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PHOTOELECTRIC CELLS

Filed March 15, 1957

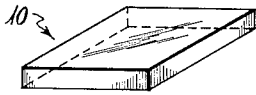


Fig. 1.

Fig. 3.

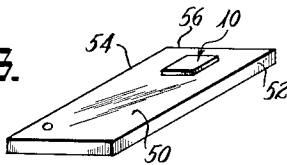


Fig. 2.

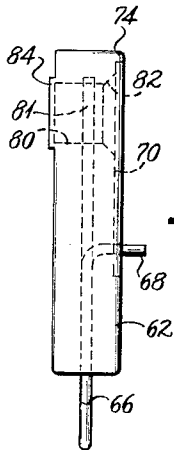
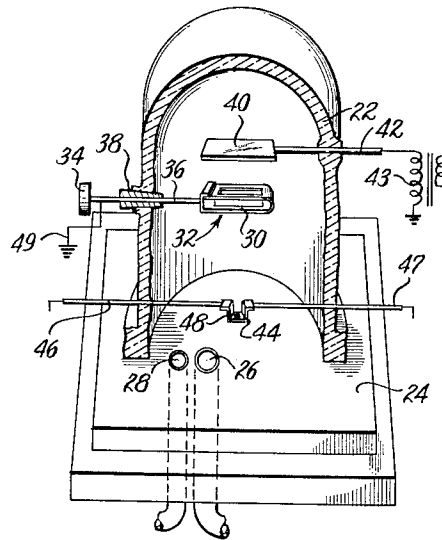


Fig. 4.

Fig. 5.

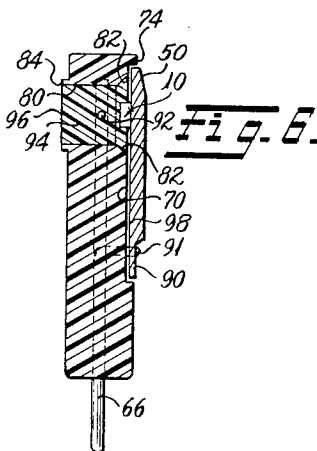
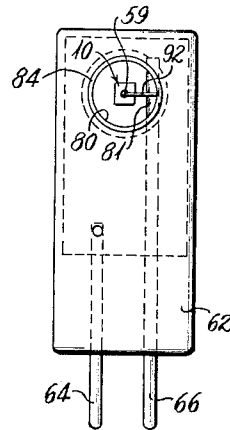
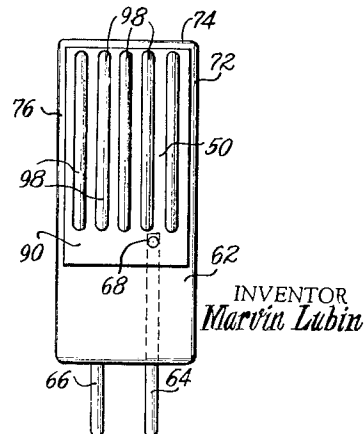


Fig. 6.

Fig. 7.



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PHOTOELECTRIC CELLS

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14 Claims. (Cl. 338—15)

This invention relates to photoelectric cells and more particularly to an improved cell housing and method of manufacture thereof for photoresistance semiconductor elements, and is a continuation-in-part of my co-pending application Serial No. 538,573 filed October 5, 1955, now abandoned.

It has been found that the mounting structure for cadmium sulfide crystals plays such an important role in the operation of the cell that otherwise satisfactory crystals are rendered worthless by improper mounting in housings. For example, the crystal ages very rapidly in improper types of housings to lose its desirable operating characteristics in a matter of a few weeks even though initial tests showed the crystal to be fully satisfactory. Since one of the principal advantages of the cadmium sulfide crystal resides in its high current carrying capacity which is large enough to operate electromagnet coils directly without further current amplification, the importance of the cell in maintaining its high current rating is one of primary significance.

It has been observed in the laboratory that cadmium sulfide crystals are capable of passing much larger currents than can safely be passed by the completed photocell with a structure enclosing such crystals. Housings to enclose the crystal are, however, essential to prevent contaminating effects caused by various elements in the atmosphere. Since the cells are commonly used in circuits where a constant voltage is applied, illumination of the cell causes a reduction in resistance and corresponding increase in current which, in general, increases the quantity of heat that must be dissipated by the crystal to a maximum value when the current flow is maximum. Increased temperature of the cell causes an increase in the resistance and hence a lower operating current which renders the cell unsatisfactory for many applications. A second harmful effect of crystal heating is the development of mechanical stresses and strains due to different rates of expansion of the various components in the photocell. Thus the connection of the electrical terminals to the crystal are weakened at their point of contact thereby reducing maximum sensitivity and causing further localized heating which shortens the life especially at high current levels of operation.

