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PHOTOCONDUCTIVE ORTHICON

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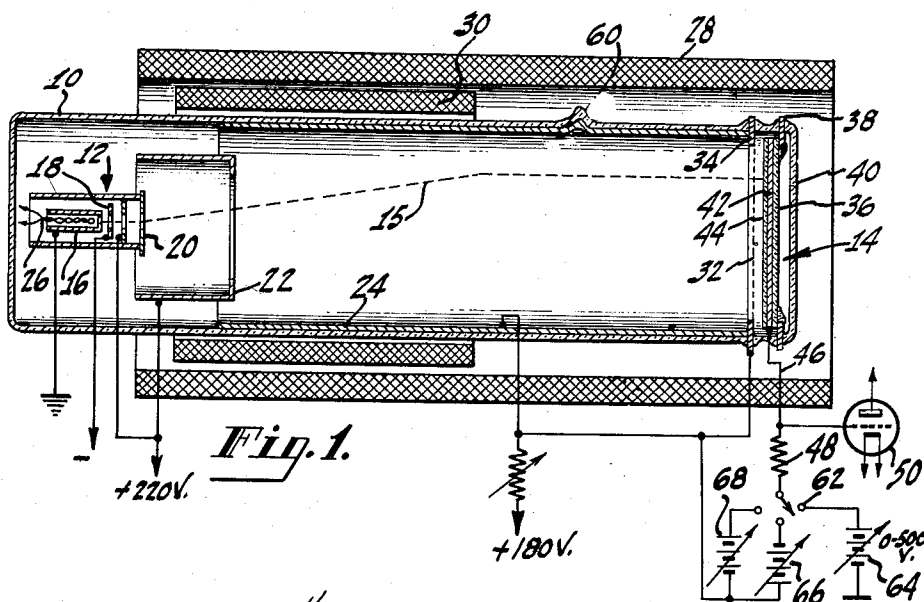


Fig. 1.

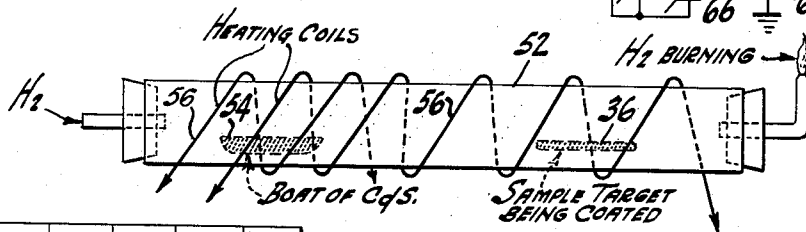
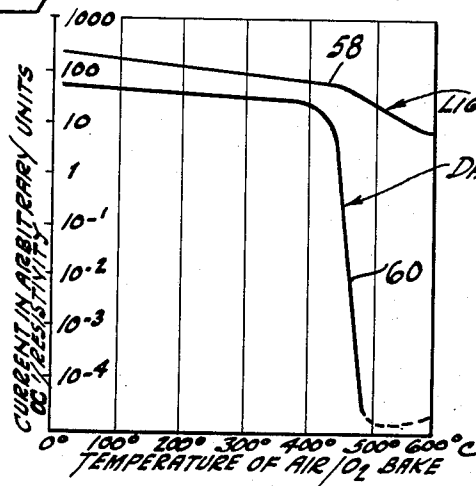


Fig. 2.



TYPICAL CURVES OF CURRENTS MEASURED AT ROOM TEMPERATURE AFTER BAKING AT VARIOUS ELEVATED TEMPERATURES.

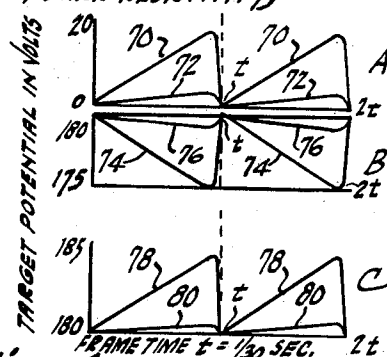


Fig. 4.

