United States Patent

De Vaux et al.

[15] 3,693,011

[45] Sept. 19, 1972

[54] **ION IMPLANTED BOLOMETER**

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[22] Filed: **Feb. 2, 1971**

[21] Appl. No.: **111,917**

[52] **U.S. Cl.** .....**250/83.3 H**, 250/83 R, 73/355 R

[51] **Int. Cl.**.....**G01j 5/10**

[58] **Field of Search** .....250/83 R, 83.3 H; 73/355 R; 338/18

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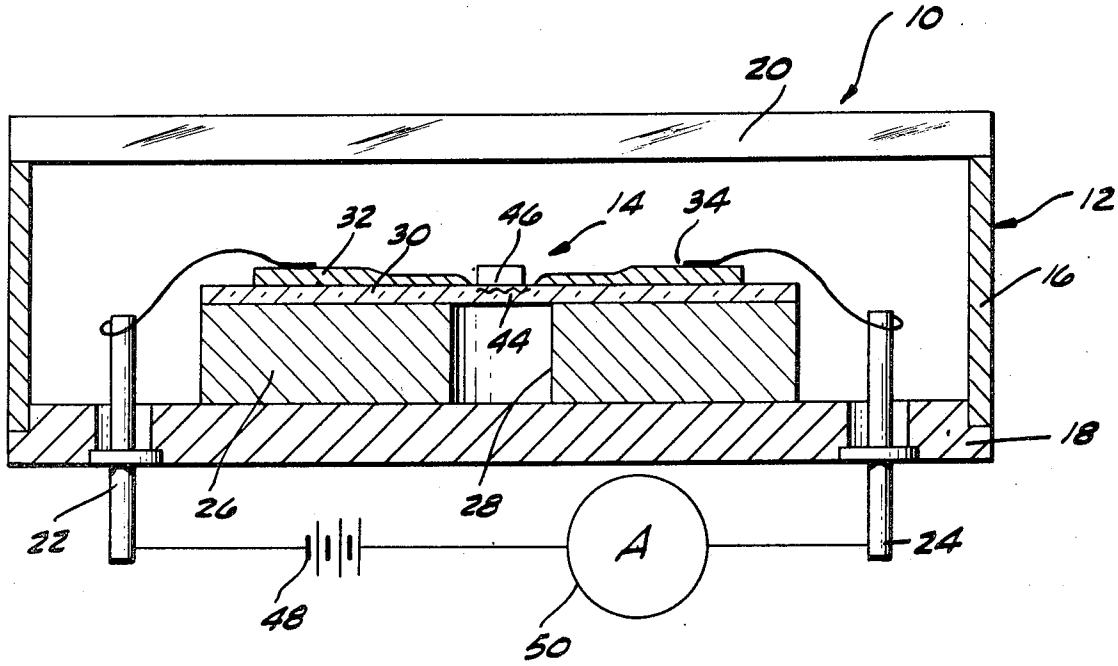
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[57] **ABSTRACT**

The bolometer comprises an insulator material having sufficient metal ions implanted therein to provide a zone of electrical resistivity. Resistance of the implanted zone is a function of temperature, which temperature is a function of the intensity of incident electromagnetic radiation. Electrical connections are made thereto and a bias voltage can be applied so that current therethrough indicates temperature. The implanted bolometer can be a thin device for low thermal capacity, or can be part of or attached to a lens in an optical system.

