

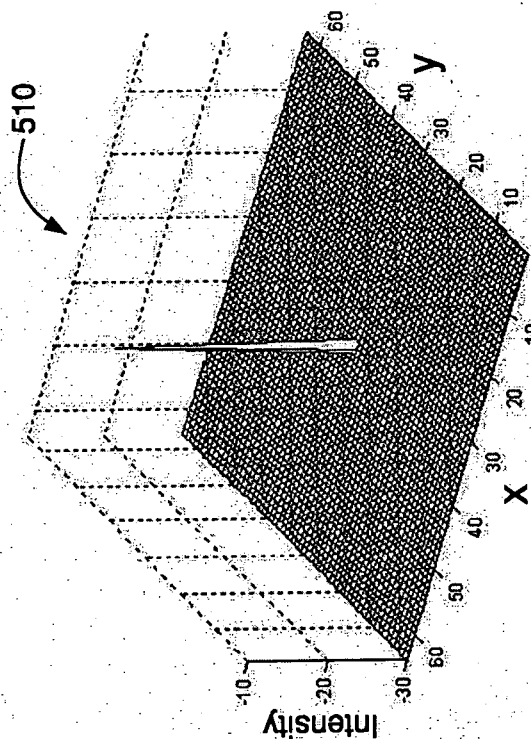


FIG. 5A

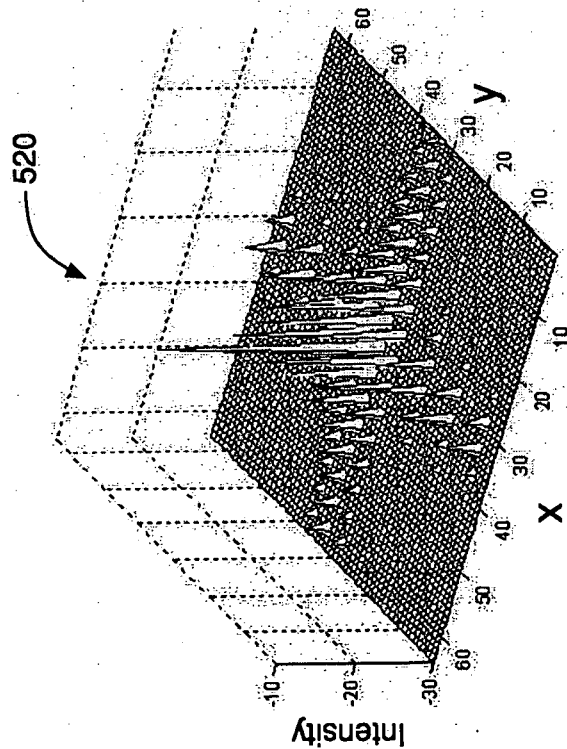


FIG. 5B

5/19

600