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2,810,087

PHOTOCONDUCTIVE ORTHICON

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5 Claims. (Cl. 313—65)

This invention is directed to a pickup or camera tube for television and more specifically to an improved photoconductive target, therefor.

A photoconductive pickup tube is one having a target formed with a supporting transparent sheet portion, which is first coated with a conductive film or signal plate and then, secondly, with a layer of known photoconductive material, over the conductive film. This target electrode is mounted within an evacuated envelope with the photoconductive coating facing an electron gun structure, which produces an electron beam substantially normal to the target surface. Either electrostatic fields or electromagnetic fields can be used to cause the electron beam to scan, in closely spaced parallel lines, over the surface of the photoconductive target layer. The scanning of the electron beam over this photoconductive layer provides a secondary electron emission from the target surface. The number of secondary electrons leaving the target surface is normally controlled by an adjacent collector electrode, whose potential will be approached by the surface of the target. This potential of the target surface, acquired by secondary electron emission, may be considered an equilibrium potential. A potential is applied to the conductive signal plate of the target which is several volts different from the equilibrium potential established on the photoconductive surface. In this manner, then, a difference of potential is established across the two surfaces of the photoconductive film. Due to the photoconductive properties of the target material used, when light is focused upon the photoconductive film, a current flow will take place across the film in the illuminated areas, and will change these areas toward the potential of the conductive film. Areas of the target not illuminated by the light will have little or no current flow depending upon the resistivity of the photoconductive material in the dark and will thus remain at the equilibrium potential established by the beam. The electron beam upon scanning over the target areas illuminated by light, will return the illuminated target areas to equilibrium potential. Since the signal plate is capacitively coupled with the scanned surface of the target, the instantaneous charging of the target by the beam to equilibrium potential will be evidenced by a voltage change in the circuit of the signal plate. This voltage change becomes the output signal of the tube.

The photoconductive property of cadmium sulphide has been well recognized for some time. However, this material has not been put into extensive use in many photoconductive devices because of certain adverse properties that prevent its use. Cadmium sulphide layers can have extremely good conductivity of an electric current, when illuminated with light, but it is also known to have relatively low electrical resistivity in the dark.

A photoconductive material, in order to be effectively used for a pickup tube target, must exhibit sufficient dark resistivity to give storage type operation. Most photoconductive cell applications also require that the dark current be low, and thus the resistivity high. Because of the

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high conductivity of cadmium sulphide when illuminated by light, this material is one which would be very desirable for use in camera pickup tubes, if it also had a high resistivity in the dark. However, the usual low resistivity of the material in the dark severely limits its being used in pickup tubes, since the equilibrium potential charge established on the surface areas of the target scanned by the electron beam must be maintained in unilluminated target areas. That is, a photoconductive material having poor resistivity in the dark cannot be successfully used, since the dark current through the material will discharge the target in these areas, thus masking the light output signal derived from the illuminated areas.

The sensitivity of a photoconductive material may be measured by the difference between the current flow through the material when illuminated by a given amount of light and the current flow through the material in the dark.

It is therefore an object of my invention to provide an improved photoconductive pickup tube.

It is another object of my invention to provide an improved pickup tube having a cadmium sulphide photoconductive target.

It is another object of my invention to provide a photoconductive pickup tube in which the photoconductive material used has large resistivity to dark current.

It is another object of my invention to provide a photoconductive-pickup tube of high sensitivity using a cadmium sulphide material which has great resistivity to dark current.

The invention specifically is that in which an improved photoconductive material of cadmium sulphide is used in a camera pickup tube, in the manner described above.

The cadmium sulphide photoconductive material is one in which the dark current resistivity of the material has been substantially increased an amount equal to substantially five orders of magnitude greater than that previously used. The cadmium sulphide photoconductive material is specifically processed in the manner described and claimed in my co-pending application Serial No. 197,019, now U. S. Patent 2,688,564, filed November 22, 1950, and issued September 7, 1954, and in which the process is that of baking the photoconductive material in an atmosphere including oxygen to improve its resistivity to dark current. Cadmium sulphide material processed in this manner is one which can be used successfully in a pickup tube.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims, but the invention itself will best be understood by reference to the following description taken in connection with the accompanying drawing, in which:

Figure 1 is a cross-sectional view of a photoconductive pickup tube using a cadmium sulphide target in accordance with my invention;

Figure 2 is a graphical showing of typical curves of photoconductive material which is processed for use in a camera pickup tube in accordance with my invention;

Figure 3 is a schematic showing of the apparatus used for producing sublimed cadmium sulphide photoconductive surfaces.