11 Claims, 4 Drawing Figures



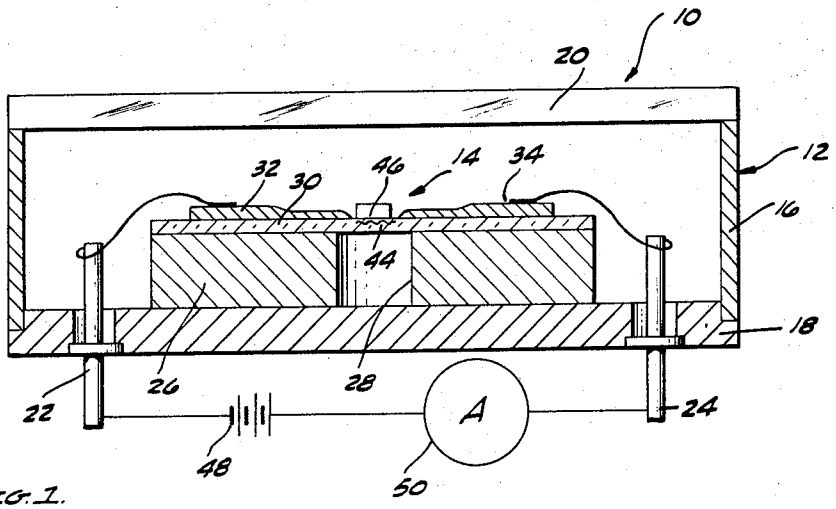


FIG. 1.

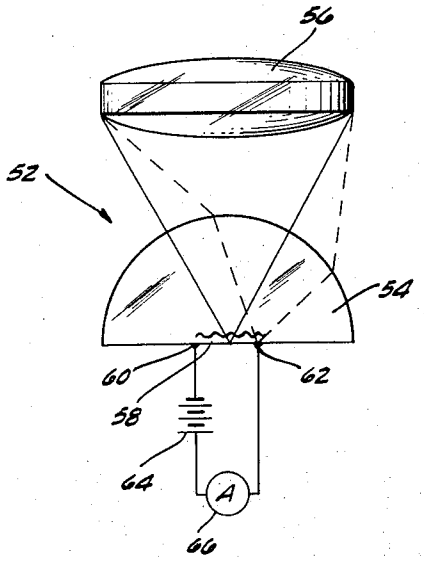


FIG. 4.

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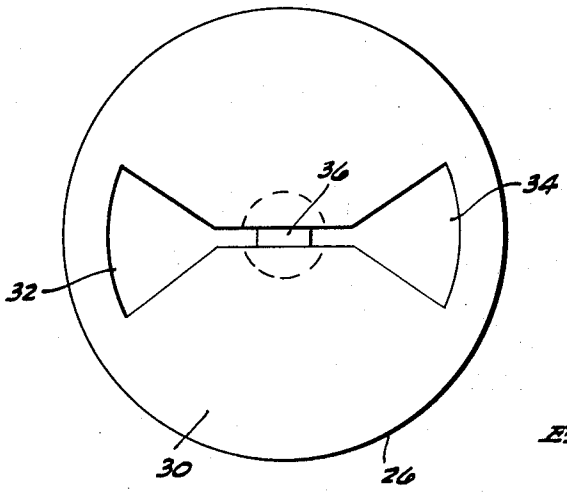


FIG. 3.

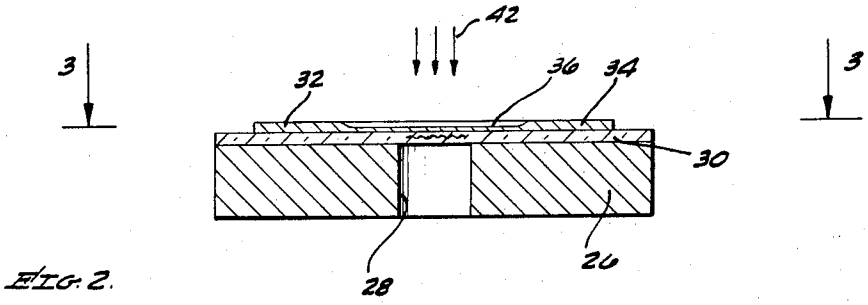


FIG. 2.

ION IMPLANTED BOLOMETER

BACKGROUND

This invention is directed to an ion-implanted bolometer, which is a device used to measure electromagnetic radiation and comprises a resistance element which changes in resistance with changes in temperature. The resistance element is a zone of metallic ions implanted into an insulator.

Present thin film thermistor bolometers are fabricated by sintering combinations of metal oxides to form thin flakes. The flakes are then cut to size and cemented to a substrate. Such fabrication and assembly techniques are not suited to the manufacture of high density multi-element thermal detector arrays which are currently of great importance in infrared systems.

