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RADIATION SENSITIVE ELECTRON EMISSIVE DEVICE

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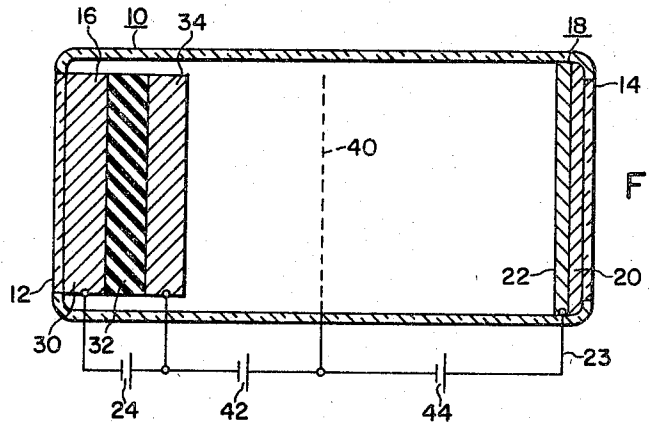


Fig.1.

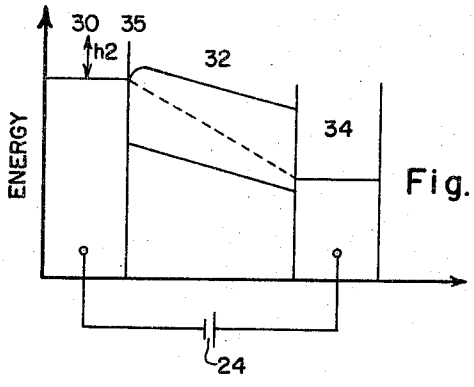


Fig.2.

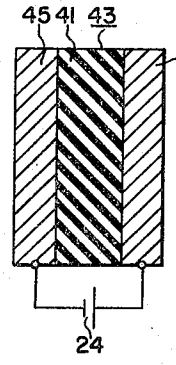


Fig.3.

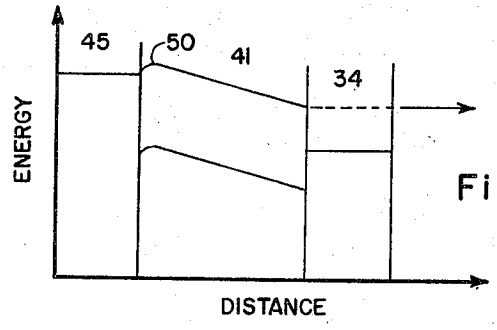


Fig.4.

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3,321,659 RADIATION SENSITIVE ELECTRON EMISSIVE DEVICE

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This invention relates to a solid-state electron device and more particularly to a radiation-sensitive electron emitter.

The present state of the radiation imaging art is particularly limited in the infrared range. Present photomissive surfaces with a vacuum work-function of less than 1 electron volt are not available. The obvious result of this limitation is that photoemissive devices cannot operate at wavelengths longer than 1.2 microns. Present thermal-imaging devices, whose operation is dependent on phenomena other than that photoemission, are severely limited by factors such as speed and resolution. It would therefore be desirable to provide surfaces that would enable photoelectrons of infrared energies to the extracted into a vacuum. This would enable one to utilize conventional electron multiplication techniques as employed in present-day imaging devices and thus high-sensitivity would be obtainable with the well-known high speed and high resolution capabilities of photoemissive surfaces.

It is accordingly an object of this invention to provide an improved solid-state radiation sensitive device.

It is another object to provide a solid-state imaging device which permits vacuum extraction of low energy photoelectrons.

It is another object to provide a solid-state infrared sensitive electron emissive cathode.

Briefly, the present invention accomplishes the above objectives by providing a metallic photosurface having a thin film of insulating material provided thereon and a thin electrically conducting film provided on the exposed surface of the insulating material. The thin electrical conducting film is treated to have a low vacuum work function.

