

United States Patent

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[73] Assignee **The United States of America as**
represented by the Secretary of the Navy

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83, 211; 252/501; 317/235 N

[56] References Cited

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[54] **CADMIUM PHOSPHIDE PHOTOCONDUCTIVE**
INFRARED DETECTOR
3 Claims, 3 Drawing Figs.

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250/83 R, 250/211 R, 252/501

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ABSTRACT: A cadmium phosphide photoconductive detector is provided having a 2.1 micron peak in photoconductive sensitivity and a 0.6 eV energy gap at 77° K. It may be compensated with various known impurities to lower the free carrier concentration.

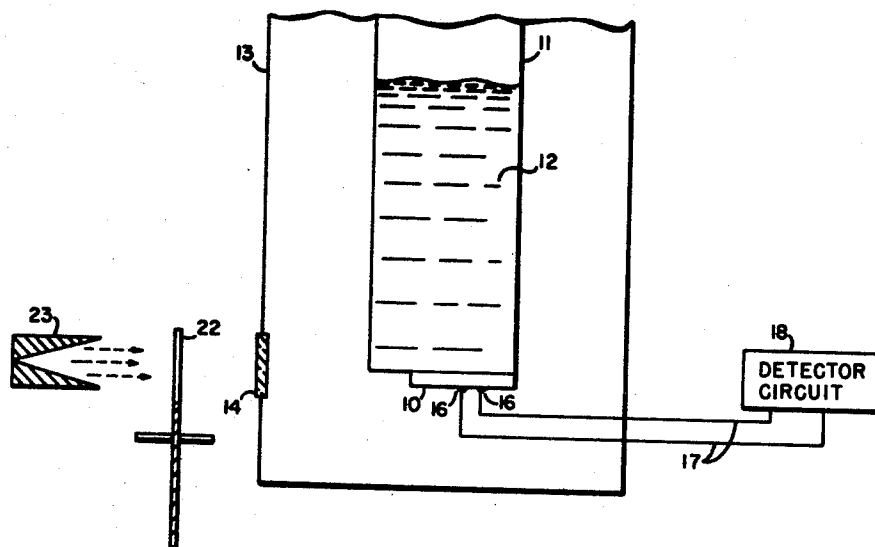


FIG. 1

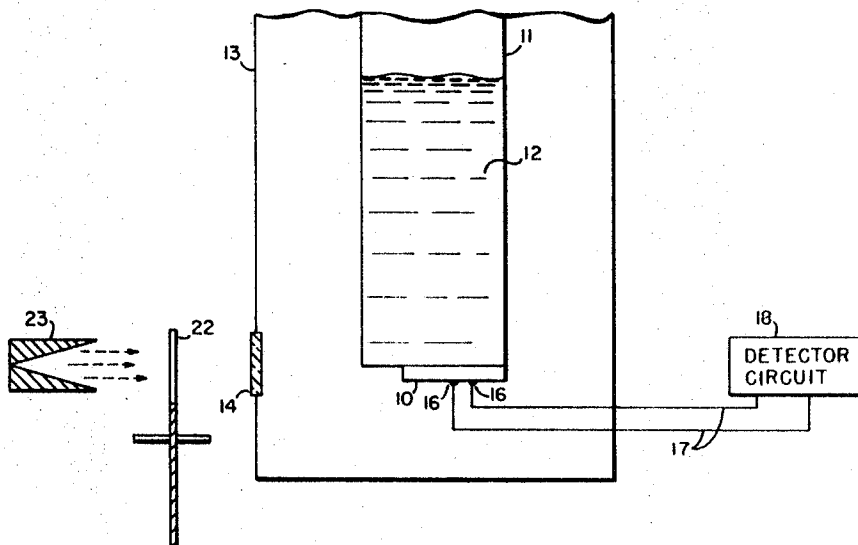
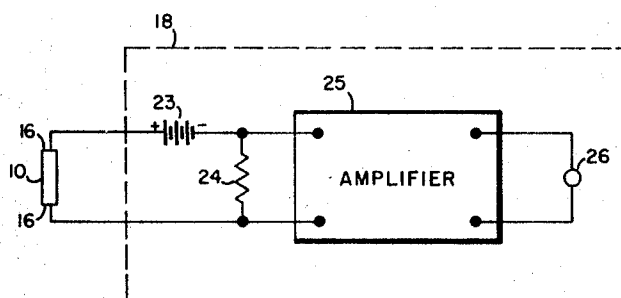