Another thermal detector, the evaporated thin film thermopile, can be fabricated precisely in relatively dense array configurations. However, this type has the disadvantage of low responsivity compared to the thermistor bolometer, and requires a number of careful processing steps to fabricate the large number of thermocouples and interconnections inherent in its design. In contrast, the ion-implanted bolometer of this invention has the advantage of high responsivity, ease of fabrication, and the ability to be made in dense array configurations. Its manufacture is compatible with well-established evaporative metal coating and ion beam technologies.

Another type of device which can be employed as a bolometer is a barretter. It consists of a fine wire or metal film having a positive temperature coefficient of resistivity. It is sometimes used for making power measurements in microwave devices.

The present bolometer is an electrical resistor device which has large resistance changes as compared to temperature changes. However, it is quite different from those previously known, because it comprises metal ions implanted into a zone in an insulator to create an electrically resistive zone, the resistance of which is a function of temperature.

As used throughout this specification, the term insulator refers to a non-metallic solid state material with an apparent resistivity in excess of 10^9 ohm-centimeter at room temperature. Prior efforts at creating electrically conductive regions within insulators have been ineffectual because of the difficulty inherent in doping an insulator. The prior efforts have been principally directed at doping by diffusion. Doping is usually understood to be the addition of a subtle (less than 1 in 10^3) amount of impurity atoms of a solid to grossly change its electrical properties, while leaving other properties essentially unaltered. The purpose of diffusing dopants into an insulator is to produce impurity centers which can contribute charge carriers to the conduction process. However, this approach is seldom successful. Insulators are not, in general, amenable to being produced in a state of high purity, and hence a large background concentration of impurities is often present. In addition, the charge associated with impurities is often localized on the impurity site and, hence, cannot contribute to conduction. Amorphous insulators are an even more complex situation; large numbers of defect centers and unsatisfied bonds act to render conventional doping approaches unfeasible.

The inventive technique propounded herein, in contradistinction to the conventional doping approach, is to implant a massive local concentration of metallic ions in the insulator. Conduction occurs by the interaction of these implanted ions, either directly or in conjunction with the electronic environment provided by the host insulator.

SUMMARY

In order to aid in the understanding of this invention, it can be stated in essentially summary form that it is directed to a new composition of matter which has a large change in electrical resistance with change in temperature; has connections thereto for the measurement of electrical resistance; and has means to direct electro-magnetic radiation thereon so that the amount of electro-magnetic radiation is indicated by the electrical resistance.

Accordingly, it is an object of this invention to produce a new composition of matter which comprises metallic ions implanted into an insulator material to a sufficient extent to provide electrical conductivity in the implanted volume, which implanted volume has a high thermal coefficient of resistance and can be employed for temperature measurement. It is another object to direct electromagnetic radiation onto a temperature sensitive device comprised of metallic ion implanted insulator to measure the quantity of the incoming electromagnetic radiation in accordance with resistance changes in the implanted volume.

Other objects and advantages of this invention will become apparent from the study of the following portion of the specification, the claims, and the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a transverse section through a preferred embodiment of the bolometer of this invention.

FIG. 2 is a transverse section through a portion of the bolometer at an intermediate stage of manufacture.

FIG. 3 is a plan view taken along the line 3—3 of FIG. 2.

FIG. 4 is a transverse section through another species of the bolometer of this invention.

DESCRIPTION

FIG. 1 illustrates the preferred embodiment of the bolometer of this invention, indicated at **10**. Bolometer **10** has a housing **12** in which is located the electromagnetic radiation sensitive structure **14**. Housing **12** has sidewalls **16**, bottom **18**, and top **20**. Top **20** is substantially transparent to the electromagnetic radiation to be detected so that the electromagnetic radiation can be directed through top **20** onto the sensitive structure **14**. Housing **12** can be constructed so that it can be evacuated and sealed to maintain a substantial vacuum environment around the sensitive structure. Electrical connectors **22** and **24** pass through bottom **18** to permit connection of electrical devices.

