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DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Improvements in or relating to Television Camera Tubes.

We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195 Broadway, New York City, New York State, United States of America, a Corporation organised and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to television camera tubes.

Of the television camera tubes presently available, the vidicon offers the best advantages of low cost and simplicity of adjustment. The vidicon includes a flat photoconductor, one surface of which is periodically scanned with an electron beam, the opposite surface being coated with a transparent conductive film and being exposed to incoming light. The conductive film is biased positively with respect to the tube cathode that projects the electron beam.

Light impingements on various parts of the photoconductor excite electrons from the valence band to the conduction band, thereby reducing localized resistivity as a function of light intensity. Electrons that have been deposited on the photoconductor target surface by the electron beam therefore "leak" across each photoconductor increment to the conductive film at a rate determined by the average light intensity to which that increment has been subjected. Hence, during the period taken to scan the entire target surface, or frame period, a voltage pattern is formed on the target surface. As the electron beam again scans the target surface, the charge it deposits varies with time in accordance with the stored photoconductor voltage pattern and therefore with the integrated illumination of successive photoconductor increments. Due to capacitive coupling, differences of electron deposition are manifested by current variations in the conductive film, which are taken as the output video signal.

It has been recognized that vidicon photoconductors must meet conflicting conditions: they must have a low enough resistivity in response to light to be reasonably sensitive, while having a sufficiently high transverse resistivity across the target surface to maintain the voltage pattern during the frame period. Substantial transverse currents due to insufficient transverse resistivity "smear" the image read out by the beam. The most satisfactory material presently available for fulfilling these requirements is antimony trisulphide, which, unfortunately, inherently presents several other problems. It loses its photoconductivity when subjected to high temperatures, which precludes vidicon fabrication by conventional vacuum tube techniques; the entire tube cannot be "outgassed" by high temperature treatment, which in turn comprises its reliability. Further, antimony trisulphide has a limited useful life expectancy, and it is susceptible to severe damage by overexposure both to light and to electron beam energy.

According to the invention, a television camera tube includes a target structure com-

[*Price 4s. 6d.*]

Price 25p

prising an n-type semiconductor having a higher concentration of deep donor centres than shallow donor centres, a flat conductor coextensive with but substantially insulated from a surface of the semiconductor and means adjacent the opposite surface of the semiconductor for conducting from the semiconductor electrons released from ionized donor centres, means for allowing an optical image to fall upon one of the surfaces so that deep donor centres may be ionized to set up a charge image, means for scanning the said opposite surface of the semiconductor with an electron beam, and means connected to the flat conductor for deriving successive signals therefrom produced by said scanning operation.

With a camera according to the invention the need for forming and maintaining a target surface voltage pattern is eliminated, as is the need for a photoconductor for producing long lifetime carriers, which alters and increases the choice of materials that can be used. Specifically, materials of long life, durability, and compatibility to vacuum tube fabrication technology can be used.

In an illustrative embodiment of the invention a vidicon-type camera tube comprises the usual cathode and beam forming and deflecting apparatus. Opposite the cathode is a flat n-type semiconductor, one surface of which is the target surface. A transparent insulator is sandwiched between the other side of the semiconductor and a transparent conductive film. A conductor bonded to the periphery of the target surface is biased in use at a small positive voltage with respect to the conductive film.

The semiconductor contains a high proportion of deep donor centres; that is, donors that cannot be thermally ionized at the temperature of operation. Incoming light through the transparent conductive and insulative films, however, excites electrons from these deep donors into the conduction band after which they are swept away from the semiconductor by the space-charge field through the target surface conductor, leaving behind positive deep donor ions. These ions are substantially immobile and so their relative concentration is indicative of localized input light intensity. Electrons from the electron beam are attracted to and recombine with the deep donor ions thus reducing the localized voltage across the insulator. Current increments are generated in the conductive film in response to the voltage changes which are taken as the video output signal. Since the energy stored in the device is defined by relative concentrations of immobile deep donor ions, the transverse resistivity problem described before is less severe than in conventional vidicons, and semiconductor materials can be used that are more durable and offer fewer fabrication problems than vidicon photoconductors. More importantly, the material requirements are altered because the mechanism of operation is fundamentally different from that of conventional vidicons.