FIG. 2

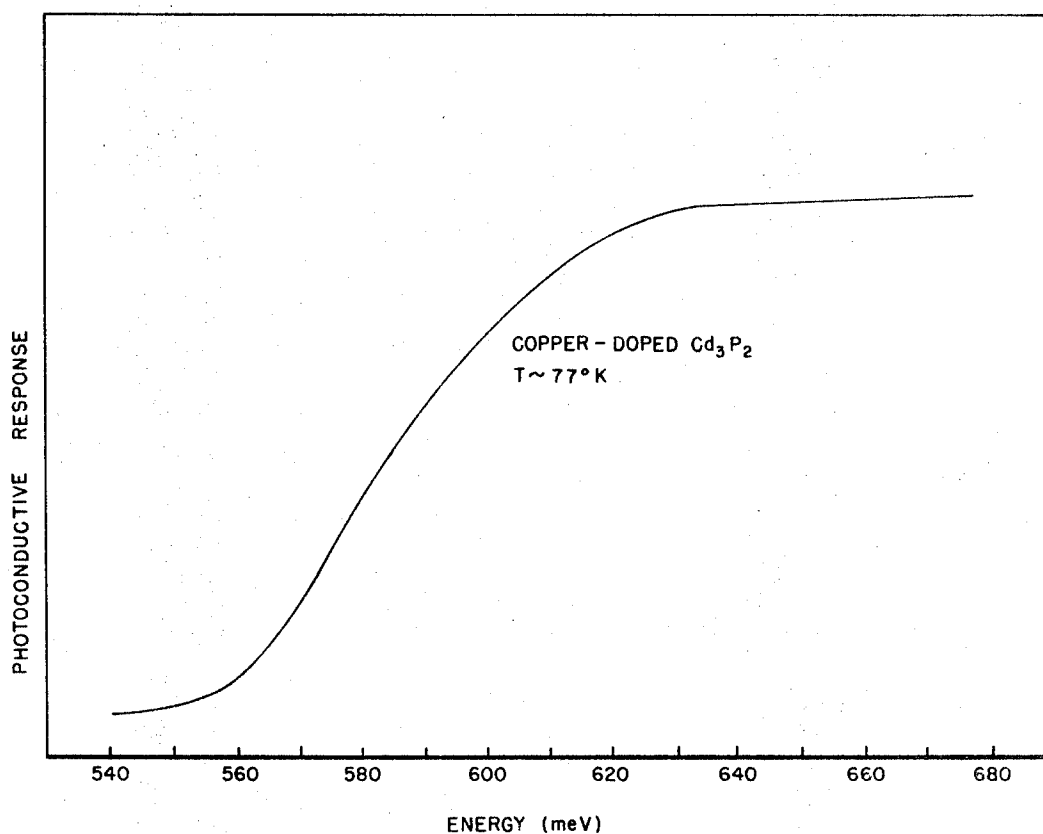


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FIG. 3



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CADMIUM PHOSPHIDE PHOTOCONDUCTIVE INFRARED DETECTOR

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

This invention relates to a semiconductor material sensitive to radiation in the near infrared. More particularly it concerns the use of cadmium phosphide as an intrinsic photoconductive detector.

Although the basic principles on which the present invention operates are generally known, it is believed appropriate to review some of the fundamental principles so that the invention will be more readily and clearly understood.