Figure 4 is a graphical showing of conditions existing on the target surface of the tube Figure 1 during different methods of tube operation.

Figure 1 discloses a photoconductive pickup tube having an evacuated envelope 10 within which is positioned an electron gun structure 12 and a target electrode 14. The electron gun 12 is for providing an electron beam which can be scanned over the surface of the target 14. The electron gun is of conventional design and consists essentially of a cathode electrode 16, a control grid 18 and an accelerating electrode 20. Electrodes 22 and

24 are beam focusing electrodes. Cathode 16 is essentially a tubular electrode closed at one end facing the target electrode 14. The closed cathode end is coated with thermionic emitting material, which is heated preferably by a non-inductive heater coil 26 to provide an electron emission. This emission is formed in a well known manner by electrodes 18 and 20, into an electron beam 15.

The electrons of beam 15 are magnetically focused to a well defined point on the surface of target electrode 14 by a magnetic coil 28 which encloses the tube envelope 10 as is shown. A yoke structure, indicated at 30, comprises essentially two pairs of coils with the coils of each pair connected in series and respectively to sources of saw-tooth currents for providing line and frame scanning of beam 15 over the surface of target 14. Such a deflection system is well known, and does not constitute a part of this invention. During tube operation, voltages are applied to the several electrodes as is indicated in Figure 1. These voltages represent appropriate values for tube operation. However, operation of the tube need not be limited to these values.

Accelerating and focusing electrode 24 may comprise a conductive coating on the inner wall of the tube envelope 10. The conductive coating 24 extends to a point closely adjacent to target electrode 14. Conductively connected to coating 24 is a fine mesh screen 32 which is mounted in the tube envelope across the opening of a ring 34 sealed in the tube envelope 10. Target electrode 14 comprises essentially a supporting insulating transparent plate 36 such as glass, for example, which is sealed to a mounting ring 38, which is in turn sealed within the tube envelope 10, as shown. Envelope 10 is furthermore closed at the target end thereof by a face plate 40 closely spaced from the target supporting sheet 36. The glass sheet 36 is coated on its surface facing the electron gun 12 with a transparent conductive film or signal plate 42. Such a conductive film may be formed from evaporated metal or of such material commercially known as "Nesa" to provide a conductive film. The conductive film is coated with a thin layer 44 of photoconductive cadmium sulphide.

During tube operation, appropriate voltages are applied to the several electrodes within the tube. The electron beam 15 which is formed thereby is scanned over the surface of the photoconductive material 44. As will be described below, the surface of photoconductive coating 44 facing the electron gun 12 will assume an equilibrium potential. The conductive signal plate 42 is connected by a lead 46 through a resistance 48 to a source of potential, to be described below, to establish on signal plate 42 a potential different from the equilibrium potential established on coating 44 by the electron beam 15. When light is focused upon the target 14, portions of the cadmium sulphide film 44 illuminated by the light will become conductive and because of the potential difference across the film 44 a current will flow in these areas. This flow of current will discharge the scanned surface of coating 44 towards the potential of signal plate 42. As the scanning beam 15 passes over the discharged areas of the screen, it tends to rapidly restore these areas to equilibrium potential. This almost instantaneous charging of a discharged area of the target to the equilibrium potential provides rapid change in potential across resistance 48 since signal plate 42 is capacitively coupled to the photoconductive film 44. The change in potential across resistance 48 is detected and amplified in a well known manner by an electron tube 50 connected, as is shown, to lead 46. This provides the video signal or output signal of the pick-up tube.