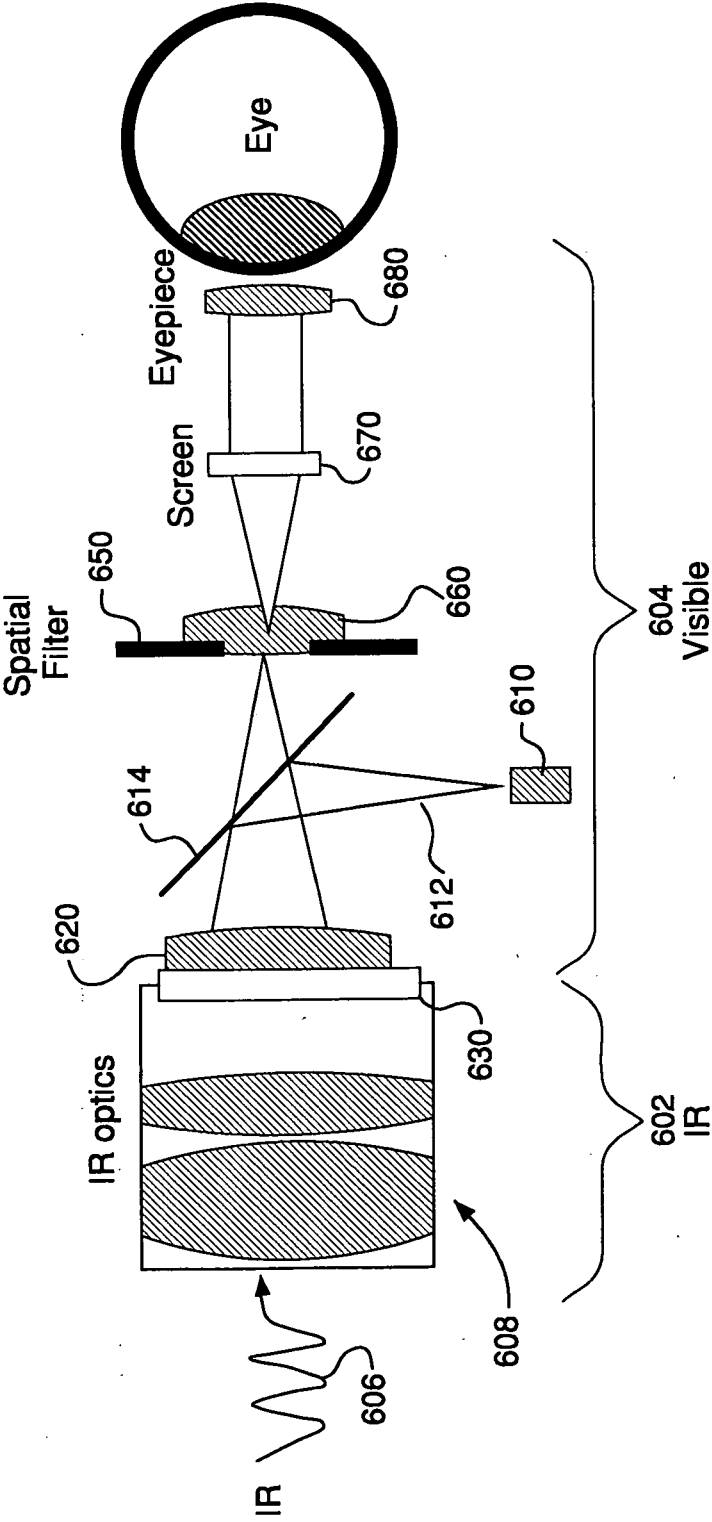


FIG. 6



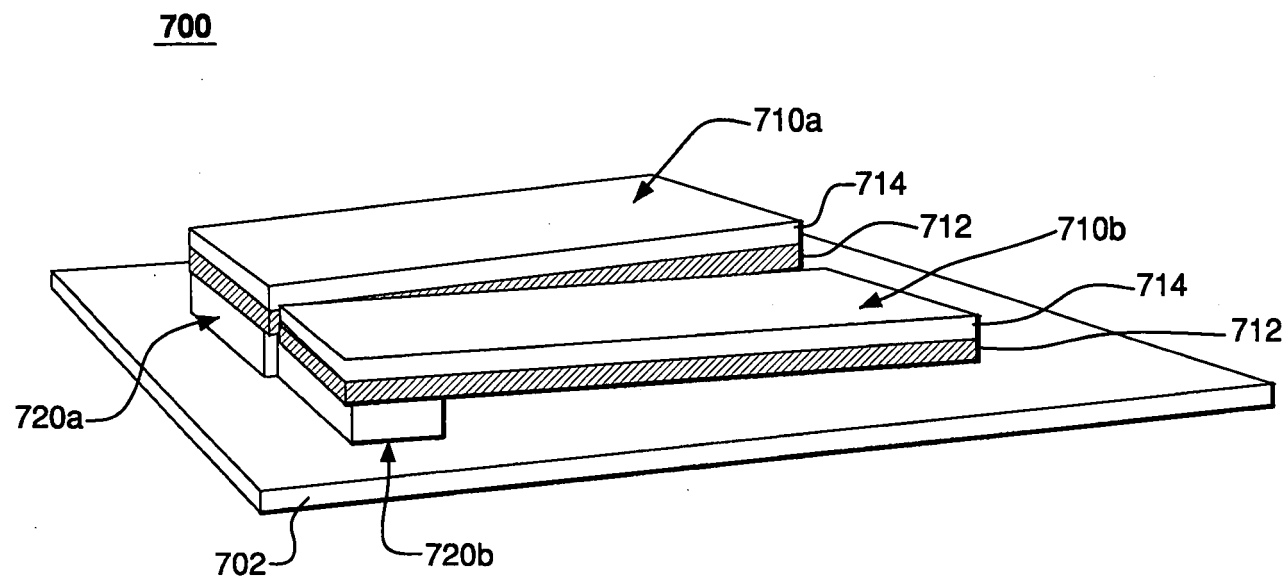


FIG. 7

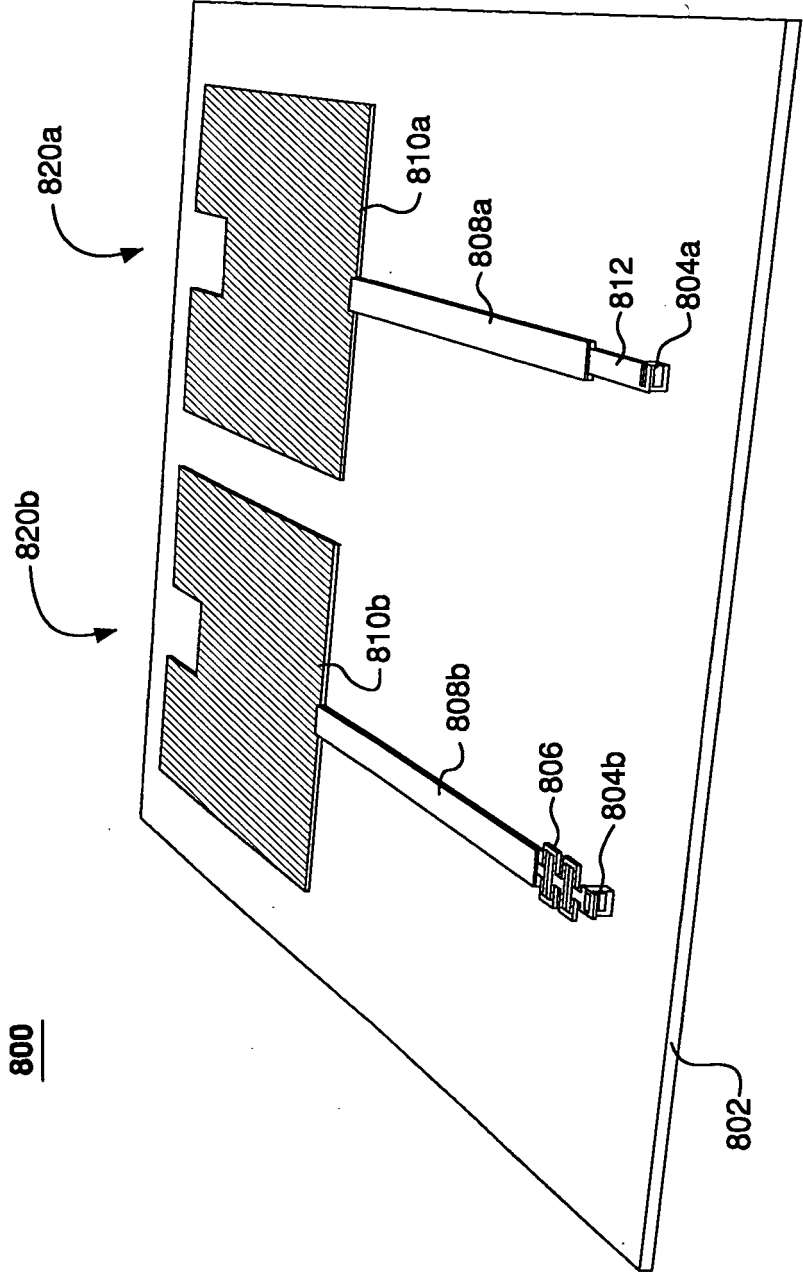