The invention will be better understood from a consideration of the following detailed description of embodiments thereof taken in coinjunction with the accompanying drawings, in which:

Fig. 1 is a schematic view of a television camera tube in accordance with the invention;

Fig. 2 is an enlarged schematic view of the target structure of the television camera tube of Fig. 1;

Fig. 3 is a view taken along lines 3—3 of Fig. 2;

Fig. 4 is a typical energy band diagram of the target structure of Fig. 2;

Fig. 5 is a typical energy band diagram of the target structure of Fig. 2 under conditions of light energy excitation;

Fig. 6 is a typical energy band diagram of part of the semiconductor of Fig. 2 illustrating various excitation mechanisms; and

Fig. 7 is a schematic view of another television camera tube in accordance with the invention.

Referring now to Fig. 1, there is shown a vidicon-type television camera tube 10 having a cathode 11 for forming and projecting an electron beam toward a target structure 12. The tube includes a conventional electron beam alignment, accelerating and focusing structure, and conventional apparatus for deflecting the beam in a line and frame sequence. Light is incident on the target structure from the side opposite the electron beam from the side appropriately focused on the target structure to define an image to be recorded and transmitted. The purpose of the tube, like that of a conventional vidicon, is to convert incoming light energy to electrical energy, store the electrical energy, and release or read out the stored energy in the form of a continuous video signal as indicated by the output arrow.

Referring to Figs. 2 and 3, the target structure 12 comprises a semiconductor 14 one surface of which defines the electron beam target surface 15, with the other side being bonded to a transparent insulating film 16. A transparent conductive film 17 is bonded to the insulating film 16 and to a transparent glass substrate 18 that forms part of the tube envelope as illustrated in Fig. 1. A grid conductor 20 including an array of parallel conductor strips 21 is bonded to the target surface 15 and is biased at a positive voltage V_B with respect to the conductive film 17. The grid conductor 20 forms an equipotential plane over the entire target surface. An insulating coating 22

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overlying the grid conductor shields the grid conductor from the beam. The dimensions shown have been distorted for purposes of clarity.

The semiconductor is appropriately treated to be n-type; that is, it contains a preponderance of donor, rather than acceptor centers. Further, it contains a higher concentration of deep donor centers than shallow donor centers. Deep donors are donor centers that cannot be ionized by thermal agitation at the temperature to which it is subjected, while shallow donors are those that can be thermally ionized. The significance of this distinction and the function of the target structure can be better appreciated from the energy band diagrams of Figs. 4 to 6.

Referring to Fig. 4, the portions M,I,S, respectively represent the energy band distributions in the transparent conductive film 17, the insulating film 16, and the semiconductor 14. The letters C represent the lower boundaries of the conduction bands, V the upper boundaries of the valence bands, and F, the Fermi level. The subscripts 1 indicate band configuration with no bias voltage across the structure, the subscript 2 denoting their response to the applied bias voltage V_B of Fig. 2.

Under a zero bias condition, the Fermi level F_1 is common to the three materials. F_1 is, of course, closer to the semiconductor conduction band edge C_{S1} than to the valence band edge V_{S1} because the semiconductor is n-type. When the bias voltage V_B is applied, the semiconductor conduction and valence band edges "bend" to the positions shown by C_{S2} and V_{S2}, the energy difference between F_1 and F_2 the new position of the Fermi level in the semiconductor being equal to V_B. Electrons that are thermally excited to the conduction band from shallow donor atoms are swept out by the electric field and removed by the target surface grid conductor 20, leaving behind shallow donor positive ions which define a depletion region, or space-charge region SC_2.

Since the films 16 and 17 are transparent, light impinges directly on the semiconductor and alters its energy band configuration as shown in Fig. 5. The incoming light excites electrons from deep donors thereby creating a larger positive ion concentration than had existed before. The electrons excited from the deep donors, like those excited from the shallow donors, are removed from the semiconductor by the target surface grid conductor 20.

This has the effect of shortening the space-charge region SC_3 and reducing the voltage drop across the semiconductor S; it also increases the localized voltage drop across the insulator I. Considering the insulator to be a dielectric between parallel capacitor plates, the increased voltage across the insulator is the equivalent of a capacitor charging voltage.

Various excitation mechanisms in the semiconductor are illustrated in Fig. 6, in which solid dots represent electrons, encircled positive symbols represent positive ions, and positive symbols that are not encircled represent holes. The shallow donor has an energy level sufficiently close to the conduction band to permit thermal excitation of an electron 25, thereby leaving a shallow donor ion 26. Incoming light may ionize deep donors either by direct or indirect light excitation. Direct excitation results from the impingement of a photon on a deep donor which raises an electron 27 to the conduction band and produces a positive deep donor ion 28. Indirect excitation is caused by the excitation of an electron 29 from the valence band to the conduction band, which produces a hole 31 in the valence band. An electron 30 from a deep donor atom then recombines with the hole 31, thus producing a deep donor ion 32. Relative deep donor ion concentrations are a function of the number of incoming photons and therefore the relative intensities of the incoming light at different locations along the interface of the semiconductor with the insulator. The resulting charge density distribution along the interface is maintained because deep donor ions are substantially immobile.