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 techniques of the present invention;

FIGURE 2 is an energy level diagram versus distance of the radiation sensitive electron source of FIGURE 1;

FIGURE 3 is a schematic drawing illustrating a modification of the radiation sensitive electron source shown in FIGURE 1; and

FIGURE 4 is an energy level diagram versus distance for the electron source shown in FIGURE 3.

Referring to FIGURE 1, a photoelectric device is shown including an evacuated envelope **10**. The envelope **10** includes an input window **12** and an output window **14**. A cathode structure **16** is provided at the input end of the envelope **10** and an output electrode **18** is provided at the opposite end of the envelope adjacent the output window **14**. The output electrode **18** is comprised of an electron sensitive phosphor layer **20** such as zinc sulfide deposited on the inner surface of the output window **14**. An electrically conductive layer **22** is deposited on the exposed surface of the phosphor layer **20**. A lead-in **23** is connected to the conductive layer **22** to provide an external terminal. The output window **14** is transmissive to the light generated in the phosphor layer **20** so that an observer may view the output image.

The cathode structure **16** consists of a metal photosurface layer **30** which may be deposited directly on the input window **12**. The photosurface layer **30** is of a suitable material such as aluminum, magnesium, bismuth or beryllium. These materials exhibit the property of absorbing input radiation, giving up energy and increasing the kinetic energy of an electron by an amount hu: u is the frequency of the input radiation, and h is Planck's constant. These increased energy electrons may be referred to as photoelectrons. The layer **30** is of a suitable thickness of a few hundred angstroms and may be deposited on the input window **12** by suitable process such as evaporation in a vacuum of about 10^{-6} torr. In the case of an infrared device, the input window **12** should be transmissive to infrared and may be of a suitable material such as sodium chloride or barium chloride.

Deposited on the exposed surface of the layer **30** facing the output electrode **18** is a layer **32** of a suitable insulating material such as aluminum oxide and of a thickness of about 50 angstroms. The insulating layer **32** may be formed on an aluminum layer **30** by admitting oxygen to the system at a pressure of a few microns. The thickness of the insulating layer **32** is selected so that the layer **32** will have a tunneling characteristic when a sufficient potential is applied across the layer **32**. In the tunneling characteristic, the current voltage characteristic 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 injection over the barrier at the barrier at the photoemissive layer **30** and insulating layer **32** interface. Another suitable insulator for the layer **32** is bismuth oxide when using a bismuth for layer **30**.

An electrically conductive layer **34** is evaporated onto the exposed surface of the insulator **32** facing the output electrode **18** to provide a low work function layer and lateral electrical conductivity. A voltage source **24** is connected across the layers **30** and **34** with polarity as shown. The electrode **34** may be comprised of an alkali metal, such as potassium, or an earth alkali metal such as barium, deposited onto the insulating layer **32**. The layer **34** may also be comprised of a metal layer that is oxidized at its surface to provide a low work function, such as barium oxidized to form barium oxide. The layer **34** may also 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 **34** would be to deposit a monolayer of a low work function material on a metal surface such as a monolayer of caesium deposited on a layer of antimony. It is also possible to provide the low work function layer **34** by disposing a mesh in a matrix pattern on the insulating layer **32**. The layer **34** may be of a thickness of about 100 angstroms. Thus, by utilizing a thin layer **34** of a material having a

low work function surface to vacuum, electrons may readily be emitted from the cathode structure **16** into the vacuum portion of the envelope and then be accelerated on into the output electrode **18**.

Suitable focusing and acceleration means may be provided, as well known in the art, in the form of electrostatic or electromagnetic means (not shown) to provide focusing of the electron image emitted from the cathode **16** onto the output electrode **18**.