FIG. 8

8/19

900

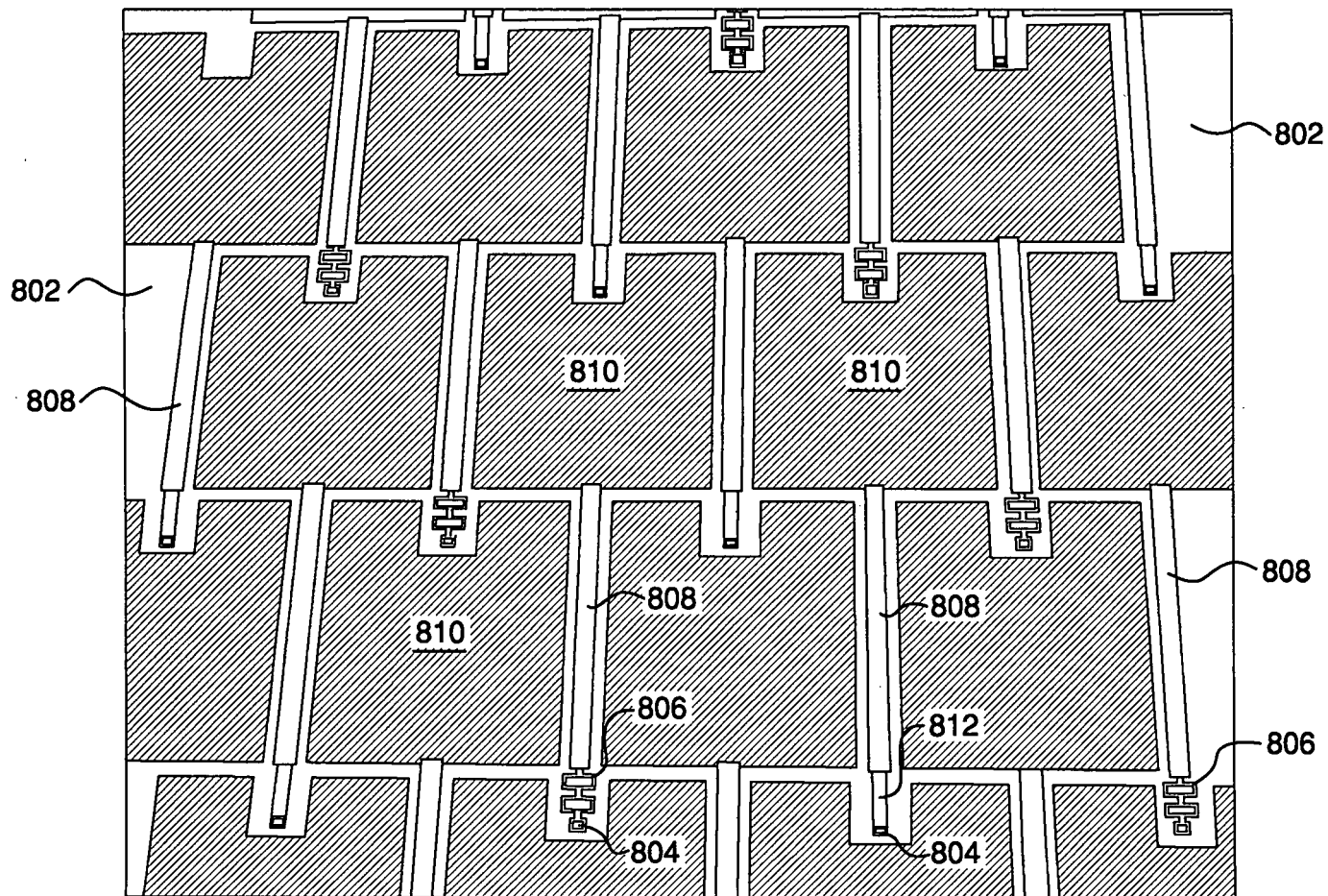


FIG. 9

9/19

1000

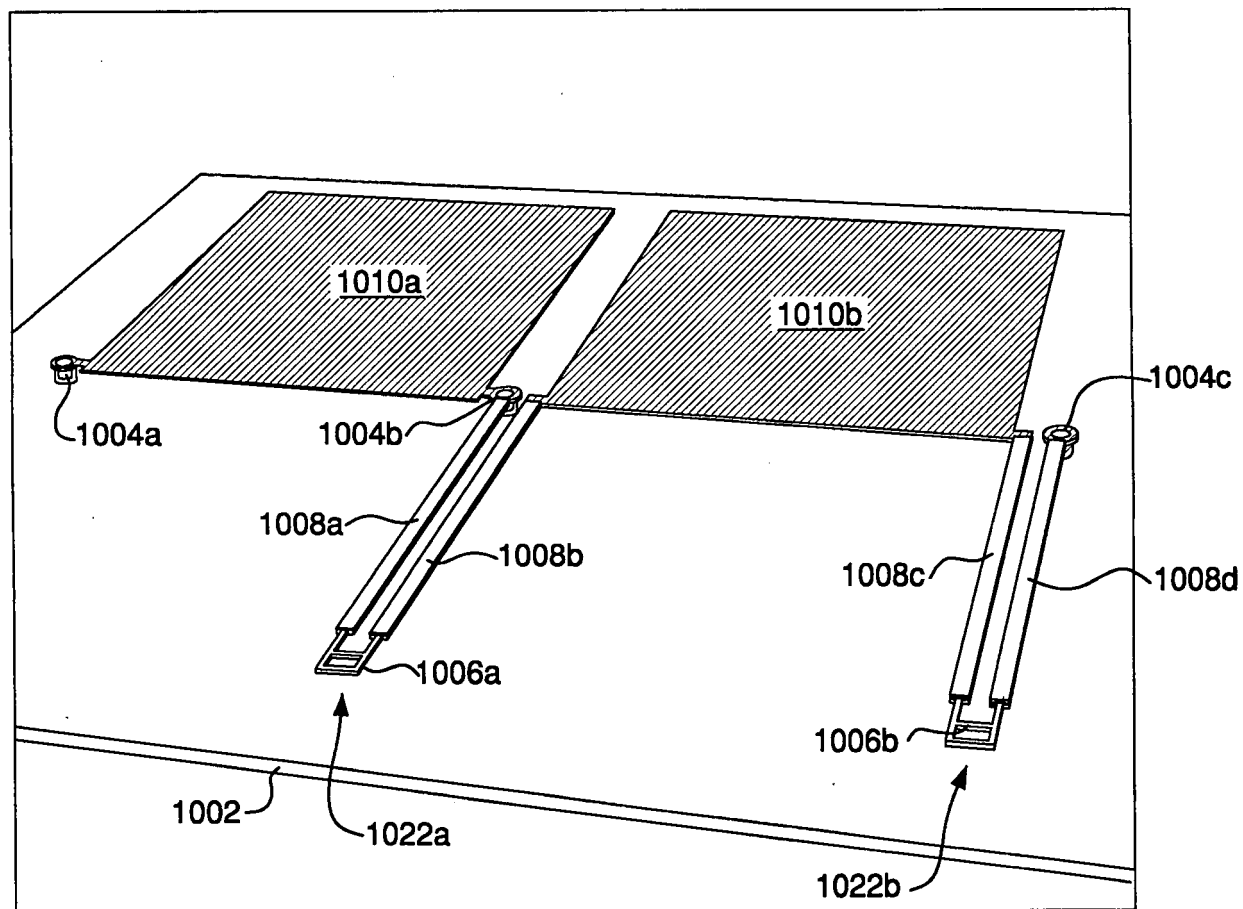