It is therefore a major object of the present invention to provide an improved housing for a cadmium sulfide or like crystal which has means for adequately and effectively dissipating the heat generated within the crystal without compromising any of the other factors necessary for satisfactory operation and long life.

Another object of this invention is to provide a heat dissipation surface of substantial extent which is supported at a position remote from the base of the photocell to improve the efficiency of heat removal.

A further troublesome problem involves the electrical nature of the contact to the crystal. It has been found this problem has been substantially eliminated by first cleansing a spot on the crystal by glow discharge as disclosed in my above-identified copending application and then gold plating the cleansed spot. By using a silver cement or similar adhesive between the gold spot and a small wire forming one terminal on the crystal, there resulted an enormous improvement in crystal characteristics including reduction of contact noise, reduction of the rectifying effect and improved linearity between voltage and current. There still remained however,

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something to be desired in the way of a smaller and compact housing with rigid electrical terminals and which lends itself better to mass assembly techniques.

It is accordingly a further object of this invention to provide an improved crystal housing which retains all of the advantages of operation provided by my prior crystal housings and which is readily adapted to mass production techniques.

A further object of the present invention is to provide a novel housing wherein the terminal leads are supported in a body of moldable insulating material and the radiation sensitive body of crystalline material is supported on a plate of thermally and electrically conducting material having a large surface area exposed to the atmosphere.

Another object of the invention is to provide an improved photocell wherein the electrical terminals are molded between opposite faces of a plate-like body of insulating material which is formed with an aperture and the body of radiation sensitive crystalline material mounted in said aperture on one surface of a plate of thermally and electrically conducting material and the latter plate secured to the plate of insulating material to provide a large radiating surface for carrying away heat dissipated by the crystalline material. As a further feature, the aperture is filled with a neutral plastic material to protect the crystal from contamination by atmospheric elements.

A still further object of the invention resides in the novel method of assembling the photocell housing of the present invention which includes first embedding the electrical terminals in a body of insulating material in such manner that one terminal extends exteriorly of the crystal housing to the side to which the plate that acts as a heat radiating body is secured and the other electrical terminal is electrically connected to the active material by a small lead which is subsequently encapsulated in an inert plastic material transparent to the radiation to be detected.

Still another and more detailed object of the invention resides in first ion bombardment cleansing only one side of the crystal and then plating the gold electrode on the cleansed side and assembling the crystal on the metal mounting plate and then subsequently ion bombardment cleansing and gold plating a spot on the exposed side of the crystal to accurately locate said spot relative to the edges of the metal mounting plate whereby the electrode connection to the spot may be made automatically by machine operated equipment during mass assembly of the crystal housings.

These and other objects of the invention will become more fully apparent by reference to the appended claims and the following detailed description when read in conjunction with the accompanying drawings wherein:

FIGURE 1 is an enlarged perspective view of a photocell as used in the present invention;

FIGURE 2 illustrates diagrammatically a form of apparatus suitable for cleaning crystal surfaces and forming the gold layer electrodes thereon;

FIGURE 3 is a perspective view showing the crystal mounted on the plate of thermally and electrically conductive material as it appears at one stage in the production of the photocell in accordance with the present invention;

FIGURE 4 is a side view showing the sub-assembly comprising the two electrodes embedded in a body of insulating material as it appears before the metal mounting plate as shown in FIGURE 3 is secured thereto;

FIGURE 5 is a front view of a completed photocell in accordance with the present invention;

FIGURE 6 is a side view in section of the completed photocell of FIGURE 5; and

FIGURE 7 is a rear view of the photocell shown in FIGURES 5 and 6.