In the specific device shown, an electron multiplier structure **40** is provided between the cathode **16** and the output electrode **18**. The structure **40** may consist of one or more multipliers and may be of the type described in U.S. Patent 2,905,844 entitled, "Electron Discharge Device," by E. J. Sternglass and assigned to the same assignee as this invention. A source of direct potential **42** is connected between the cathode **16** and the multiplier electrode **40** with the positive terminal connected to the electrode **40** and the negative terminal connected to the cathode **16**. The potential of the battery **42** may be about 300 volts. A second voltage source **44** is connected between the electrode **40** and the output electrode **18**. The voltage of this source **44** may be 10,000 volts.

In order to further explain the operation of the device shown in FIGURE 1, reference is made to the energy diagram of FIGURE 2. The input radiation which may be in the form of infrared photons, is focused on the front metal film **30**. The photons on impingement on the layer **30** excite electrons within the layer **30** to an energy *hu* above the Fermi level of the material in layer **30**. If these excited electrons or photoelectrons are sufficiently energetic to overcome the barrier **35** at the interface between the metallic layer **30** and the insulating layer **32**, they will pass through or over the barrier **35** provided at the interface between the layers **30** and **32**. A bias voltage is applied by the battery **24**. The negative terminal is connected to the layer **30** and the positive terminal to layer **34**. The voltage source may be of a potential of about 2 volts. The photoelectrons will pass through the insulator layer **32** and the layer **34** and be emitted into the vacuum portion of the envelope. The electrons emitted into the vacuum are then accelerated by the voltage source **42** and impinge on the multiplier electrode **40**. The impingement of the photoelectrons on the electrode **40** results in an amplification of the input and provides an amplified electron image output. The output of the multiplier electrode **40** is then accelerated to the output electrode **18**. The electrons will pass through the layer **22** and bombard the phosphor **20** causing emission of light from layer **20** which in turn may be viewed through the output window **14**.

It is of course obvious that several modifications may be utilized to derive the signal sensed by the cathode structure **16**. For example, the electron image generated by the cathode **16** may be directed onto a storage element such as found in an image orthicon type of pickup tube and an electron beam utilized to scan the opposite surface of the storage electrode to derive an electrical signal representative of the electron image directed onto the storage electrode.

The transport of the electrons into the insulating layer **32** may take place by tunneling through or by being excited over the potential barrier **35** between the layer **30** and the insulating layer **32**. The contact between the insulating layer **32** and the layer **30** should be nearly ohmic or an electron injecting contact. This type of contact will provide only a small barrier to the electrons. The material in layer **30** should be matched with the material in layer **32** to provide that the Fermi level is above or within a few tenths of an electron volt of the conduction band edge of the material in layer **32** when placed in intimate contact. Infrared photoelectrons, by virtue of their excess energy (*hu*) would then have a considerably enhanced probability of tunneling into the conduction band of the

insulating layer **32** and hence move into and through the film **34**.

Instead of utilizing a tunneling barrier such as illustrated and explained with regard to FIGURES 1 and 2, a thicker insulating layer may be used in the cathode assembly such as shown in FIGURE 3. In this device, a cathode **43** consists of a layer **45** of an electrically conductive material such as indium of a thickness of a few hundred angstroms. An insulating layer **41** of a material such as cadmium sulfide and of a thickness of 100 angstroms to 1 micron is provided on the layer **45**. The conductive layer **34** is provided on the layer **41**. The photoelectrons from the layer **45** are transported into the conduction band of the insulator layer **41** by space charge limited processes. The energy diagram of this embodiment is shown in FIGURE 4. This structure requires the presence of a small potential barrier **50** between the metal layer **45** and the insulating layer **41**.

In the operation of this device, photoelectrons are injected into the insulating layer **41** by an ohmic injecting contact in the form of the layer **45** and are transported across the insulating layer **41** by the field applied by the battery **24**. As is the case in the tunneling device described with regard to FIGURE 1, the film **34** is made sufficiently thin that a large fraction of the electrons are able to penetrate through it into the vacuum. By varying the potential of battery **24**, the height of the potential barrier **50** may be varied.