The energy levels of the inner electrons of atoms in solids are essentially the same as they are in isolated atoms, whereas those levels available to the binding electrons spread into almost continuous bands of levels associated with the entire solid rather than with individual atoms. If the highest occupied energy band is completely filled and the next highest allowed band is completely empty, and if the two bands are separated by an energy gap of finite width, then the solid is an insulator at low temperatures.

Semiconductor materials without impurities behave like insulators in that they have narrow "forbidden" energy gaps. A significant number of the binding electrons can be promoted from the highest normally filled band (the valence band) into the next higher normally empty band (the conduction band) either thermally or by the absorption of electromagnetic radiation. These conduction band electrons can carry a current through the solid. Such electron transitions may be caused by the absorption of electromagnetic energy or by thermal energy of the crystal lattice. The "holes" or empty states in the valence band also conduct, moving in an electric field as positive charge carriers in a direction opposite to that of the electrons.

In the operation of a photodetector cell it is desirable to provide a photoconductive material that is sensitive to radiation that falls within one of the so-called atmospheric windows. These "windows" are ranges of radiation wavelengths that do not become absorbed while passing through the atmosphere. It is also desirable that such materials be insensitive to room temperature black-body radiation (background noise) that occurs between 2 and 3 micron.

SUMMARY OF THE INVENTION

A cadmium phosphide intrinsic photoconductive detector has been developed which is sensitive to radiation having wavelengths from the visible 2.3 microns. Photoconductive detection is obtained when the material is suitably compensated with acceptor-type impurity atoms and maintained at a temperature sufficiently low to obtain the sensitivity required for a particular application. The cadmium phosphide of this invention exhibits a 0.6 eV energy gap and provides a peak sensitivity at 2.1 micron when cooled to the temperature of liquid nitrogen.

OBJECTS OF THE INVENTION

It is an object of the present invention to provide a novel intrinsic photoconductive detector.

It is another object of this invention to provide a novel two-constituent compound semiconductor constructed from group II^A—V^A materials.

It is also an object of the present invention to provide a semiconductor material sensitive to radiation of wavelengths less than 2.3 micron.

It is a further object of the present invention to provide a semiconductor material having a peak photoconductive sensitivity falling within the range of the 2.0—2.4 micron "atmospheric window."

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

FIG. 1 is a schematic drawing, partly in section, illustrating a simplified detector cell utilizing the photoconductive element of this invention.

FIG. 2 represents a partial schematic drawing of a typical external circuit which may be used with the present invention.

FIG. 3 is a graph indicating the photoconductive response of detector element of this invention as a function of the energy and wavelength of the incident radiation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The photoconductive element of this invention comprises cadmium phosphide which includes a sufficient number of acceptor impurities to compensate for any accidentally introduced donor impurities, typically 10^{17} or less acceptor impurity atoms per cm^3 of Cd_3P_2 . The addition of acceptor impurities in the above range causes the electrical properties of the material to be dominated by an impurity energy level separated from the filled valence energy band by approximately 0.6 electron volt.

In the use of the novel intrinsic cadmium phosphide detector for measurement of infrared radiation, the detector element is arranged on a dewar to receive the radiation to be detected. The element is maintained at approximately N_2 temperature. An external circuit is connected to the detector element to measure its change in conductivity due to the incident radiation. This change in conductivity of the detector produces a change in the current flow of the external circuit, which change is amplified and displayed by a suitable indicating or recording means. Provision may be made for filtering out radiation other than that of the radiation band to be detected. Provision may also be made for chopping the incoming radiation to obtain a pulsating signal which facilitates amplification and recording of small photocurrents.

Referring to FIG. 1 of the drawings, a detector element, indicated generally at 10, is supported in a conventional manner on a cooled dewar 11 of known construction. Means, not shown, are provided for maintaining a body of liquid nitrogen in the chamber 12 of the dewar.

The outer wall 13 contains a window 14 made of any suitable transparent material such as CaF_2 , quartz, etc. through which the incident radiation is directed toward the detector element 10. A vacuum is maintained between the dewar 12 and the outer wall 13. The detector element 10 may be a wafer of any suitable dimensions. A pair of ohmic electrodes 16, are secured to the detector element by means of indium solder. Leads 17 are secured to and couple the electrodes 16 to a signal detector circuit 18 for measuring the photocurrent developed as a result of the radiation incident on the photoconductive detector element 10.