FIG. 10

1100

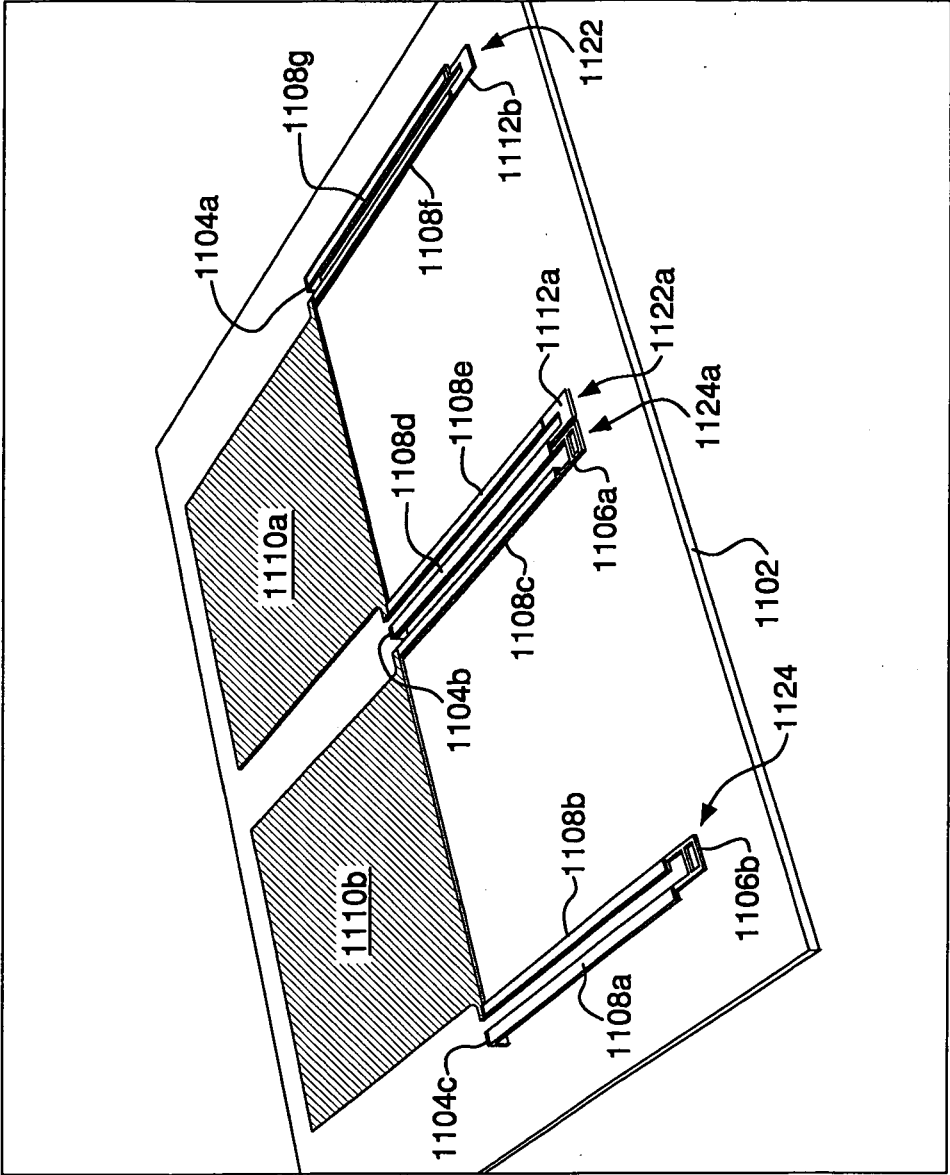


FIG. 11

11/19

1200

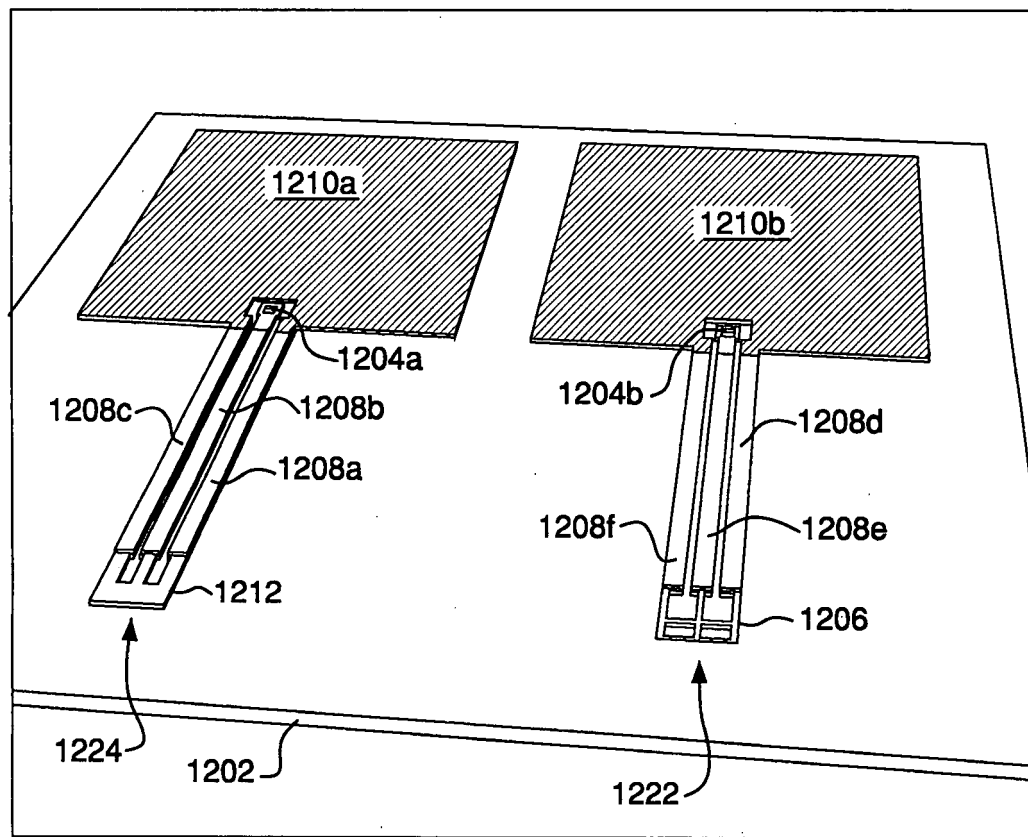