With continued references to the drawings wherein like reference numerals are used throughout to designate like elements, the photo-crystal designated generally by reference numeral 10 and as illustrated in FIGURE 1 is in the form of a small single crystal or body of photosensitive semiconducting material which preferably is cadmium sulfide. Crystal 10 may be grown in a form of a single crystal by the basic methods as disclosed in copending application Serial No. 486,927 filed February 8, 1955 by Leonard E. Ravich, now Patent No. 2,890,939, and assigned to the same assignee as the present invention, though crystals produced by other methods may be also used. Cadmium sulfide crystals of this type generally range in size from a few square millimeters to several square centimeters in area and usually range from a few tenths of a millimeter to several millimeters in thickness. Satisfactory results are obtained in mounts of the present invention with crystals as small as 0.3 centimeter on each side and with the usual thickness of a fraction of a millimeter. Photocells constructed in accordance with the present invention have at least as great a current carrying capacity under comparable voltage and illumination conditions as cadmium sulfide crystals offered in the commercial market by others of which I am aware which have 40 times the size of sensitive area as the above exemplary dimensions.

For example, photocells of the present invention have a dark resistance of 50 to 500 megohms. With 45 volts D.C. applied across the terminals and an illumination of 50 foot candles, a current from 30 to 100 milliamperes is obtained thereby providing a resistance of from about 450 to 1500 ohms and a light to dark ratio of from 10^5 or 10^6 .

To obtain the characteristics described above, photoelement 10 as shown in FIGURE 1 is first treated by ion bombardment and the bombarded area plated with gold. A simple form of apparatus for so treating crystal 10 is illustrated in FIGURE 2 to which reference will now be made.

In FIGURE 2, a bell jar 22 and a base plate 24 on which it seals together define the vacuum chamber from which the atmosphere may be evacuated through an exhaust line 26 to roughing and holding vacuum pumps (not shown). If desired, an inlet line 28 also may be provided for flushing the chamber with a selected gas or vapor prior to the cleaning and plating operations described below.

Within the vacuum chamber, the photocrystal blank 30 is mounted in a mask and a holder assembly 32 which is generally of the type shown in FIGURE 3 in my above-identified copending application which is preferably rotatable by suitable means 34 fixed to the outer end of a mounting stem 36 through a seal 38 in the bell jar wall. Mounting stem 36 is made of metal and grounded as indicated by reference numeral 49. Electrode 40 is mounted above mask 32 and is provided with an electrical lead 42 to the exterior of the bell jar. Below the mask and holder assembly, a strip or filament type heating element 44 is mounted between an electrically connected pair of lead wires 46 and 47 which extend to the exterior of the bell jar for connection across a battery or other electrical current source which is capable of passing sufficient current through heater element 44 to raise it to a temperature adequate to vaporize gold material 48 placed in or on the heater element as illustrated.

The cleaning and electrode plating operations are carried out sequentially, preferably in the steps of selecting a properly matched crystal and mask and inserting them in holder assembly 32 and adjusting handle 34 so that the one exposed face of the crystal is substantially normal to the path between the crystal and electrode 40. The exposed area of crystal 10 on the first face to be treated is preferably relatively large as this is the face which in

the preferred method of assembly will be secured to the thermally conducting plate 50. Then the roughing pump is connected to evacuate the bell jar. Pressure within the bell jar preferably is first reduced to between 0.05 and 0.1 millimeter and upon reaching this pressure a glow discharge between crystal 10 and electrode 40 is initiated by energizing coil 43 with a high alternating voltage in the range of about 10,000 to 14,000 volts. The residual gas ions are accelerated toward and impinge upon the exposed upper surface of crystal 10 where they have the effect of reducing or eliminating the surface insulating barrier which is characteristic of the untreated crystal and which probably is due to the presence of adsorbed gases. The length of time during which ion bombardment is continued depends on the particular application for which the crystal is intended; in general a glow discharge continued for approximately 10 minutes is effective to completely or at least effectively remove the surface barrier.

After ion bombardment of one side of the crystal is completed, the glow discharge voltage is disconnected and the roughing pump closed off and, without breaking the vacuum in the bell jar, the holding pump is connected to further reduce the bell jar pressure preferably to between 0.05 and 0.1 micron. The crystal 10 is then turned as by rotation of holder stem 36 so as to place the cleansed surface of crystal 10 in a position above and facing heater 44.

With the pressure held between these approximate limits, heater element leads 46 and 47 are connected to a current source to raise the temperature of the heater element 44 sufficiently to vaporize the gold material 48 previously placed thereon onto the downwardly facing surface of crystal 10. This electrode deposition operation is continued until the electrode is built up to a desired thickness. In the preferred embodiment the size of this gold electrode is a spot having a diameter of at least 0.060 inch. Since the same mask is used, the metal electrode is coextensive with the area cleansed by the ion bombardment treatment.