A video output signal representative of the charge-density distribution is generated when the target surface is scanned by the electron beam. Referring to Fig. 1, notice that the resistor R_L is part of a circuit defined by the battery and the target structure, with the output signal being a function of the current through R_L. Whereas in a conventional vidicon the target is analogous to a succession of resistors having different resistances the target structure of our device is analogous to a succession of capacitors having different charges. Different charges stored on opposite sides of each insulator increment are, of course, indicative of the average light intensity on that increment during one frame period.

As the beam impinges on each target increment, beam electrons recombine with the deep donor ions and thereby discharge the incremental capacitor. A current increment then flows through R_L in response to the discharge and a voltage across the output terminals is generated. The successive output voltages therefore depend on the charge on successive capacitor increments so that the time varying output voltage is a function of the average spatial light intensity distribution on the target surface over one frame period. The spacing of the parallel strips 21 of the grid conductor 20 is

chosen such that the electrons are swept out before they can recombine with positive ions in the adjacent regions. After scanning, the capacitor increments are again charged due to incoming light; this charging current may or may not interfere with the derived signal voltage depending on the specific apparatus being used. Since the charging current must flow to the target surface grid conductor 20, the current from the battery to conductor 20 may be sampled and subtracted from the output signal to eliminate this problem. Appropriate circuitry for implementing this function is within the skill of a worker in the art.

For proper operation, the deep donor density in the semiconductor should be more than about $10^{17}/cm^3$ and preferably in the range of $10^{19}/cm^3$, while the shallow donor concentration should be less than about $10^{16}/cm^3$. In order to permit indirect excitation, the band gap (BG of Fig. 6), or the energy separation between valence and conduction bands, should be smaller than the photon energy of light to be recorded. In any case, the energy separation between the deep donors and the conduction band must not be greater than the photon energy. On the other hand, if the band gap is too small, deep donor doping is difficult. These various requirements can be met by using for the semiconductor material one of the II—VI compounds such as cadmium sulphide and cadmium selenide or a III—V compound such as gallium arsenide. These materials can be doped to high deep donor concentrations by conventional techniques and, as is known, their deep donor densities can be determined in various ways. Moreover, the carrier mobility and dielectric relaxation time of cadmium sulphide, cadmium selenide, or gallium arsenide are appropriate for lateral electron transit times that are large with respect to the recombination time.

Typical dimensions of the target structure may be as follows: length and width, 1/2×1/2 inch; semiconductor thickness, 1—10 microns; insulative film thickness, .1 micron, conductive film thickness, .1 micron. The parallel strips 21 of the grid conductor 20 may each be about 10 microns wide, separated from each other by about 100 microns, and covered by a suitable insulator of several tenths of a micron thick and about 30 microns wide. Conventional thin film techniques, particularly vapour deposition, can be used for making the target structure to these dimensions. For an application that tolerates less resolution, single crystal material, with or without epitaxially grown layers, can also be used.

The target surface grid conductor 20 may be biased at about +1 volt with respect to the conductive film 17 and at about +5 to +30 volts with respect to the cathode 11. With these parameters and with an electron beam density typically used in vidicon tubes, the diffusion gradient and the space-charge forces on impinging beam electrons will be appropriate to cause sufficient diffusion into the semiconductor to ensure substantially complete recombination with the ionized deep donors. The spacings of parallel strips 21 are sufficiently small to avoid impairment of resolution due to spurious electron recombination. Other spacing can be used depending on the semiconductor characteristics or the desired resolution, or, as described below, the strips can be eliminated if secondary emission electron removal is used.

If the shallow donor concentration and the electron mobility are such that the transverse or lateral conductance is high, resolution may be impaired by transverse spreading of beam electrons. It can be shown that appropriate resolutions for vidicon operation are assured by additionally making the resistivity of the semiconductor to be in the range of 10^6 to 3×10^{10} ohm-centimeters. The lower limit of this range is sufficient for giving a fundamental output frequency of 10^6 cps and the upper limit gives a sufficient dielectric relaxation time to permit electrons to be swept out by the grid conductor within a frame time of 1/30 of a second. The lower limit may be made still lower if the recombination can be made to occur in less than 10^{-6} sec.