FIG. 12

12/19

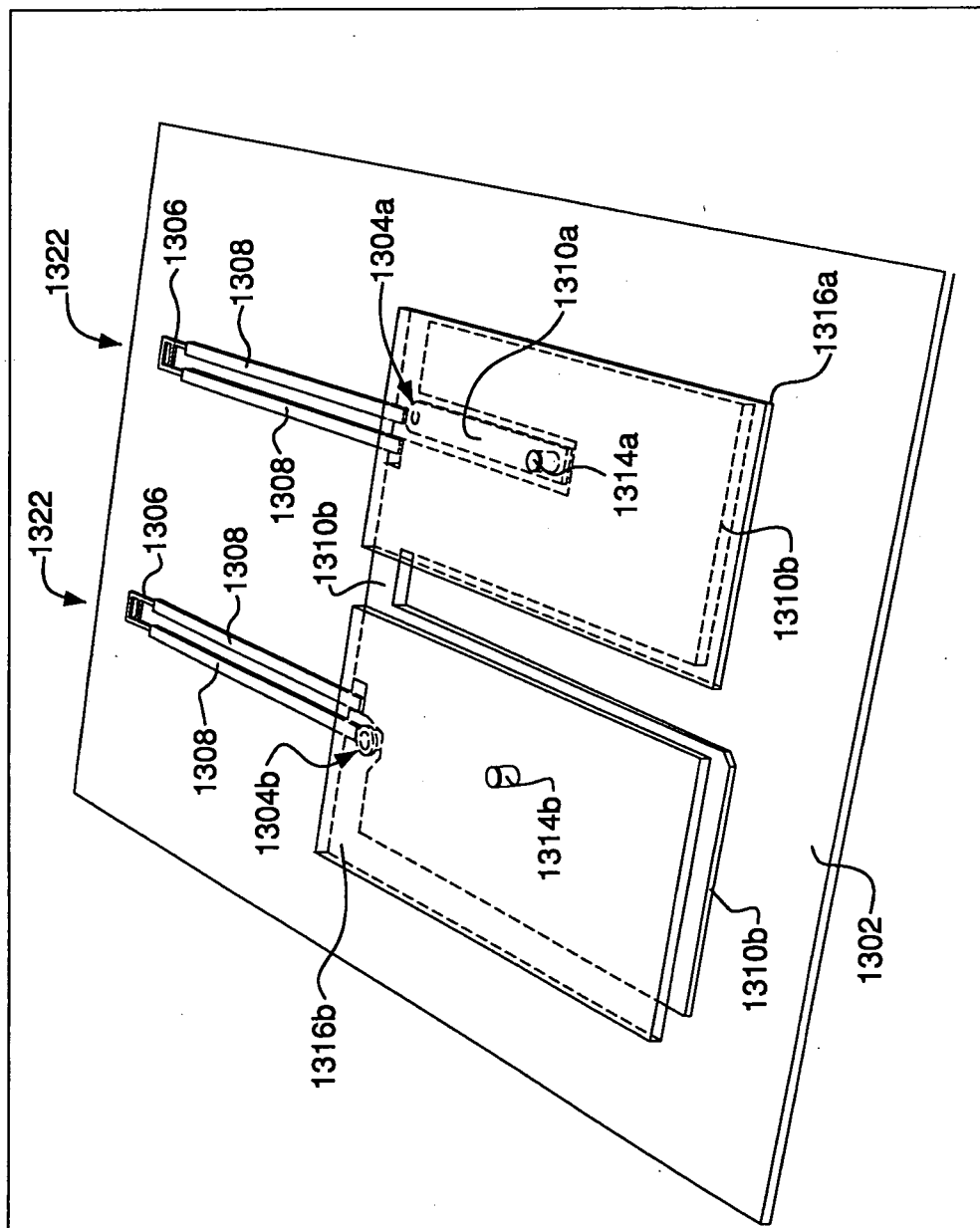
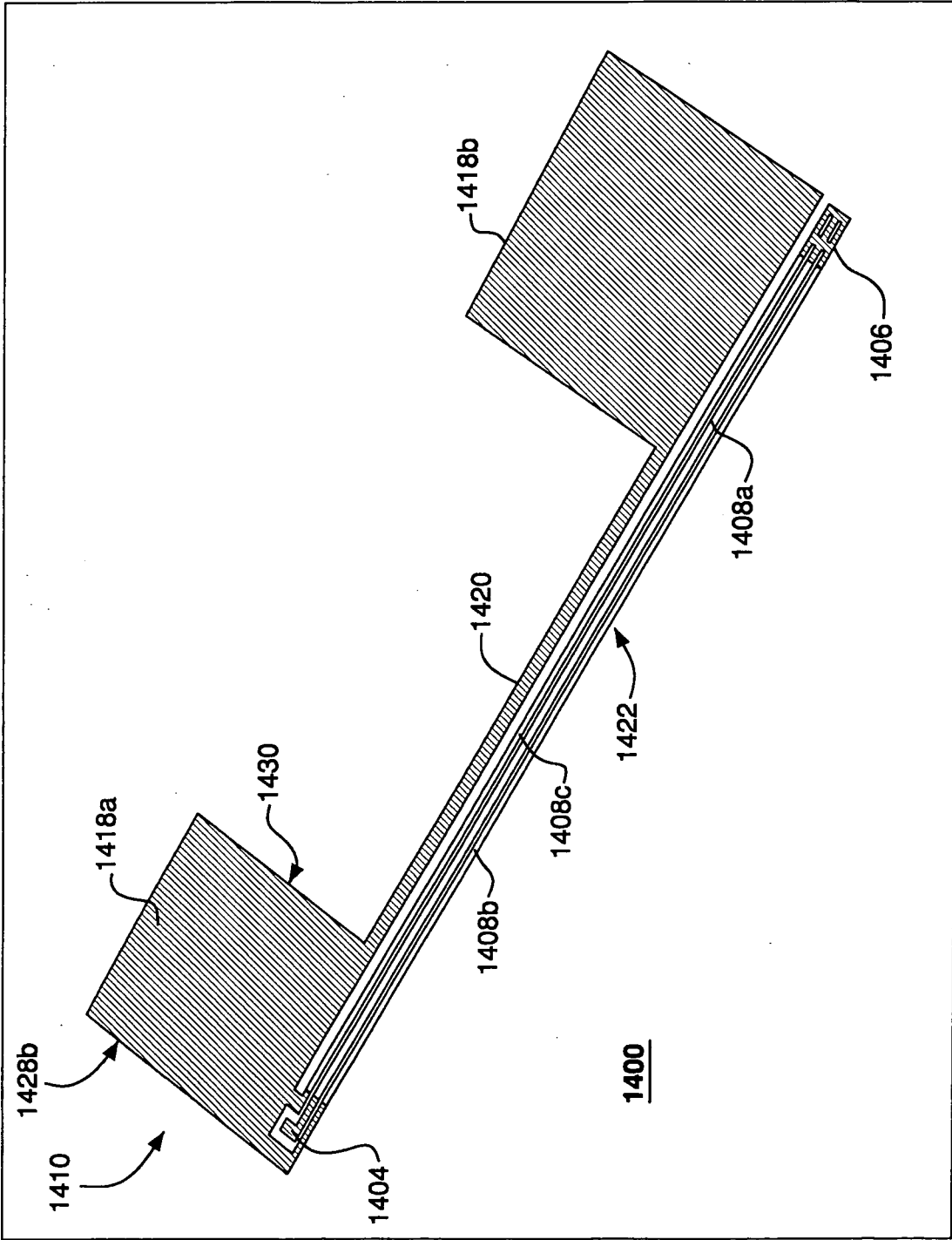