The role of the low conductivity region **32** and **41** in FIGURES 1 and 3 respectively is to enable a sufficiently large bias voltage to be developed across the region so that electrons arriving at the barrier between the insulating layer **32** or **41** and the layer **34** have sufficient energy to allow them to escape through the layer **34** into the vacuum. The presence of the two bias terminals from the battery **24** to the layers **30** or **45** and **34** also affords the possibility of modulating the photo-output of the cathodes **16** or **43**. This feature may have advantages from the point of view of amplification and signal enhancement. On the other hand, the provision of the uniform bias over an extended area will almost certainly require the provision of a conducting grid structure over the exit film of such dimensions that the transverse voltage drop in the film regions between the grid "wires" is not significant.

As with all photodetectors of the quantum type, the thermal energy kT of the electrons must be less than *hu* of the incident radiation. This means that the cathode will probably have to be cooled for wavelengths greater than about 5 microns.

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 arrangement of elements may be resorted to without departing from the scope and spirit of the present invention.

I claim as my invention:

1. An electron device comprising a photosensitive solid state electron emissive source and an output electrode for collecting electrons emitted from said electron emissive source, said electron emissive source comprising a first layer of electrically conductive material exhibiting the property of absorbing radiations directed on a first surface thereof and permitting substantially all the photoelectrons generated within the layer in response to the radiation to reach a second surface of said layer; a second layer of insulating material in intimate contact with said first layer and providing a potential barrier to transmission of electrons of an energy less than the energy of said photoelectrons and a third layer of electrically conductive material in intimate contact with said second layer.

2. An electron device comprising a photosensitive solid state electron emissive source and an output electrode for collecting electrons emitted from said electron emissive source, said electron emissive source comprising a first

layer of electrically conductive material capable of absorbing substantially all of the input radiation directed thereon and provide transmission of substantially all excited photoelectrons through said layer, a second layer of insulating material in intimate contact with said first layer and providing a tunneling barrier, the height of said tunneling barrier being such as to suppress transmission of all electrons from said first layer with the exception of said excited photoelectrons by said radiation, and a third layer of electrically conducting material in intimate contact with said second layer of low work function material and thin enough to permit transmission of electrons through said third layer into a vacuum.

3. An electron discharge device comprising an evacuated envelope and having therein a radiation sensitive cathode, said radiation sensitive cathode comprising a first layer of electrically conductive material exhibiting the property of absorption of input radiation directed on a first surface and generation of photoelectrons within said first layer in response to said radiation and in which said photoelectrons are able to reach a second surface of said first layer, a second layer of insulating material on said second surface of said first layer in intimate contact with said first layer and providing a potential barrier to the transmission of the electrons having less energy than said photoelectrons, a third layer in intimate contact with said second layer, said third layer of electrical conductive material to permit the photoelectrons energetic enough to overcome said potential barrier to pass through said third layer into the vacuum of said envelope, an electron multiplier positioned in front of the emission surface of said radiation sensitive cathode for collecting the electrons emitted from said cathode and emitting a larger number of electrons and an output electrode positioned on the opposite side of said electron multiplier with respect to said cathode for collecting the output of said electron multiplier to derive an amplified input signal.

4. An image converter comprising an evacuated envelope and having therein a large area radiation photocathode surface for receiving and emitting an electron image corresponding to the radiation input directed on said photocathode, a transmission type electron multiplying structure positioned in front of said photocathode for receiving the electron image from said photocathode and multiplying the electron image, an output electrode of a material exhibiting the property of emitting light in response to electron bombardment and means for directing the electron image from said electron multiplier onto said output electrode to produce an output light image corresponding to said radiation input image, said radiation sensitive photocathode comprising a first layer of electrical conductive material exhibited the property of absorption of said input radiation and creation of photoelectron within said first layer in response to said radiation, a second layer of insulating material in contact with said first layer, a third layer of electrically conductive material in contact with said second layer, said second layer providing a potential barrier with regard to electrons within said first layer having an energy less than the energy of said photoelectron and means for impressing a potential across said first and third layers for transporting said photoelectrons from said first layer through said second and third into the vacuum between said photocathode and said electron multiplier electrode.

