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CATHODE INCLUDING PHOTOCONDUCTIVE AND TUNNELING LAYERS

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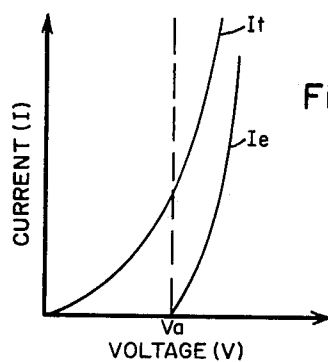
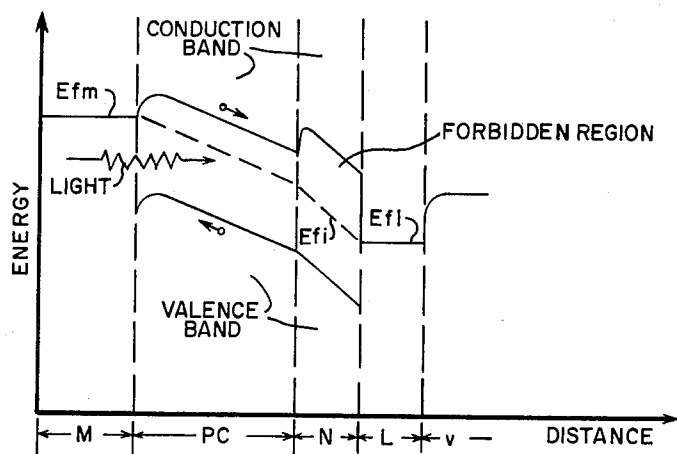
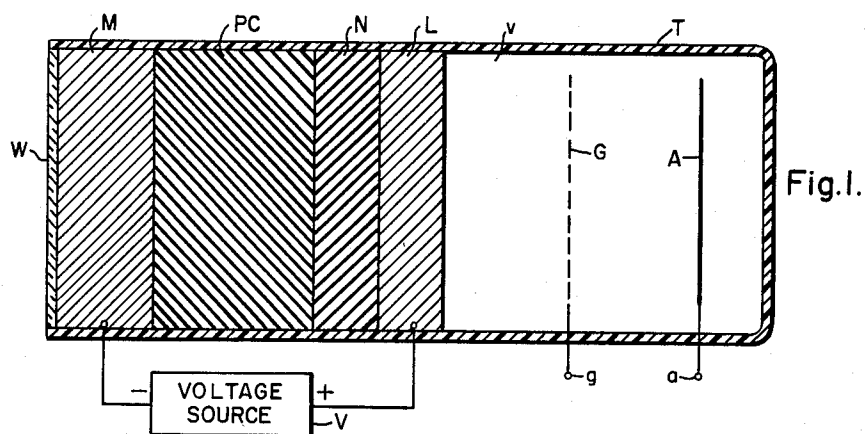


Fig. 3.

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**CATHODE INCLUDING PHOTOCONDUCTIVE
AND TUNNELING LAYERS**

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6 Claims. (Cl. 315-94)

The present invention relates to electron discharge devices, and more particularly to electron discharge devices utilizing photoconductors.

It has been observed that when a thin photoconducting film sandwiched between two metal electrodes has an electric field applied thereacross a much higher yield is obtained than with ordinary photocathodes. If an electric field is placed across the photoconducting film, the electrons in the conduction band of the photoconductor are accelerated toward the positive electrode. Part of the electrons gain sufficient energy to be able to penetrate the positive metal electrode and escape into an adjacent vacuum. The gain of the photoconductor is quite high and may have a yield of the order of 1,000 electrons per photon. Since the penetration probability of low work function metal films may be of the order of .01, the photon yield of such a device can be expected to be around 10. This yield compares quite favorably with the yield of conventional photoemitter of the order of 0.2. However, the above device has a certain disadvantage that only photoconductors of a very low dark conductivity can be used so as to keep the dark emission current low. To have a highly light sensitive device, it is necessary that the unilluminated or dark condition of the photoconductor be readily distinguished from its illuminated condition. To keep the dark current of the photoconductor at a minimum, it may be necessary to cool the device. Also, such a device would not be effective as infrared sensitive photoconductors as such photoconductors generally have characteristically high dark current. Therefore, it would be very advantageous to substantially eliminate any dark current flowing in the non-illuminated state of the photoconductor. This is because a greater sensitivity may be achieved by having substantially no electron emission in the dark state as compared to the high electron emission in the illuminated state; thus, resulting in a contrast enhancement.

It is therefore an object of the present invention to provide a new and improved photoconductive electron discharge device of high sensitivity.

It is a further object of the present invention to provide a new and improved photoconductive electron discharge device in which a high gain is achieved and which high sensitivity is obtained by substantially eliminating dark currents.

Broadly, the present invention accomplishes the above objectives by placing a layer of photoconductive material and a layer of insulating material having a tunneling characteristic between a transparent film and a low work function film. Dark currents are substantially eliminated due to the insulating layer when the photoconductor is in its dark state; while a copious supply of electrons is permitted to pass through the structure into vacuum when the photoconductor is in its illuminated state.