FIG. 13

1300

FIG. 14





1500

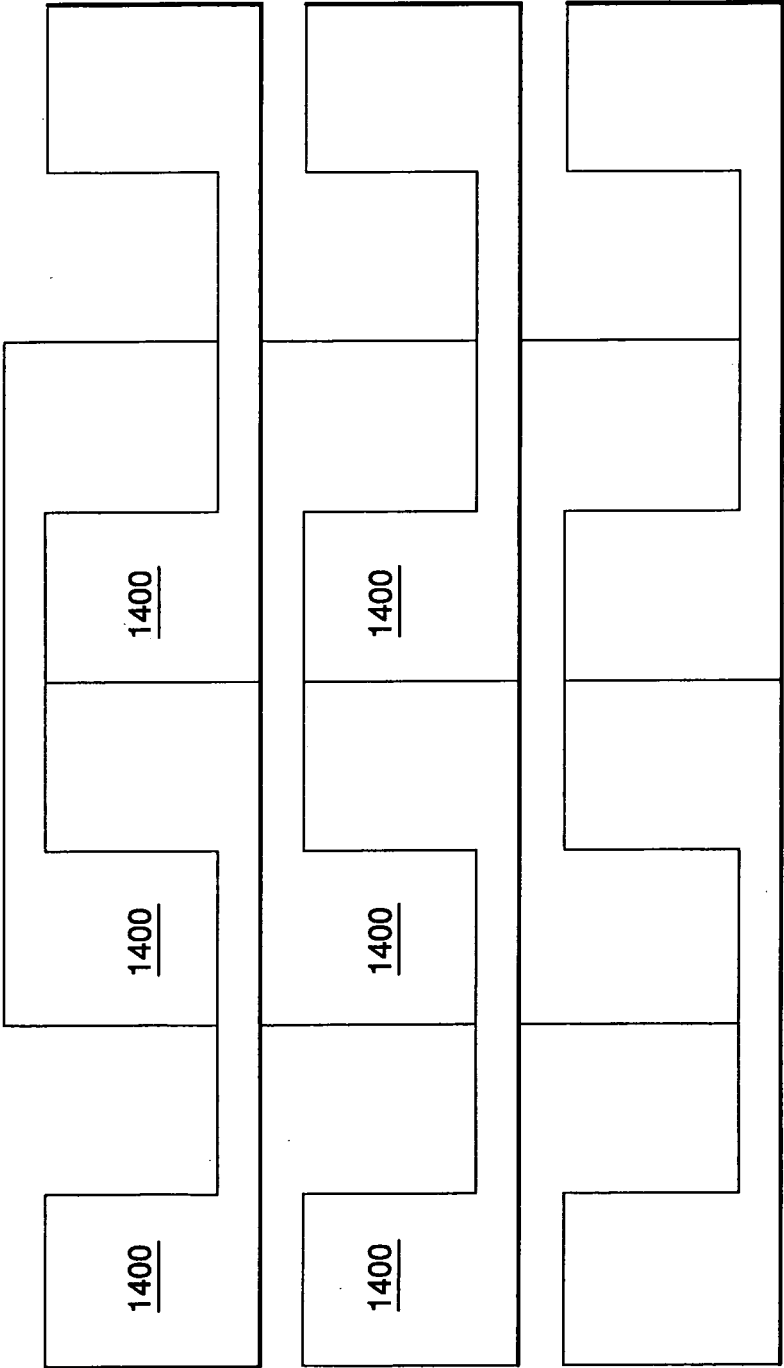
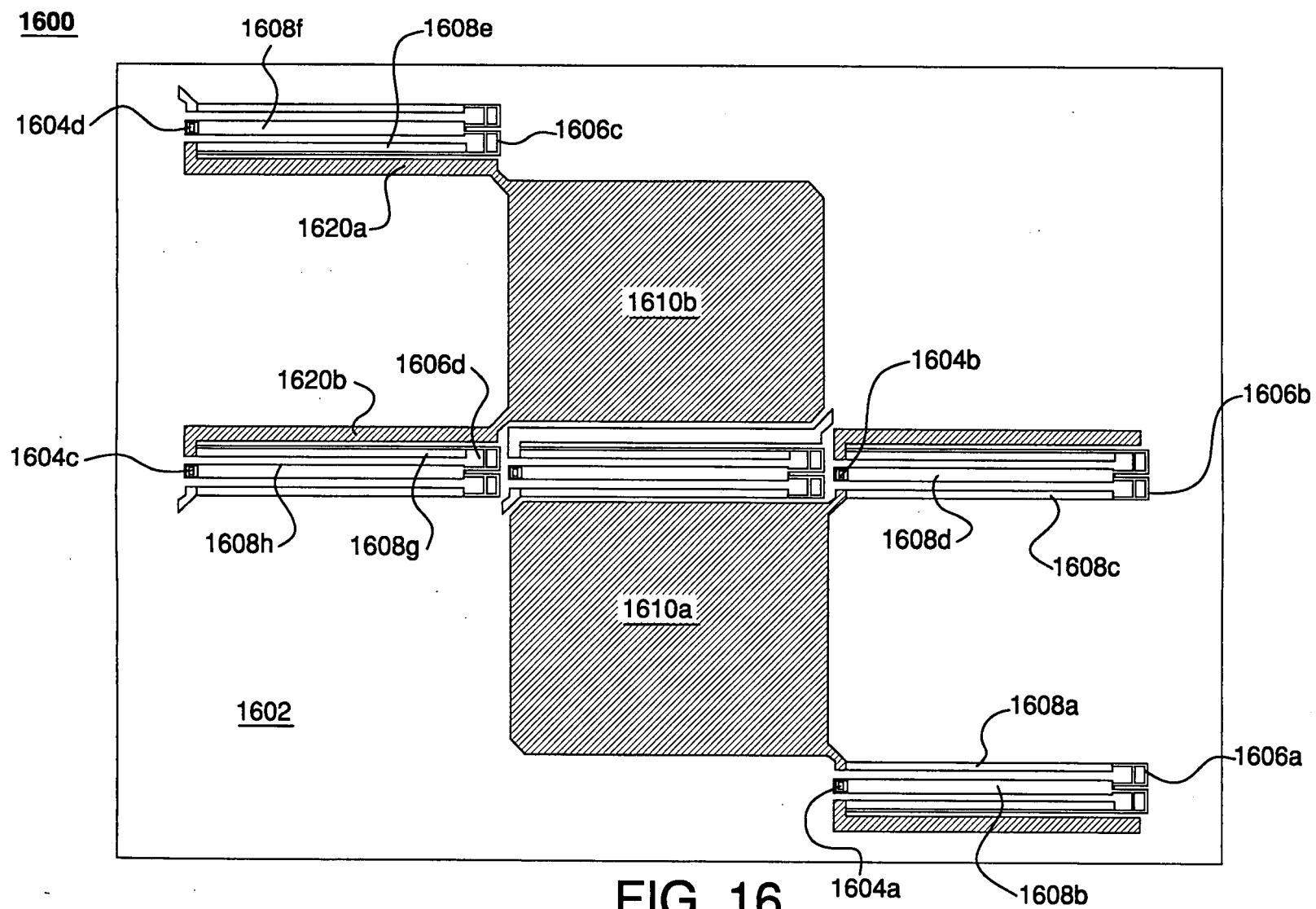