Referring to FIGS. **1**, **2**, and **3**, base **26** supports the electromagnetic sensitive structure **14**. Base **26** has a central hole **28** therein. A layer of insulator material **30** is positioned on top of and is secured to base **28**. In the preferred embodiment, base **26** is sapphire, which is

crystalline aluminum oxide (Al_2O_3), while the insulator material **30** is a thin sheet of alumina, which is amorphous aluminum oxide. When the sensitive area is about 1 cm square, the hole has a diameter of about 2 cm and material **30** is about .05 cm thick. The base is chosen to be of the same material for thermal expansion purposes. It could be just as well made of alumina as sapphire.

Vapor-deposited on top of the insulator material layer are pads **32** and **34** which has connector **36** therebetween, passing over the opening **28**. A portion of pads **32** and **34** is pre-evaporated to build up sufficient thickness for bonding. As is seen in FIG. **1**, electrical connection is respectively accomplished between connector **22** and pad **32**, and connector **24** and pad **34**. The pads **32** and **34** are preferably thicker than connector **36**, to aid in the mechanical connection. Connector **36** will define the active region by virtue of surface charge masking. Pads **32** and **34** and connector **36** are preferably formed by vapor-deposited gold.

In the embodiment shown in FIGS. **1** through **3**, the portion of the insulator material **30** which is chosen for implantation is defined by the thin connector region **36**. This portion has a low thermal mass, if it is located over central opening **28**.

An ion beam **42** is directed toward connector **36** and insulating material **30**. The ion beam **42** has sufficient energy to implant metal ions through connector **36** and into the insulating material **30**. The implanted zone is controlled in geometrical extent by surface charge masking and, hence, conforms to the shape of connector **36**. During implantation, the connector **36** is grounded to drain off the charge, which results from the ion beam, to permit implantation therethrough. Implantation continues for an adequate length of time to provide an implanted thermally responsive resistor zone. As an example, antimony ions are implanted by a beam having an average beam current of 50 microamperes and a beam voltage of 12 keV for 60 minutes. This is an ion dose equivalent to about 1,000 monolayers delivered to the surface, or about 10^{18} ions per square centimeter, which is considered to be the minimum dosage to render the implanted zone resistive instead of insulative. The resultant sheet resistance was approximately 10^5 ohms per square after implantation, as compared to a value of greater than 10^{12} ohms per square for the unimplanted insulative layer, both at 20° C. The resistance of the implanted region changes rapidly with changes in temperature.

While antimony implanted into alumina is the example given, metallic ions selected from the group consisting of silver, gold, antimony, aluminum, copper and gallium and many others can be employed. Furthermore, the insulative material can be any material selected from viscous liquid, monocrystalline insulator material, amorphous insulator material, including the group consisting of alumina, sapphire and glass, insulating metallic oxides, metallic nitrides, metallic carbides, Al_2O_3, AlN and CoO_2.

During implantation, the connector **36** and at least one of the pads **32** and **34** are connected to system ground to prevent any surface charge buildup which would prevent implantation. In the preferred embodiment, this happens naturally, since **36** is an extension of **32** and **34**. During implantation, much of the connector **36** is sputtered away. However, the ends of the pads **32** and **34** remain connected to the edges of the resistive zone to make electrical connection thereto. If necessary, additional metallic deposition between the pads and the edges of the resistive zone can be accomplished to provide the necessary connection.

In order for implantation to be effective, the metal layer of connector **36** must be sufficiently thin that something is driven into the substrate. That which is driven in is both the incoming ion beam and atoms from the connector **36** of electrically conductive material. In addition, the incoming ion beam causes sputtering of the surface. The presence of a metal film affects the sputtering rate. The ion dose is large and, thus, the ratio of ions arriving in the beam to the ions lost by sputtering is important. Normally, the metal connector layer **36** is sufficiently thin that at least part of the incoming ion beam passes therethrough and is implanted into the insulative substrate, part of the layer is sputtered away, and part of the thin film layer is driven into the insulative substrate. As the implantation proceeds, the metal connector layer **36** may be completely sputtered away and driven in, so that no identifiable layer continues to exist. In this case, the conductivity of the implanted region must be sufficient to dissipate the surface charging affect, if implantation is to continue.