In the above described operation of the tube of Figure 1, it is necessary for successful tube operation that there be little or no current flow between the surfaces of the photocathode coating 44 in those areas of the target which are not illuminated by light when a picture is focused upon the target 14. It is obvious that if there

is a large "dark" current flow in the unilluminated areas of the target, then all of the scanned surface of photoconductive film 44 will become discharged to the potential of signal plate 42. Beam 15, then, in scanning across the target surface will not provide any distinguishing potential changes across resistance 48 to provide a video or picture signal from the tube.

Up to the present time very little success has been obtained in using cadmium sulphide as a photoconductive material in pickup tubes of the type described above. Although the photoconductivity of cadmium sulphide is good when illuminated by a light source, it is also true that in the dark, the material has considerable conductivity. For storage type of pickup tube operation, with a $\frac{1}{30}$ second scanning (frame) frequency, a dark resistivity of 10^{12} to 10^{11} ohm-centimeters is required. This insures that the scanned target surface in the dark areas will not be discharged by an appreciable flow of dark current in $\frac{1}{30}$ of a second. Sublimed or evaporated layers of CdS have consistently fallen far short of this resistivity, so that the inherent high light sensitivity possible from CdS has not been fully utilized.

In accordance with my invention, I have discovered that if a cadmium sulphide target of the type described above for Figure 1 is baked in an atmosphere containing oxygen the dark resistivity of the material is vastly improved; that the dark resistivity is increased to 5 orders of magnitude or more above its previous resistivity.

Target 14 of the tube of Figure 1 may be formed in the following manner. Glass target support sheet 36 is first coated with a conductive film 42, for example, by metal evaporation or by any other appropriate transparent conductive coating. The glass target support sheet 36 may be placed in a tubing or an appropriate chamber 52, as shown in Figure 3. A ceramic boat 54 of pure cadmium sulphide material is also placed within container 52. As indicated in Figure 3, hydrogen gas is passed through the tube, first to drive out all the air and then to form a hydrogen atmosphere for promoting the coating of glass target 36 with the cadmium sulphide film. The container 52 is surrounded with heating coils 56 in a manner such that the coils are closer together in the region surrounding boat 54 to provide a temperature of substantially 1000° C. At this temperature, the cadmium sulphide tends to sublime into the hydrogen atmosphere. The heater coils 56 are spaced farther apart in the region of target plate 36 so that the temperature in this region is substantially between 700° C. to 800° C. The sublimed cadmium sulphide will tend to collect or condense within this cooler region and upon the coated target plate 36. It is not entirely clear what the complete action of the hydrogen atmosphere is. It is believed however, that to some extent the flow of hydrogen gas physically conveys the sublimed cadmium sulphide into the cooler region of the target plate 36. However, also a chemical reaction takes place in which the hydrogen combines with the sulfur of the cadmium sulfide to form hydrogen sulphide gas and sublimed cadmium metal. The sublimed metal condenses or deposits on the target plate 36 and then reacts chemically with the hydrogen sulphide gas to form a cadmium sulphide layer on the surface of the coated target sheet 36. These chemical reactions, which are believed to take place in container 52, permit the sublimation and formation of the target at a lower temperature. A sublimed cadmium sulphide target has been formed by the use of nitrogen gas but only by heating the cadmium sulphide boat to some 200° C. higher than that needed with the hydrogen atmosphere.

To provide the required higher resistivity in the dark for cadmium sulphide material I have found it necessary to bake the cadmium sulphide target in an atmosphere containing oxygen for more than about 10 minutes and at a temperature of between 250° C. and 650° C. This oxygen baking of a cadmium sulphide target increases the resis-

tivity of the cadmium sulphide in the dark from a value somewhat less than 10^6 ohm-centimeters to above the minimum required value of 10^{10} ohm-centimeters for a pickup tube of the type described above.

Figure 2 shows typical results obtained by an oxygen baking of many samples of cadmium sulphide target material. Curve 58 of Figure 2 shows the photoconductive current of the cadmium sulphide material under illumination, while curve 60 represents the dark current of the photoconductive material. The current values given along the vertical axis of the graph are arbitrary units. The temperatures indicated along the horizontal axis of the graph are those to which the material was subjected during a series of oxygen or air bakes, after which the material was cooled to room temperature and the light and dark current values of the curves obtained. It is noted that at first as the temperature of the air bake increases, there is very little change between the dark current and light current values, until the material is baked at a temperature between 400°C . and 500°C . Within this temperature range and as indicated by the curves, the light current value of the cadmium sulphide material typically decreases slightly while the value of the dark current of the same material takes a decided drop, of some 5 or more orders of magnitude from the original value of the dark current.