FIG.15

15/19





17/19

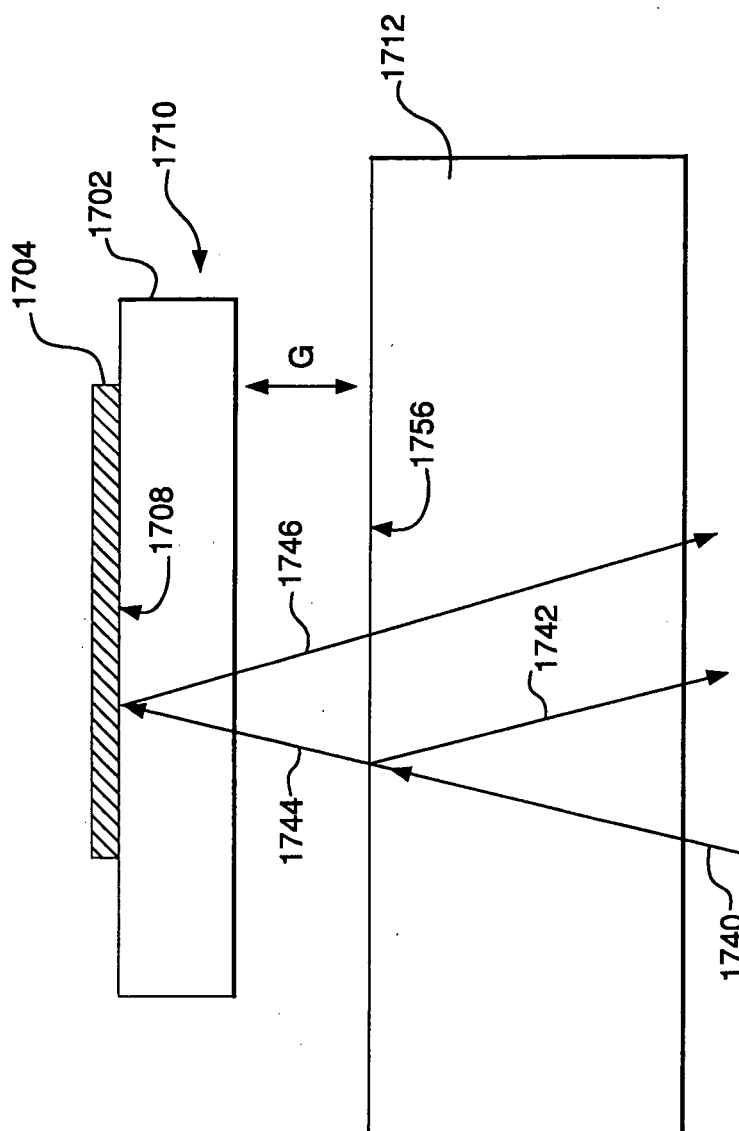


FIG. 17B

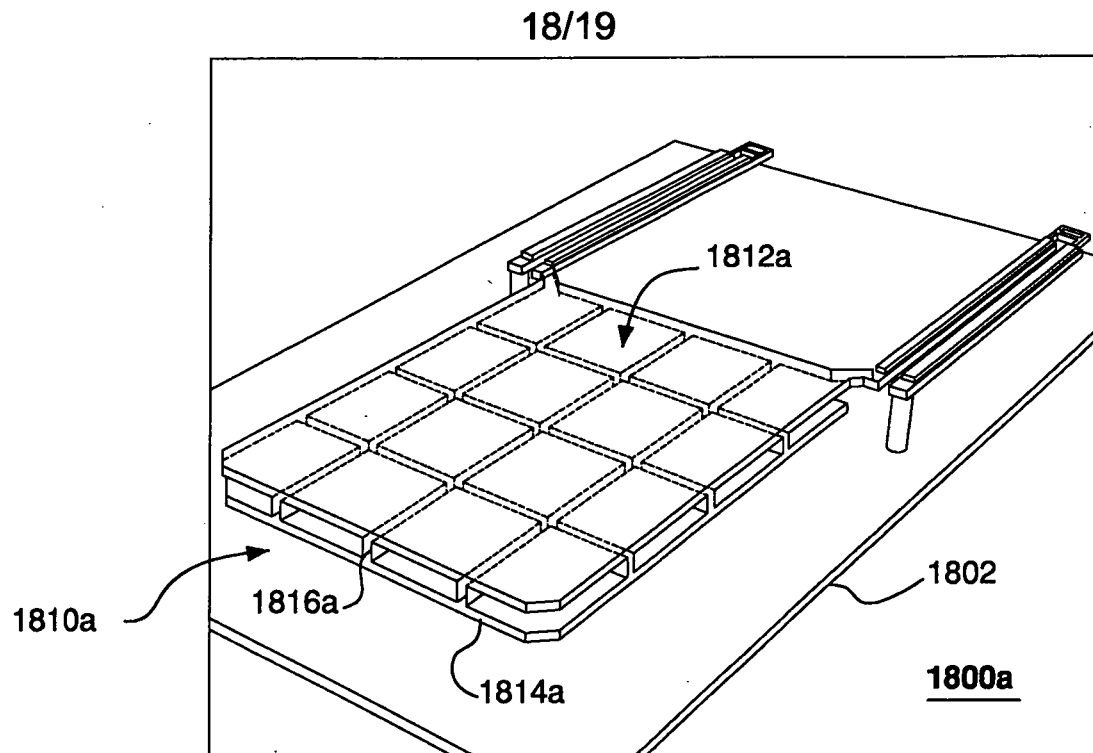


FIG. 18A

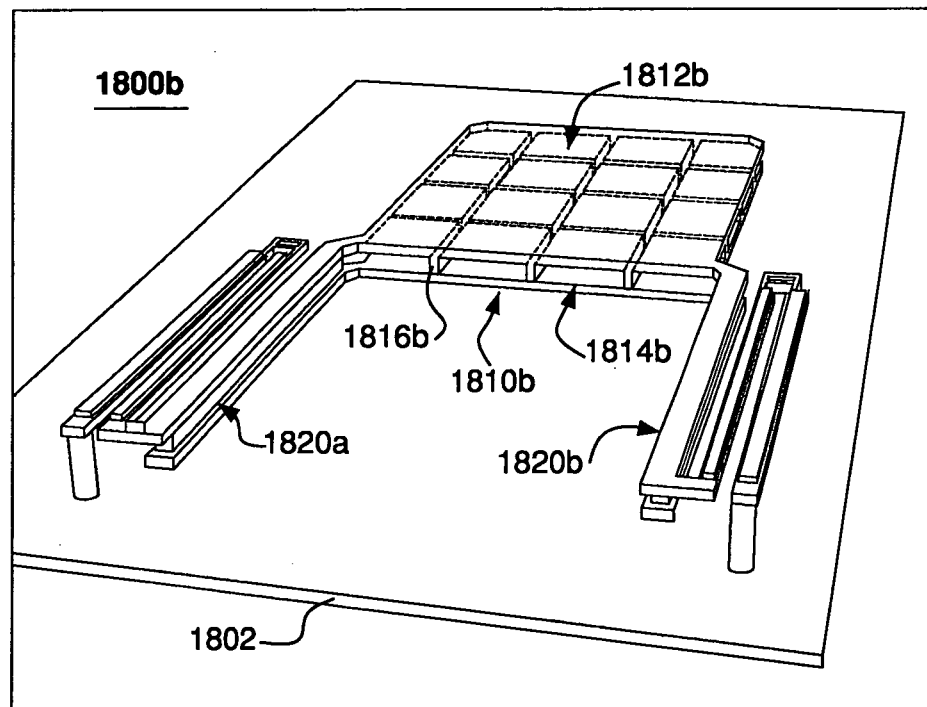
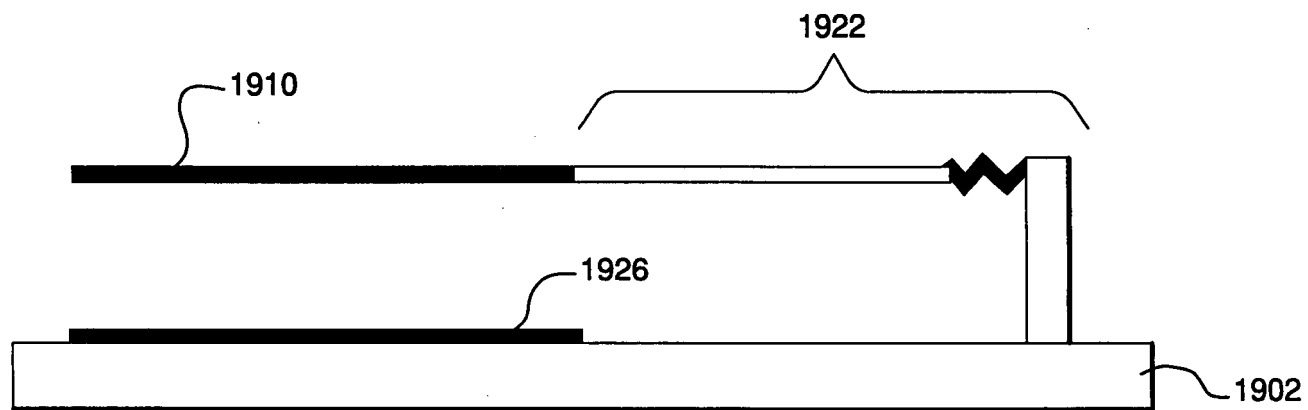


FIG. 18B

1900



19/19

FIG. 19

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2008/007472

## A. CLASSIFICATION OF SUBJECT MATTER

INV. G01J5/40

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
G01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document,* with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 080 988 A (ISHIZUYA TOHRU [JP] ET AL) 27 June 2000 (2000-06-27) figure 10; example 7 -----	1-10
X	US 2003/111603 A1 (SONE TAKANORI [JP] ET AL) 19 June 2003 (2003-06-19) paragraphs [0072], [0073], [0171], [0172]; figures 6, 21 -----	1-10
X	YANG ZHAO ET AL: "Optomechanical Uncooled Infrared Imaging System: Design, Microfabrication, and Performance" JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 11, no. 2, 1 April 2002 (2002-04-01), XP011064755 ISSN: 1057-7157 paragraph [000E]; figure 5 ----- -/-	1-10

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

☒ See patent family annex.

### \* Special categories of cited documents:

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
- \*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- \*X\* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- \*G\* document member of the same patent family

Date of the actual completion of the international search

4 November 2008

Date of mailing of the international search report

12/11/2008

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040,  
Fax: (+31-70) 340-3016

Authorized officer

Rödig, Christoph

## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2008/007472

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>ISHIZUYA T ET AL: "160 x 120 pixels optically readable bimaterial infrared detector"</p> <p>PROCEEDINGS OF THE IEEE 15TH. ANNUAL INTERNATIONAL CONFERENCE ON MICRO ELECTRO MECHANICAL SYSTEMS. MEMS 2002. LAS VEGAS, NV, JAN. 20 - 24, 2002; [IEEE INTERNATIONAL MICRO ELECTRO MECHANICAL SYSTEMS CONFERENCE], NEW YORK, NY ; IEEE, US, vol. CONF. 15, 1 January 2002 (2002-01-01), pages 578-581, XP010577721 ISBN: 978-0-7803-7185-9 figure 3</p> <p>-----</p>	1-10



# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2008/007472

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 6080988	A	27-06-2000	NONE	
US 2003111603	A1	19-06-2003	FR 2833702 A1 JP 2003185496 A	20-06-2003 03-07-2003