5. An electron device comprising a photosensitive solid state electron emissive source and an output electrode for collecting electrons emitted from said electron emissive source, said electron emissive source comprising a first layer of electrically conductive material exhibiting the property of absorbing radiations directed on a first surface thereof and permitting substantially all the photoelectrons generated within the layer in response to the radiation to reach a second surface of said first layer, a second layer of insulating material in intimate contact with said first layer and providing a potential barrier to transmission of

electrons of an energy less than the energy of said photoelectron, a third layer of electrically conductive material in intimate contact with said second layer, and a voltage source connected across said first and third layers to vary said potential barrier.

6. An electron device comprising a photosensitive solid state electron emissive source and an output electrode for collecting electrons emitted from said electron emissive source, said electron emissive source comprising a first layer of electrically conductive material capable of absorbing substantially all of the input radiation directed thereon and provide transmission of all excited photoelectrons through said layer to the opposite surface thereof, a second layer of insulating material in intimate contact with said first layer and providing a tunneling barrier, the height of said tunneling barrier being such as to suppress transmission of all electrons from said first layer with the exception of said excited photoelectrons by said radiation, a third layer of electrically conducting material in intimate contact with said second layer of low work function material to provide transmission of electrons through said third layer into a vacuum, and a voltage source connected across said first and third layers to modulate the number of transmitted photoelectrons.

7. An electron discharge device comprising an evacuated envelope and having therein a radiation sensitive cathode, said radiation sensitive cathode comprising a first layer of electrically conductive material exhibiting the property of absorption of said input radiation and generation of photoelectrons within said first layer in response to said radiation, a second layer of insulating material on the surface of said first layer in intimate contact with said first layer and providing a potential barrier to the transmission of electrons from said first layer having less energy than said photoelectrons, a third layer in intimate contact with said second layer, said third layer of electrical conductive material to permit photoelectrons energetic enough to overcome said potential barrier to pass through said third layer into the vacuum of said envelope, a voltage source connected to said first and said third layer to accelerate said photoelectrons, an electron multiplier positioned in front of the emission surface of said radiation sensitive cathode for collecting the electrons emitted from said photocathode to multiply the number of electrons and an output electrode positioned on the opposite side of said electron multiplier and said radiation cathode for collecting the multiplied output of said electron multiplier to derive an amplified input signal.

8. An image convertor comprising an evacuated envelope and having therein a large area radiation photocathode surface for receiving and emitting an electron image corresponding to the radiation input directed on said photocathode, a transmission type electron multiplying structure positioned in front of said photocathode for receiving the electron image from said photocathode and multiplying the electron image, an output electrode of a material exhibiting the property of emitting light in response to electron bombardment, means for directing the electron image from said electron multiplier onto said output electrode for producing an output light image corresponding to said radiation input image, said radiation sensitive photocathode comprising a first layer of electrical conductive material exhibited the property of absorption of said input radiation and creation of photoelectron within said first layer in response to said radiation, a second layer of insulating material in contact with said first layer, a third layer of electrically conductive material in contact with said second layer, said second layer providing a potential barrier with regard to electrons within said first layer having an energy less than the energy of said photoelectron and means for impressing a potential across said first and third layers for transporting said photoelectrons from said first layer through said second and third in a vacuum between said photocathode and said electron multiplier electrode.

(References on following page)

References Cited by the Examiner

UNITED STATES PATENTS

2,594,740	4/1952	De Forest	313—95
2,757,293	7/1956	Teves	250—213
2,972,691	2/1961	Kossel	313—94
2,985,783	5/1961	Garbung	250—83.3
3,056,073	9/1962	Mead	317—234
3,116,427	12/1963	Giaever	317—234
3,246,200	4/1966	Kanter	313—94 X

OTHER REFERENCES

C. A. Mead: Operation of Tunnel-Emission Devices, Journal of Applied Physics, vol. 32, No. 4, April 1961, pp. 646–652.

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