Parallel strips 21 may be eliminated if provision is made to extract that portion of the electrons injected into the semiconductor by the electron beam which is in excess of the number of electrons required for deep donor recombination. This can be achieved, for instance, by modulating the electron beam energy in time about the average value, at beam energies lower than this average value electrons are injected, and at higher energies electrons are extracted due to secondary emission. The beam may be velocity modulated by driving an appropriate electron gun grid with modulating energy from a source 23 shown in Fig. 1. For operation corresponding to a fundamental output frequency of 10^6 cps, the modulating frequency should be (1 to 10)×10^6 cps. Design of the relevant tube parameters to give a secondary emission ratio in excess of one in response to high energy electrons is within the ordinary skill of a worker in the art.

As is apparent from the above description, the purpose of the insulating film 16 is to prevent any current flow between the semiconductor 14 and the conductive film 17; it is an electronic barrier. Alternatively, an electronic barrier between the metal and semiconductor can be made by

coating the semiconductor directly onto the metal such as to make a junction contact which is substantially insulating under reverse bias conditions. Also, because the semiconductor 14 of Fig. 1 is thin, there is nothing in principle that requires incoming light to impinge on the side of the semiconductor opposite the target surface; it could be directed at the target surface. These two alternative aspects of the invention are illustrated by the embodiment of Fig. 7.

The television camera tube 40 of Fig. 7 has a target structure 41 comprising an n-type semiconductor 42 bonded by a junction contact to a conductor 43. A grid conductor 44 is bonded to the target surface of the semiconductor in the same manner as the target surface conductor of Fig. 3. The tube 40 is an iconoscope-type camera tube having a cathode 45 for forming an electron beam that is deflected in a manner well known in the art to scan the target surface in a line and frame sequence. The cathode 45 is appropriately displaced so that light can be focused directly on the target surface scanned by the electron beam.

The mechanism of storage and read-out is essentially the same as that of the device of Fig. 1. Deep donors in the semiconductor are ionized by incoming light, with the scapping beam generating an output voltage across R_L as a function of the resulting charge density distribution in the semiconductor. Electrons excited to the conduction band of the semiconductor from deep and shallow donors and from the valence band are swept out by the target surface conductor 44. The junction between the conductor 44 and semiconductor 42 establishes a sufficient barrier to preclude any current flow across it.

Although large area junction contacts can be made and have been made by vapour deposition of semiconductor material onto metal to a thickness of only a few microns, it should be emphasized that great care is required during fabrication for forming a junction or barrier layer having a uniformly high energy difference between the metal and semiconductor to be substantially and uniformly insulative under reverse bias conditions. Localized imperfections on the metal surface being coated, foreign impurities, or irregular deposition can result in interface regions capable of high rates of carrier generation and thus a poor junction contact. As is known, the edges of the metal to semiconductor junction should be masked to minimize the edge generation problem.

Because of the fabrication problems inherent in thin film large area semiconductor-metal junction contacts, and the acknowledged advantages of vidicon operation over iconoscope operation, the embodiment of Fig. 1 is presently strongly preferred over the embodiment of Fig. 7. Future technological developments may, however, lead to a preference for the Fig. 7 embodiment, the use of a metal-insulator-semiconductor target structure of the type shown in Fig. 1 in the iconoscope tube of Fig. 7, or the use of a metal-semiconductor junction contact target structure of the type shown in Fig. 7 in a vidicon tube. In the latter modification the metal conductor would, of course, be thin and transparent.

WHAT WE CLAIM IS:—

1. A television camera tube including a target structure comprising an n-type semiconductor having a higher concentration of deep donor centres than shallow donor centres, a flat conductor coextensive with but substantially insulated from a surface of the semiconductor and means adjacent the opposite surface of the semiconductor for conducting from the semiconductor electrons released from ionized donor centres means, for allowing an optical image to fall upon one of the surfaces so that deep donor centres may be ionized to set up a charge image, means for scanning the said opposite surface of the semiconductor with an electron beam, and means connected to the flat conductor for deriving successive signals therefrom produced by said scanning operation.

2. A camera tube according to claim 1 wherein the flat conductor is insulated from the semiconductor by a thin transparent insulating layer, the conductor also being transparent, the optical image being formed on the said one surface of the semiconductor.