As a result, there is a tradeoff between sputtering and implantation. As long as the metal film continues to exist, it participates in the implantation and in the sputtering.

Finally, when the metal film is sputtered away, equilibrium between implantation and substrate sputtering occurs. Equilibrium is dependent upon the energy of the incoming ions and the sputtering rate of the insulative material **30** upon which the incoming ions impinge. The ions penetrate only a short distance, on the order of tens to hundreds of angstroms. Maximum concentration is achieved in a localized region, as an equilibrium is reached between the number of incoming ions and the sputtering rate. Typically, peak concentrations of 10^{22}/ cm^3 are feasible. We have found that the minimum total number of ions which must be delivered to the insulator surface to achieve saturation concentration is on the order of **1,000** monolayers (i.e., 10^{18} ion per square centimeter).

With respect to patterning of the area which is implanted, surface charging by the incoming ion beam causes reflection of ions, except where the surface charge is drained away. As described above, this is accomplished by the placement of a metal film. Since implantation thus occurs only in the area where the metal film occurs and is appropriately grounded to prevent surface charging, the surface charge results in a masking effect. By this means, the area to be implanted can be designed and its lateral outline shaped by placing the charge removal metal film where implantation is desired. Surface charge masking is fully effective to laterally shape the implanted areas. After the metal film is sputtered away, there is an implanted region therebelow which is sufficiently conductive that implantation continues to occur only in those areas which had been positioned under the metal film. If the ion beam is of sufficient lateral scope, additional masking is not necessary. The pads **32** and **34** are sufficiently thick

to not be sputtered away and surface charge masking prevents implantation into any portion other than those covered by the pads **32** and **34** and connector **36**. Thus, mechanical masking is not necessary, but surface charge masking can be solely employed to define an effective area or zone under the connector **36** which is implanted.

After implantation is completed, a heat-absorbing coating **46** is optionally positioned over the resistive zone. The absorbing coating can be a matte black coating to minimize energy reflection.

After the electromagnetic radiation sensitive structure **14** is completed, it is optionally placed in the housing **12**, as indicated in FIG. **1**. Electrical connections are made between the pads and the electrical connectors **22** and **24**. When electromagnetic radiation is directed onto the heat-absorbing coating, or the resistive zone **44**, the resistive zone **44** is heated. Since the electrical resistance is a function of temperature of the zone, the resistance changes. Power supply **48** and current sensitive device **50**, in the form of an ammeter in the specific example, are serially connected between the electrical connectors **22** and **24**, the current flux sensed by current sensing device **50** is related to the incoming infrared radiation. However, the bolometers can be used in either voltage or current mode. It is the resistance which is a function of temperature. In a specific example of the bolometer **10** of FIG. **1**, central opening **28** is 0.2 cm diameter. The insulator material **30** overlying the opening is an aluminum oxide film about 1,000 angstroms thick. A gold layer approximately 100 A thick was evaporated onto the Al_2O_3 film prior to implantation. This layer was in the shape of a rectangle 0.1 cm × 0.3 cm. Antimony is implanted through the gold layer into the film to form a resistive zone **44** of rectangular shape (0.1 cm × 0.3 cm). Gold pads **32** and **34** were in place prior to evaporation of gold connective layer **36** and hence are attached to opposite edges of the long dimension of the rectangular implanted region. By supplying a current between **22** and **24**, a resistance of 400,000 ohms was measured at room temperature following implantation. With a 7 volt bias supplied, the bolometer has an open circuit responsivity of 84 volts per watt. The time constant of the bolometer is 60 milliseconds.