Although not shown in Figure 2, some samples of cadmium sulfide have shown a decided improvement in dark current resistivity after being baked at 250°C ., while other samples have shown improved dark current resistivity after baking as high as 650°C . From baking and testing many samples, it can be said that the dark resistivity of cadmium sulfide material starts to increase by baking in an atmosphere containing oxygen at 250°C . and is still greatly improved after such a baking at 650°C . The optimum baking temperature range however, is between 400°C . and 500°C .

The current flow indicated in Figure 2 is also an indication of the resistivity of the material, but in an inverse sense. Figure 2 indicates that baking a cadmium sulphide material in oxygen and between 400°C . and 600°C . will increase the resistivity of the material by substantially 5 orders of magnitude or more.

The actual process of baking the target electrode is as follows. The photocathode surface formed as described above is placed in an oven and baked at around 450°C . for a period of time between 5 minutes and $\frac{1}{2}$ hour. The atmosphere of the oven may be air or pure oxygen. The target is then mounted in the tube structure and the tube processed in the conventional manner.

The oxygen content of the normal atmosphere is sufficient to activate the cadmium sulfide material in the time specified. However, activation may be carried out with a greater or less percentage of oxygen in the atmosphere used. For example, successful activation has taken place with a pure oxygen atmosphere. It is only necessary that the baking take place sufficiently long and with sufficient oxygen in the atmosphere to complete activation. A longer baking time than necessary will not produce any ill effects.

The activation of the photoconductor target may also take place after the target has been mounted in the tube. For example, the cadmium sulfide film may be formed on the glass target after the glass sheet 36 has been mounted within the tube and before the gun structure 12 has been assembled within the tube envelope. After the electrode structure has been formed and mounted within the tube, the tube envelope is then processed normally by the conventional steps of exhausting the tube envelope and simultaneously baking and degassing the electrodes of the tube. Before the tube is sealed oxygen is admitted into the envelope and a high frequency wand placed adjacent to the face plate 40 of the tube to establish a glow discharge in the region of the cadmium sulfide film 44. This process is similar to that described in detail in U. S. Patent 2,065,570 to Essig. The oxidation of the target is allowed

to take place for 5 minutes and more until it is completely activated.

Another variation of the oxygen baking or activation of the target is that in which the above process is repeated but instead of the use of a high frequency wand, the tube is baked at 400°C – 500°C . with the oxygen atmosphere in the tube, after which the tube is processed and evacuated in the normal manner. It has been found that the activation or sensitizing of the photoconductive film takes place completely within 10 minutes and any further baking or sensitizing generally produces no great effect either favorable or unfavorable. Furthermore, the baking of the target appears to not critically change the spectral response of the tube. Cadmium sulphide photoconductive material has a peak sensitivity in the green with some blue response and a low red response.

The photoconductive cadmium sulfide film when used in a pickup tube of the type described in Figure 1, has a thickness of substantially 0.1 mil or 2.5 microns. This thickness appears to be about the optimum thickness for a pickup tube of the type described. If the photoconductive film were thinner than this, the charge established in the light areas of the target would be too high to be discharged by the beam 15. The normal beam current for a pickup tube of the type described is one of substantially 1 to 3 microamperes. If the target film were thicker than this optimum value, the thickness would be such that there would be undue loss of light penetration. It is desirable that such a photoconductive film have about 50% light absorption so that there will be sufficient current conductivity in the illuminated areas of the target film. If a portion of the photoconductive film is not sufficiently illuminated by the light, then the photoconductive material will tend to have too much resistance and to behave as an insulator in the poorly lighted areas. To provide this optimum thickness of the photoconductive film, it has been determined by trial and error that a period of time between 15 minutes and 1 hour for sublimation of the CdS material has given the proper thickness of target film under the conditions, described above.