These and other objects will become more apparent when considered in view of the following specification and drawings, in which:

FIGURE 1 is a schematic drawing embodying the teachings of the present invention;

FIGURE 2 is a plot of energy versus distance for the structure of FIGURE 1; and

FIGURE 3 is a plot of the current versus voltage characteristic of the device of FIGURE 1.

Referring to FIGURE 1, an electron discharge device is shown having an envelope T, which may be evacuated to form a vacuum v therein. An anode electrode A is disposed at one end of the envelope T and has an external terminal a . Disposed within the envelope T is a grid electrode G, which has an external terminal g . At the other end of the envelope T, adjacent to the wall W, which may be light transparent glass, is disposed the cathode structure. Onto the wall W is evaporated a thin, metal film M, which is electrically conducting but transmissive to light such as indium. The metal film M may be of a thickness of approximately 200 Angstroms. Onto the metal film M is deposited a layer PC of photoconductive material, such as cadmium sulfide. The photoconductive layer PC may be of a thickness from 1 to 100 microns. Next an insulating layer N is disposed adjacent to the photoconductive layer PC by, for example, evaporation. The insulation layer N should be of a thickness of approximately 50 to 100 Angstroms. The insulating layer N may, for example, be of aluminum oxide or magnesium oxide. The thickness of the insulating layer N is selected so that the layer will have a tunneling characteristic when a sufficient potential is applied across the layer. That is, the current-voltage characteristics of the device should have a steep rise in current for a relatively small increase in voltage. Such a characteristic need not entirely result from tunneling alone, but may also result from electron ejection over the barrier at the photoconductor-insulator interface due to the thermal aided field emission effect. The combined effect of tunneling and thermally aided field emission may be termed field emission, with the device having a field emission characteristic. A metallic layer L is evaporated onto the insulating layer N. The electrode L may comprise an alkali metal, such as potassium, or an earth alkali metal, such as barium, deposited onto the insulating layer N. Or, the layer L may comprise a metal layer that is oxidized at its surface to provide a low work function, such as barium oxidized to form barium oxide. Also the layer L could be formed by alloying a metal layer with another material, for example, gold alloyed with barium. Another method of providing the low work function layer L would be to deposit a monolayer of a low work function material on a metal surface such as a monolayer of cesium deposited on a layer of antimony. There are, of course, other methods that could be used to provide the low work function layer L, for instance, disposing a mesh in a matrix pattern on the insulating layer N. The layer L may be of thickness of approximately 150 Angstroms. Thus, by utilizing a material having low work function surface to vacuum and having a thickness of approximately 150 Angstroms, a low work function barrier is provided at the layer L to vacuum interface, so that, electrons may readily pass through the cathode structure into the vacuum v . A source of direct potential V is provided with its positive terminal connected to the thin metallic layer L and with its negative terminal connected to the transparent metallic layer M.

In order to better explain the operation of FIG. 1, reference is made to the energy diagram of FIG. 2, and the current versus voltage characteristic of FIG. 3. In the dark or unilluminated state of the device, with no or very few photons being injected into the photoconductive layer PC, the photoconductive layer will have a certain dark resistivity. By selecting the magnitude of the potential of the voltage source V, a predetermined voltage drop will occur across the layer PC. The remaining voltage drop to complete the circuit, will appear across the insulating layer N. The given potential across the layer N will sustain a tunnel current I_t , as is shown in FIG. 3. However, there will be no emission current I_e

into the vacuum v until a critical voltage V_a is reached. The voltage V_a will provide sufficient energy to accelerate a portion of the electrons through the low work function layer L. Thus, in the dark state the tunneling current will equal the dark current of the device. The voltage that appears across the insulating layer N will cause some electrons to tunnel through the forbidden region of the insulating material N into the conduction band of the insulating material and then be accelerated by the potential appearing across the layer N. However, because of the resistivity of the photoconductive layer PC in its dark state, there will not be sufficient energy applied to the electrons tunneling into the conduction band of the insulating layer N to permit these electrons to penetrate the metallic layer L into the vacuum v . There will be no emission current I_e until the critical potential V_a is reached, which will permit electrons to be emitted into the vacuum v .