3. A camera tube according to claim 1 wherein the flat conductor is insulated from the semiconductor by means of a junction contact between the two, the optical image being formed on said other surface of the semiconductor.

4. A camera tube according to claim 2 or 3 wherein the means adjacent the opposite surface of the semiconductor comprises a conducting grid structure.

5. A camera tube according to claim 4 wherein the grid structure comprises conductive strips overlaid with insulating material and separated by a distance of about 100 microns.

6. A camera tube according to any preceding claim wherein the semiconductor has a deep donor centre density of greater than 10^{17} per cubic centimeter and a shallow donor centre density of less than 10^{16} per cubic centimeter.

7. A camera tube according to any preceding claim wherein the semiconductor is a II—VI compound or a III—V compound, having a resistivity of from 10^6 and 3×10^{10} ohm-centimeters.

8. A television camera tube circuit including a camera tube according to any pre-

coating the semiconductor directly onto the metal such as to make a junction contact which is substantially insulating under reverse bias conditions. Also, because the semiconductor 14 of Fig. 1 is thin, there is nothing in principle that requires incoming light to impinge on the side of the semiconductor opposite the target surface; it could be directed at the target surface. These two alternative aspects of the invention are illustrated by the embodiment of Fig. 7.

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Although large area junction contacts can be made and have been made by vapour deposition of semiconductor material onto metal to a thickness of only a few microns, it should be emphasized that great care is required during fabrication for forming a junction or barrier layer having a uniformly high energy difference between the metal and semiconductor to be substantially and uniformly insulative under reverse bias conditions. Localized imperfections on the metal surface being coated, foreign impurities, or irregular deposition can result in interface regions capable of high rates of carrier generation and thus a poor junction contact. As is known, the edges of the metal to semiconductor junction should be masked to minimize the edge generation problem.

Because of the fabrication problems inherent in thin film large area semiconductor-metal junction contacts, and the acknowledged advantages of vidicon operation over iconoscope operation, the embodiment of Fig. 1 is presently strongly preferred over the embodiment of Fig. 7. Future technological developments may, however, lead to a preference for the Fig. 7 embodiment, the use of a metal-insulator-semiconductor target structure of the type shown in Fig. 1 in the iconoscope tube of Fig. 7, or the use of a metal-semiconductor junction contact target structure of the type shown in Fig. 7 in a vidicon tube. In the latter modification the metal conductor would, of course, be thin and transparent.

WHAT WE CLAIM IS:—

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2. A camera tube according to claim 1 wherein the flat conductor is insulated from the semiconductor by a thin transparent insulating layer, the conductor also being transparent, the optical image being formed on the said one surface of the semiconductor.

3. A camera tube according to claim 1 wherein the flat conductor is insulated from the semiconductor by means of a junction contact between the two, the optical image being formed on said other surface of the semiconductor.

4. A camera tube according to claim 2 or 3 wherein the means adjacent the opposite surface of the semiconductor comprises a conducting grid structure.

5. A camera tube according to claim 4 wherein the grid structure comprises conductive strips overlaid with insulating material and separated by a distance of about 100 microns.

6. A camera tube according to any preceding claim wherein the semiconductor has a deep donor centre density of greater than 10^{17} per cubic centimeter and a shallow donor centre density of less than 10^{16} per cubic centimeter.

7. A camera tube according to any preceding claim wherein the semiconductor is a II—VI compound or a III—V compound, having a resistivity of from 10^6 and 3×10^{10} ohm-centimeters.

8. A television camera tube circuit including a camera tube according to any pre-

eding claim wherein the means adjacent the opposite surface of the semiconductor establishes over that surface an equipotential plane of higher positive voltage than the d—c voltage of the flat conductor.

9. A television camera tube circuit including a camera tube according to any one of claims 1 to 7 including means for varying the velocity of the electron beam between a value at which the secondary emission ratio of the target structure is greater than unity and a value at which that ratio is smaller than unity.

10. A circuit according to claim 9 wherein the frequency of the variation is from 10^6 to 10^7 cycles per second.

11. A television camera tube arranged and adapted to operate substantially as herein described with reference to and as shown in Figs. 1, 2 and 3 or Fig. 7 of the accompanying drawings.

12. A target for a television camera tube arranged and adapted to operate substantially as herein described with reference to and as shown in Fig. 2 or elements 42, 43, 44 of Fig. 7 of the accompanying drawings.

13. A television camera tube circuit arranged and adapted to operate substantially as herein described with reference to and as shown in Fig. 1 or Fig. 7 of the accompanying drawings.

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