The cadmium sulphide film may be applied directly to the target plate 36 after it has been mounted within the tube. This may be done by the use of a side-arm 60 through which the cadmium sulphide may be introduced in a boat formed of, or supported by, a wire coil which can be heated by a R. F. current introduced by another R. F. coil superimposed over the first coil. Furthermore, the cadmium sulphide film may be also formed by another method such as evaporation of cadmium sulphide upon the supporting glass surface 36 by heating cadmium sulphide in a vacuum. This method of forming film 44 may take place after the target glass 36 has been mounted within the tube and by the use of evaporators mounted adjacent the target 14 in any well known manner. With this method the cadmium sulphide material is evaporated on the glass 36 until the light transmission through the glass has fallen to substantially 50%. At this point the evaporation of the material may be stopped and the cadmium sulphide sensitized by an oxygen bake as described above.

The tube of Figure 1 may be operated in any one of several ways. For example, if the lead 46 of signal plate 42 is connected to terminal 62 through a variable voltage source 64 to ground, the operation of the tube can be that of an orthicon in which beam 15 is caused to approach target 14 at very low velocity. The adjustable voltage source 64 may be regulated so that the potential of the signal plate 42 is established at about 20 volts positive relative to the potential of gun cathode 16. The electron beam 15 then upon approaching the target 14 will be slowed down to substantially zero velocity and will deposit electrons upon the scanned surface of the cadmium sulphide film 44 to drive that surface down to an equilibrium potential, which is very close to that of the gun cathode 16. At this potential, then, the electrons of the

beam 15 will be repelled back toward the accelerating anode 20 of the gun. The signal plate electrode 42 being at about 20 volts positive relative to the cathode, and the scanned surface of cadmium sulphide film 44 being at substantially gun cathode potential there is thus established a potential difference between the two surfaces of the photoconductive film 44. This is the condition of the target 14, when no light is focused upon the target. If now, a scene or picture is focused on target 14, photoconductivity will be established through film 44 between the surfaces thereof and in the areas illuminated by the light of the scene or picture. In these illuminated areas a current flow will take place across film 44 and proportional to the amount of light falling upon each illuminated target area. In this manner, the illuminated areas of photoconductive film 44 will, on the scanned side thereof, be charged in potential toward the potential of the signal plate 42 and an amount corresponding to the amount of light falling on each respective target area.

Figure 4-A, shows the conditions existing on the target surface during tube operation. Curve 70 indicates the charge established on a target area illuminated with light. The area charges up from the equilibrium potential toward signal plate potential, within a frame time t , and before the illuminated area is again struck by beam 15. At the end of frame time t , the target area is discharged by the beam back to equilibrium potential. If the area remains illuminated it will again charge toward signal plate potential in the second frame time, $2t$.

Curve 72 indicates the charge acquired by dark areas adjacent to the illuminated areas. These dark areas are also driven to equilibrium potential by beam 15 at the end of each frame time. If the resistivity of photoconductive film 44, were not of the order specified, the dark current would be great enough to discharge the dark target areas in the manner indicated by curve 70 and within the $\frac{1}{30}$ second scanning time.

The difference between a charge on an illuminated area and that on an adjacent dark area at the time both are discharged by beam 15, as indicated in Figure 4-A, is a measure of tube sensitivity. It can be readily seen that if the dark current of the photoconductive film 44 were larger, the sensitivity of the tube would become indirectly proportionally less. It is, thus, necessary to have a high dark resistivity of the photoconductive film 44 to provide sufficient sensitivity for pickup tube operation. By providing an oxygen or air bake of the cadmium sulfide material in the manner described above, the dark resistivity of the material is increased to an order sufficient for its use in a pickup tube.