In mass production assembly, the crystal is then removed from bell jar 22 and placed on a mounting plate 50 as illustrated in FIGURE 3. Mounting plate 50 is made of thermally and electrically conducting material such as copper, and a thin coating of silver on plate 50 is preferred to prevent oxidation of the copper and because of the improved electrical nature of the contact between the gold plated electrode on crystal 10 and the silver coating on plate 50.

Crystal 10 is then placed centrally between the side edges 52 and 54 of plate 50 and near end 56 for purposes which will become apparent as the description proceeds. A jig or other suitable equipment (not shown) is preferably used to provide uniform positioning in mass assembly production. The crystal is then soldered or otherwise secured with an adhesive having a high metallic content to the silver plated copper plate 50 with the gold plated surface facing plate 50.

Plate 50 with crystal 10 attached to it is then placed in a bell jar equipment such as that shown in FIGURE 2 and a suitable mask provided exposing a small area of approximately 0.030 inch in diameter on crystal 10. A vacuum is produced and the exposed surface bombardment cleaned as described above. Then the holder is turned over without breaking the vacuum and a gold plating applied to the cleansed spot. The mask contains suitable positioning surfaces cooperating with edges 52, 54 and 56 to accurately locate the mask aperture uniformly on each unit. Plate 50 with crystal 10 attached to it is then removed from the bell jar and is ready for assembly with the remainder of the photocell housing next described below.

Referring now to FIGURE 4, the principal element of the mount is a body 62 of moldable insulating material such for example as Bakelite which, in the illustrated embodiment has a generally rectangular shape with

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a thickness much smaller than either of the dimensions of the rectangular front and rear faces. Before body 62 is formed, a pair of rigid wires 64 and 66, also shown in FIGURES 5 through 7, are placed in the mold. Wire 64 is provided with a right angle bend to cause end 68 to extend outwardly beyond the material in the mold. Wire 66 extends straight through body 62 and both wires 64 and 66 lie in a central plane thereof. Body 62 is formed with a recessed rear wall 70 surrounded with ridge surfaces 72, 74 and 76. A through aperture 80 is provided in body 62 with a conical counter sink 82 adjacent rear wall 70. Aperture 80 is sufficiently large so that section 81 of conductor 66 is exposed and bare as best shown in FIGURE 5. A front ridge 84 may be provided if desired thereby serving as a lip extending around the walls forming aperture 80.

After body 62 is molded with leads 64 and 66 in place so as to provide rigid terminals whereby the crystal housing may be placed in a suitable socket, metal mounting plate 50 with crystal 10 is placed in the recess against rear wall surface 70 with crystal 10 in aperture 80. Any suitable adhesive may be used to permanently secure metal plate 50 to rear surface 70. Projection 68 shown in FIGURE 4 on conductor 64 is cut off flush with rear surface 90 of metal plate 50 and electrically connected to metal plate 50 as by a solder connection 91 (see FIGURE 6).

Since in mass production the crystal is accurately located on metal plate 50 by means of a suitable jig, crystal 10 is uniformly located near the center of aperture 80 with the exposed gold plate spot 59 accurately positioned on each crystal at precisely the same location in each mounting structure, which for example may be at the center of aperture 80. This facilitates making the electrical connection between gold plated spot 59 and section 81 of lead 66. This connection is preferably in the form of a small flexible piece of Phosphor bronze wire 92. Wire 92 preferably is first soldered to gold plated spot 59 on crystal 10 and then the wire bent over and soldered to section 81 of lead 66. Aperture 80 is subsequently filled with a suitable thermoplastic material 94 transparent to radiation to be detected and chemically inert to the crystal material, which for example may be a thermal setting polyester such as "Kelon" or "Selectron." The thermoplastic material 94 runs underneath conical surface 82 thereby assuring permanency of the assembly. The front surface 96 of thermoplastic material protrudes as a slight convexity and may be either left in that shape to take advantage of such focusing action as may be provided or polished smooth to be flush with ridge 84 as illustrated in FIGURE 6.

The advantages resulting from the crystal housing of the type described above are several. By having plate 50 on an outer surface of the principal housing body 62, a large surface area is provided for efficient removal of heat generated within crystal 10. It may be preferred in some installations to provide ridges 98 illustrated in FIGURE 7 on the surface plate 50 exposed to the ambient atmosphere to increase the efficiency of the heat removal though this is not necessary in all units. The large area gold electrode and solder (or cement having a high density of metal) securing crystal 10 to plate 50 serves as a continuous metallic connection between the crystal and the relatively large, highly thermally conducting heat radiating surface and causes the heat developed in the crystal to be efficiently distributed throughout plate 50 thus preventing localized regions of high temperatures. Tests have shown that for two cells both carrying the same current, that one completely encapsulated in a thermoplastic material while the other is of the form herein described, a temperature difference on the order of 40° C. at the crystal is obtained. Thus the mount of the present invention is extremely effective in maintaining a low crystal temperature.