A light chopper 22, which may be of conventional design, is shown arranged between the infrared source 23, indicated in a conventionalized manner, and the window 14. It causes a modulated radiation signal to be incident on the photoconductive detector element 10 whereby in operation of the detector device, a varying photocurrent is produced which can be amplified in an AC system and recorded independently of the steady thermal background.

In FIG. 2, a suitable external circuit 18 is shown connected to the photoconductive element 10. This circuit includes a suitable DC voltage source 23 and a load resistor 24. A potential is applied across the photoconductive element 10 from the DC voltage source by means of the leads 17 connected to the

electrodes 16, 16 on the element 10. An amplifier 25 is connected across the load resistor 24 to amplify the change in current due to change in the conductivity of the photoconductive element 10 in response to a change in the intensity of the infrared radiation incident on said photoconductive element. Suitable means 26 is connected to the amplifier 25 for recording or displaying the output from the amplifier.

The electrodes 16, 16 on the photoconductive element 15 may consist of indium solder which is applied to the freshly etched cadmium phosphide sample with a soldering iron. The leads 17, which may be copper, are soldered to the electrodes also with indium solder.

The efficiency of a copper-doped Cd_3P_2 detector element is illustrated by the curve in FIG. 3. This curve shows the relative photoconductive response to incident radiation of varying energies of wavelengths. As shown, the sensitivity of said element extends from about 2.3 microns to past 1.9 micron into the visible light spectrum. Due to other optical properties of the cadmium phosphide, its peak sensitivity occurs at wavelengths of about 2.1 micron.

The cadmium phosphide detector elements of the present invention were grown by the well-known open-tube sublimation technique. It should be understood, of course, that the practice of the present invention is not limited to producing the elements by any particular technique or with any particular means. Effective results may be obtained with any of the methods which are currently used and well known in the art.

To obtain good photoconductive response, it is necessary to reduce the free carrier concentration which occurs in the as-grown Cd_3P_2 crystals. This has been accomplished by doping the crystals with copper, and achieving high electrical resistance (low free carrier concentration at low temperature) through compensation. Other dopants may achieve the same end, and it may be possible to lower the carrier concentration by annealing the crystals for long periods of time under a phosphorous atmosphere.

The electrical resistance of a typical device in the dark at 77°K exceeds 10^{10} ohms. However, when light with

wavelengths shorter than 2.3 micron falls upon the detector, it is absorbed and excites electron-hole pairs which are free to move under the influence of the bias voltage and cause an increase in the current flowing through the crystal.

An especially desirable feature of the Cd_3P_2 element is that the peak sensitivity wavelength of about 2.1 micron falls in the 2.0 to 2.4 micron atmospheric "window." Another desirable feature of the element is that its long wavelength cutoff occurs at about 2.3 micron, and it is therefore less sensitive to the steeply rising profile of room temperature black-body radiation (which produces background noise) than detectors with photoconductive response which extend to longer wavelengths.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What we claim and desire to be secured by Letters Patent of the United States is:

1. A device for the detection of infrared radiation comprising a photoconductive detector element of cadmium phosphide including 10^{17} or less acceptor impurity atoms per cubic centimeter of cadmium phosphide, means for maintaining said detector element at a temperature approximating liquid nitrogen, means to expose a surface of detector element to infrared radiation, and means to measure the change in conductivity of said detector element in response to incident infrared radiation wherein the amount of acceptor impurity atoms is sufficient to cause the electrical properties of the material to be dominated by the impurity energy level separated from the filled valence energy band by approximately 0.6 electron.

2. The device recited in claim 1 wherein said detector element has maximum sensitivity for radiation wavelengths of about 2.1 micron.

3. The device recited in claim 1 wherein the acceptor impurity atoms are copper.

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