A second method of operation in the tube of Figure 1 is that in which the signal plate 42 is connected through a variable potential source 66 to the common potential source of electrode 24 and screen 32. The variable potential 66 is adjusted so that signal plate 42 is substantially several volts negative, such as five volts, with respect to the potential of screen 32. The potential of the signal plate 42 is sufficiently great that the electrons of beam 15 strike the cadmium sulfide film 44 at above the first cross-over and will produce a secondary emission from film 44 of more than unity. If any area of film 44 struck by beam 15 is negative to screen 32, then the secondaries from that surface area will pass to the more positive screen 32 and the target area will tend to go positive until it is at substantially the potential of screen 32 or slightly positive thereto, at which point practically as many electrons will pass to screen 32 as strike film 44 from the primary beam 15. This potential can be considered as an equilibrium potential and will be maintained as long as the beam remains on that target area. If any area of the target film 44 is more positive than the screen 32 when the beam strikes that target area, screen 32 will tend to suppress the secondary emission and drive the secondary electrons back to the target. This will reduce the potential of the target area to equilibrium or sub-

stantially the potential of screen 32. Thus, when no light is focused upon target 14, the beam in scanning over the photoconductive surface 44 will drive all areas of that surface to substantially the equilibrium potential of screen 32. Again, in the dark there is established a potential difference across the photoconductive film 44 which is that between the potential of signal plate 42 and equilibrium potential as described above.

When a picture or scene is focused upon target 14, a current flow will take place across film 44 in the illuminated areas of the target surface. These areas then, as described above for the orthicon operation of the tube, will be discharged in a negative direction toward the potential of signal plate 42. The electron beam 15 in scanning over each illuminated area of the target will instantaneously charge the target surface back to equilibrium potential, thus establishing a displacement current or voltage in the circuit of signal plate 42, and in the manner described above.

Figure 4-B indicates by curves 74 the charge conditions on an illuminated area in the frame times between scans of beam 15. In a manner similar to that described for Figure 4-A, the illuminated areas are discharged from equilibrium potential toward signal plate potential by the photoconductive current. The beam on each scan charges the area back to equilibrium potential. Curves 76 indicate the charge conditions on adjacent "dark" areas of the target.

Another high velocity beam operation of the tube of Figure 1 is that in which the signal plate 42 may be connected to the positive terminal of a variable voltage source 68 so that the signal plate is operated positively to the equilibrium potential established by the beam on the scanned surface of target 44. The operation of the tube in this case is again similar to that described above, and the photoconductive surface 44 is charged to a potential above equilibrium potential and in proportion to the amount of light striking the illuminated area. Figure 4-C indicates by curve 78 the charge conditions existing on the illuminated areas of the target during a frame time and by curve 80, the charge conditions on a dark area of the target. Under this manner of tube operation, the illuminated target surface is charged toward target plate potential by the photoconductive current and discharged to equilibrium potential at the end of each frame time, to provide the output signal of the tube.

While certain specific embodiments have been illustrated and described, it will be understood that various changes and modifications may be made therein without departing from the spirit and scope of the invention.

I claim:

1. An electron discharge device comprising, an electron gun for establishing an electron beam along a path, a target electrode mounted transversely to said beam path, said target electrode comprising a conductive signal plate and a photoconductive film having one surface thereof in contact with said signal plate and the other surface thereof facing said electron gun, said photoconductive film comprising cadmium sulphide combined with oxygen.
2. An electron discharge device comprising, an electron gun for establishing an electron beam along a path, a target electrode mounted transversely to said beam path, said target electrode comprising a conductive film and a photoconductive film having one surface thereof in contact with said conductive film and the other surface thereof facing said electron gun, said photoconductive film comprising cadmium sulphide material combined with oxygen.
3. An electron discharge device comprising, an electron gun for establishing an electron beam along a path, a target electrode mounted transversely to said beam path, said target electrode comprising a transparent support member, a conductive film on a surface of said support member, and a photoconductive film having one surface thereof in contact with said conductive film and the other surface thereof facing said electron gun, said photoconductive film

comprising cadmium sulphide material combined with oxygen.

4. An electrode for an electron discharge device, said electrode comprising, a support member having a conductive surface and a photoconductive film having one surface thereof in contact with said conductive support surface, said photoconductive film comprising cadmium sulphide combined with oxygen. 5

5. A target electrode for a pickup tube, said target electrode comprising a support member, a conductive film on 10

one surface of said support member, and a photoconductive film, said photoconductive film comprising cadmium sulphide material combined with oxygen.

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