In addition, with the use of a solder contact between

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the gold evaporated electrodes on the crystal and the adjoining circuit on both sides of the crystal connections, the improved electrical characteristics of the contact are obtained as the rectification effect and noise are both greatly reduced and the voltage-current linearity becomes substantially perfect. Preliminary field tests on the housing of the present invention lasting over a period of four weeks have shown no failures under conditions where approximately 50% of the older type cells, which were completely encapsulated in a plastic, failed.

The improved crystal housing of the present invention is especially adapted to be inserted in circuits by means of sockets similar to vacuum sockets. Leads 64 and 66 are rigidly secured in the principal housing 62 which is easily grasped for a desired manipulation of the crystal housing and provides an extremely rugged construction whereby no physical damage occurs to the housing or change in operating characteristics is caused by the usual handling given electronic components. Moreover, the housing supports the sensitive material approximately $\frac{3}{4}$ of an inch from the socket into which leads 62 and 64 are mounted in a position to receive radiation energy in a plane perpendicular to the direction of leads 62 and 64. Metal mounting plate 50 is also advantageously supported away from the socket receiving leads 62 and 64 to permit air to circulate freely across its exposed surface from which heat generated within crystal 10 is removed.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by United States Letters Patent is:

1. In a housing formed of a body of insulating material for a photosensitive element of crystalline cadmium sulfide, a supporting base of good electrical and heat conducting material large relative to the size of said photosensitive element positioned on an exterior surface of said housing, means mounting said photosensitive element to have one face in a good thermally and electrically conducting relation on one surface of said base, a first conductor electrically connected to said base at a point remote from said photosensitive element and providing at its opposite end a rigid terminal, a second conductor electrically insulated from said base by said body of insulating material and having a rigid end parallel to and spaced from said other end of said first conductor forming socket terminals on said housing, and a small flexible wire mechanically secured and electrically connected to said second conductor and having its free end electrically connected to a second face on said photosensitive element.

2. In a mount for a photosensitive body of crystalline cadmium sulfide comprising a housing including a body of insulating material, a base of good electrical and heat conducting material large relative to the size of said photosensitive body positioned on an exterior surface of said housing, means mounting said photosensitive body to have one face in a good thermally and electrically conducting relation on one surface of said base, a first rigid conductor supported by said housing electrically connected at one end to said base and providing a rigid terminal at its free end, a second rigid conductor electrically supported by said housing to be insulated from said base and said first conductor and having a free end parallel to and adjacent the free end of said first conductor, and a flexible wire mechanically and electrically connected to said second conductor at a position adjacent said body of cadmium sulfide and secured against a second face of said photosensitive body.

3. A photocell comprising a housing of insulating material having a pair of electrical terminals at one end, a body of good electrical and heat conducting material supported on an exterior surface of said housing and having an exposed outer surface of substantial extent at a position remote from said one end, an aperture in said housing communicating with said body of conducting material, a slab of crystalline material sensitive to radiation supported on said body of conducting material and positioned in said aperture, and means electrically connecting said slab between said electrical terminals.

4. In a radiation sensitive device having a housing comprising a body of insulating material having a through aperture, a pair of electrical conductors imbedded in said insulating material with one of said conductors extending into said aperture and with free end portions on each of said pair of conductors extending outside said body of insulating material in parallel directions perpendicular to the axis of said aperture, a base of good electrical and heat conducting material larger than said aperture secured to said body of insulating material with one face thereof exposed to the atmosphere and extending over said aperture, a body of crystalline material sensitive to radiation mounted with one face in good heat and electrical conducting relationship to a second surface of said base of conducting material and positioned within the aperture in said body of insulating material, a flexible wire electrically connected between said one of said conductors and a second face on said body of crystalline material, and means connecting the other of said pair of conductors to said base.