With light being supplied through the wall W and the thin transparent layer N, photons will be injected into the photoconductive layer PC. In the illuminated state, the resistivity of the photoconductor will substantially decrease. Electron-hole pairs will be created, with electrons in the conduction band of the photoconductor moving toward the insulating layer N, at a positive potential, and holes moving in the valence band of the photoconductor toward the negative metal layer M. The conduction in the photoconductor will continue until the holes move into the negative metal layer M. Since the resistivity of the photoconductor layer PC is substantially lower in its illuminated state, there will be an increased potential across the insulating layer N so that the critical potential V_a will be exceeded. Electrons may then tunnel through the forbidden region of the thin insulating layer N and then be accelerated in the conduction band of the insulating layer N with sufficient energy to penetrate through the low work function layer L and thus into the vacuum v . This can be seen from the energy diagram of FIG. 2, in which, the Fermi energy level of the metal layer M is at a level E_{fm} . The electrons in the conduction band of the photoconductive layer PC must have sufficient energy to tunnel through the forbidden region of the insulating layer N into the conduction band of the insulating layer N, where additional energy must be supplied, for a portion of the electrons to penetrate the metal layer L and be emitted into the vacuum v . If the Fermi level E_{fl} of the metal layer L and the Fermi level at the vacuum interface are too high, most of the electrons will not have sufficient energy to penetrate into the vacuum v . However, if the Fermi level E_{fl} of the metal layer L is reduced by using a low work function material, such as potassium, it will require less energy for the electrons to be able to penetrate the low work function layer L into the vacuum v , above the substantially lowered work function of the vacuum-metal interface, as is shown in FIG. 2. Thus, upon illumination of the photoconductive layer PC, a copious supply of relatively low energy electrons will be permitted to be emitted into the vacuum v with a substantial degree of stability. Once the electrons are in the vacuum v , the discharge device may operate in the well known manner with the electrons being controlled by the operation of the grid and anode electrodes.

Due to the sharp rise of the tunnel current I_t of the insulated layer L, practically the total change in photoconductor current can be utilized. That is, there is not just a change of photoconductive current from a substantial dark current to a somewhat larger illuminated current; but the change is from a very small dark current to a rapidly increasing and large illuminated current. Moreover, because of the even steeper rise of emission current I_e , the device has an inherent contrast enhancement characteristic. Thus, if the illumination is doubled, this will result in an even greater increase in the emission current I_e . This characteristic would be of particular usefulness in various light sensitive imaging devices.

Moreover, because the present device substantially eliminates dark current, its utilization in infrared detection devices would be highly advantageous.

Although the present invention has been described with a certain degree of particularity, it should be understood that the present disclosure has been made only by way of example and numerous changes in the details of fabrication, materials used and the combination and arrangement of elements may be resorted to without departing from the scope and the spirit of the present invention.

I claim as my invention:

1. An electron emissive device including, a first layer comprising a light transparent electrically conductive material, a second layer disposed adjacent said first layer and comprising a photoconductive material, a third layer disposed adjacent said second layer and comprising an insulating material having a field emission characteristic, the thickness of said third layer being selected to provide a current-voltage characteristic having a relatively large increase in current for a relatively small increase in voltage, and a fourth layer disposed contiguous said third layer comprising material having a low work function surface.

2. A photocathode electron emissive device including, a first layer comprising a light transparent electrically conductive material, a second layer disposed contiguous said first layer and comprising a photoconductive material, a third layer disposed adjacent said second layer and comprising an insulating material having a thickness of less than 150 Angstroms, the thickness of said third layer being selected to provide a current-voltage characteristic having a relatively large increase in current for a relatively small increase in voltage, and a fourth layer disposed contiguous said third layer and comprising a low work function alkali metal.

3. A photocathode electron emissive device including, a first layer comprising a light transparent electrically conductive material, a second layer disposed adjacent said first layer and comprising a photoconductive material, a third layer disposed adjacent said second layer and comprising an insulating material having a thickness of less than 100 Angstroms, the thickness of said third layer being selected to provide a current-voltage characteristic having a relatively large increase in current for a relatively small increase in voltage, and a fourth layer disposed contiguous said third layer comprising a metallic material coated with a monolayer of an alkali metal to have a low work function.

4. A photocathode electron emissive device including, a first layer comprising a light transparent electrically transparent conductive material, a second layer disposed adjacent said first layer and comprising a photoconductive material, a third layer disposed adjacent said second layer and comprising an insulating having a field effect characteristic, the thickness of said third layer being selected to provide a current-voltage characteristic having a relatively large increase in current for a relatively small increase in voltage, and a fourth layer disposed contiguous said third layer comprising a material oxidized at its surface to have a low work function, and excitation means to apply an electrical potential across said second and third layers.

5. An electron discharge device responsive to light including, an anode, a grid, and a cathode, said cathode comprising a first layer comprising a light transparent electrically conductive material, a second layer disposed adjacent said first layer and comprising a photoconductive material, a third layer disposed adjacent said second layer and comprising an insulating material having a field effect characteristic, the thickness of said third layer being selected to provide a current-voltage characteristic having a relatively large increase in current for a relatively small increase in voltage, and a fourth layer disposed contiguous said third layer comprising a material having a low work function.

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6. An electron discharge device responsive to light including, an anode, a grid, and a cathode, said cathode comprising a first layer comprising a light transparent electrically conductive material, a second layer disposed adjacent said first layer and comprising a photoconductive material, a third layer disposed adjacent said second layer comprising an insulating material having a thickness of less than 100 Angstroms, the thickness of said third layer being selected to provide a current-voltage characteristic having a relatively large increase in current for a relatively small increase in voltage, and a fourth layer disposed contiguous said third layer and comprising a low

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work function alkali metal having a low work function and having a thickness of less than 500 Angstroms.

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