FIG. **4** illustrates a specially-mounted bolometer **52**. Mounted bolometer **52** comprises hemispherical lens **54**, which preferably has a field or focusing lens **56** positioned in front of it. Both lenses are of such material as to pass infrared radiation. The lens **54** is a standard immersion lens which receives the radiation from the primary system or field lens **56**. The immersion lens acts to reduce the size of the detector necessary to cover a given aperture or field of view. In the bolometer **52**, the detector is an implanted detector which forms a resistive zone **58**. Resistive zone **58** is formed by the implantation of metallic ions directly into the rear face of the hemispherical immersion lens. Implantation into the glass of the lens is accomplished in the same manner as described above with respect to implantation into alumina. Thus, a metal ion selected from the group consisting of silver, gold, antimony, aluminum, copper, and gallium and others can be implanted. The lens is of a suitable material for optical transmission of the electromagnetic radiation in question, and must be an insulative material. The lens material is a material selected from the group consisting of glass, quartz, and sapphire.

Electric contacts **60** and **62** are connected to the edges of the resistive zone **58**. Serially connected between these contacts are power supply **64** and current sensing device **66**, shown as being an ammeter. The voltage mode of sensing can alternatively be employed. Since resistance of the resistive zone **58** changes with temperature, and the temperature changes with incident radiation, the current flowing through current sensing device **66** is a function of the incident radiation. The large thermal sink provided by the immersion lens increases the response speed.

As described above, there is a minimum implantation dosage, equivalent to about 1,000 monolayers, which is in the order 10^{18} ions per square centimeter. This results in a saturation concentration in the implanted region hundreds of angstroms thick. In this region, the chemical composition differs markedly from the remainder of the body. This region is virtually an atomic cermet within the solid insulator. To achieve this implantation, a minimum beam current of about 10 microamperes appears to be necessary. Furthermore, a minimum beam acceleration potential of 10 keV is required. The maximum required beam energy is 40 keV, and 25 keV is a practical level. Too high an acceleration potential on the beam results in excessive sputtering.

This invention having been described in its preferred embodiment, it is clear that it is susceptible to numerous modifications and embodiments within the ability of those skilled in the art and without the exercise of the inventive faculty.

What is claimed is:

1. A bolometer, said bolometer comprising:

an electrical insulator material;

an electrically-resistive zone formed of ions implanted into said resistive material in sufficient quantity to permit the passage of electric current through said resistive zone, said resistive zone having a resistance which is a function of temperature;

electrical connections to said resistive zone so that the resistance of said resistive zone can be sensed; and

means permitting passage of radiation of such frequency as to affect the temperature of said resistive zone to said resistive zone so that the resistance of said resistive zone is a function of incident radiation thereto.

2. The bolometer of claim **1** wherein said insulative material is selected from the group consisting of glass, alumina, and sapphire.

3. The bolometer of claim **2** wherein said implanted ion is selected from the group consisting of silver, gold, antimony, aluminum, copper, and gallium.

4. The bolometer of claim **1** wherein said implanted ion is selected from the group consisting of silver, gold, antimony, aluminum, copper, and gallium.

5. The bolometer of claim **2** wherein said insulative material is a thin sheet of insulative material and is secured to base, an opening in said base, said implanted zone being positioned over said opening so that said base does not extend under said implanted zone to limit the thermal responsivity of the implanted zone.

6. The bolometer of claim 5 wherein pads are deposited on said insulative material and extend to overlap with said implanted zone, said pads being electrically connectable to said resistance sensing device.

7. The bolometer of claim 6 wherein a heat-absorbing coating is deposited on said insulative material over at least a portion of said resistive zone.

8. The bolometer of claim 1 wherein said insulator material is a substantially hemispherical immersion lens having a rear surface which is of a material which is substantially transparent to the incident radiation and said resistive zone is implanted into a portion of the rear surface of said immersion lens.

9. The bolometer of claim 8 wherein said insulative material is selected from the group consisting of glass, alumina, and sapphire.

10. The bolometer of claim 9 wherein said implanted ion is selected from the group consisting of silver, gold, antimony, aluminum, copper, and gallium.

11. The bolometer of claim 1 wherein a heat-absorbing coating is deposited on said insulative material over at least a portion of said resistive zone.

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