5. In a device of the type described having a housing comprising a body of insulating material having a through aperture, a pair of electrical conductors embedded in said insulating material with one of said conductors extending into said aperture, a plate of good electrical and heat conducting material with faces on opposite sides thereof having dimensions in two directions substantially larger than the thickness of the plate between said opposite faces secured to said body of insulating material having one of said faces on the outside of said body and covering the aperture therein, a slab of crystalline material sensitive to radiation mounted to have one surface in good heat and electrical conducting relation on the other of said faces of said plate of heat conducting material and positioned in said aperture in the body of insulating material, an electrical conductor electrically connected to said one of said pair of electrical conductors and contacting an exposed surface on said slab of crystalline material, and the other of said pair of conductors being electrically connected to said plate of conducting material.

6. The device as defined in claim 5 further comprising sealing means transparent to the radiation to be detected covering said aperture on the side of said body of insulating material opposite from said plate of conducting material for protecting said slab of crystalline material from atmospheric elements.

7. A radiation sensitive device comprising a flat body of insulating material having faces on opposite sides with the smallest dimension of said faces being considerably larger than the thickness of the body between said faces, an aperture extending between the faces in said body, a pair of electrical conductors imbedded in said body between said faces with one of said conductors extending into said aperture and the other of said conductors extending through one of said faces, a plate-like body of good heat and electrical conducting material with surfaces on opposite sides thereof and assembled with one of said surfaces secured to said one of said faces on said flat body so as to cover said aperture and be in electrical contact with said other of said conductors, a slab of crystalline material sensitive to radiation mounted with one side in good electrical and heat transferring relation to said one surface of said plate-like body of conducting

material and positioned in said aperture, a lead connected between said one of said conductors and the exposed surface of said crystalline slab, and means connecting said other of said conductors to said body of conducting material.

8. The device as defined in claim 7 further comprising sealing means transparent to radiation to be detected in the aperture of said insulating plate protecting and preventing contamination of said crystalline slab from atmospheric elements.

9. In a photosensitive device, a body of cadmium sulfide material having a substantially flat surface of appreciable area on one side, an electrode comprising a layer of metal formed as a plating on said surface to substantially cover said surface, a massive slug of high thermal conductivity material considerably larger than said body of cadmium sulfide material, means mechanically securing said body of cadmium sulfide material to said massive slug with said electrode layer forming a high thermal and electrical conductivity connection between said body and said slug for maintaining the temperature of the body of cadmium sulfide when carrying current as low as possible.

10. A photocell comprising a housing and a massive slug of highly thermally conducting material secured to said housing in a manner to radiate heat from said slug into the atmosphere surrounding said photocell, a body of cadmium sulfide having a substantially flat surface on one side, a layer of gold plating on said flat surface, means including a substance having a high metal concentration for securing said gold layer to one side of said massive slug to provide a continuous metallic connection between the body of cadmium sulfide and the heat radiating surface of the photocell exposed to the atmosphere, a first electrical terminal connected electrically to said slug and extending outwardly from said housing, a second electrical terminal extending through said housing and insulated from said first electrical terminal, and means connecting said second electrical terminal to a second side of said body of cadmium sulfide opposite said substantially flat surface.

11. The photocell as defined in claim 10 wherein said last mentioned means comprises a layer of gold plating applied to said second side of said body of cadmium sulfide and said second electrical terminal is secured in good electrical relationship to said gold plating.

12. The photocell as defined in claim 10 wherein the surface on said second side of the body of cadmium sulfide is cleansed and plated with gold over at least a portion of its area and the second electrical terminal is connected to said gold plating whereby noise and rectification are reduced and the voltage-current linearity is greatly improved.

13. A photocell comprising a housing having an opening, a massive slug of highly thermally conducting material secured to said housing in a manner whereby heat from said slug is radiated into the ambient atmosphere surrounding the photocell, a generally flat body of cadmium sulfide having one side of substantial area plated with a metal and secured in the opening of said housing to said massive slug thereby providing a continuous metallic connection between said body of cadmium sulfide and the heat radiating surface of the photocell, a pair of electrical terminals electrically connected to opposite sides of said body of cadmium sulfide and extending exteriorly of said housing, and a body of encapsulating plastic material transparent to the radiation to be detected in said opening sealing said body of cadmium sulfide from the atmosphere but covering only part of said massive slug.

14. A high current photocell comprising a casing member having a hollow interior portion, a relatively massive slug of high thermal conductivity material supported by said casing member, a body of photosensitive semicon-

ductor material containing a large area metallic electrode on at least one surface thereof, said body being disposed in the hollow interior portion of said casing member with its metallic electrode in electrically and thermally conductive relation to said slug, and means including cooling fins exposed outside of said casing member and in thermally conductive relation to said slug. 5

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