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SOLID STATE ELECTRON MULTIPLIER INCLUDING
REVERSE-BIASED, DISSIMILAR
SEMICONDUCTOR LAYERS
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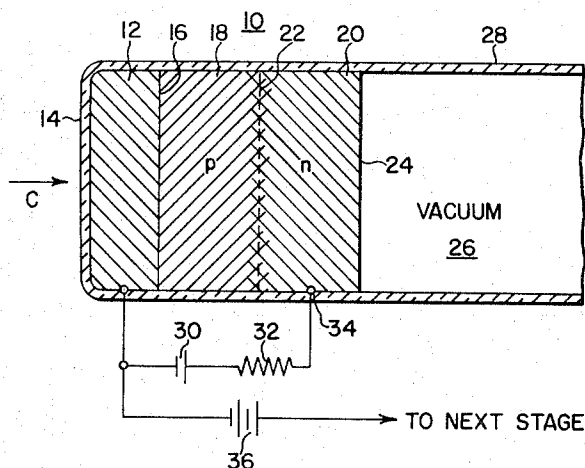


Fig. 1.

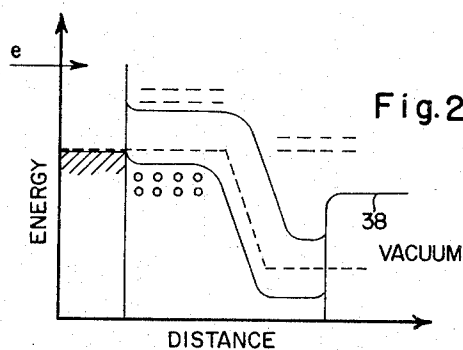


Fig. 2.

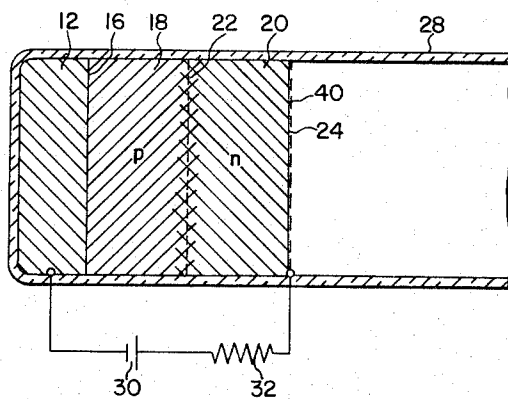


Fig. 3.

WITNESSES

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SOLID STATE ELECTRON MULTIPLIER INCLUDING REVERSE-BIASED, DISSIMILAR SEMICONDUCTOR LAYERS

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6 Claims. (Cl. 307—308)

The present invention relates to electron multipliers, and more particularly to electron multipliers incorporated in solid state semiconductor devices.

Many of the solid state electron multipliers have the inherent failing of being of relatively low yield. That is, the number of electrons actually emitted is low for the number of incident electrons applied to the device. The reason for the low yields may be explained due to various factors such as impurities in the materials used, unjudicious selection of materials and thicknesses. Even a more fatal defect in devices is that of the mechanism by which the device functions in only supplying a limited number of electrons of sufficient energy to escape and serve a useful function.

It is therefore an object of the present invention to provide a new and improved electron multiplier.

It is a further object of the present invention to provide a new and improved electron multiplying device utilizing the characteristics of a reverse-biased p-n junction within a semiconductor structure.

Broadly, the present invention provides an electron multiplying device in which a semiconductor device having a p-n junction therein is irradiated with high energy electrons to generate a large number of electron-hole pairs. These pairs are separated at the p-n junction, which is reverse-biased, and are accelerated towards the surface. With appropriate construction, a large number of electrons are emitted for each incident electron.

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

FIGURE 1 is a schematic diagram showing one embodiment of the electron multiplier of the present invention;

FIG. 2 is an energy diagram demonstrating the operation of the embodiment of FIG. 1; and

FIG. 3 is another embodiment of the electron multiplier of the present invention.

Referring to FIG. 1, a single stage of an electron multiplying device is shown. Of course, a plurality of stages may be connected in tandem with the output electrons of one stage serving as the input incident electrons to the next stage with multiplication occurring in each of the stages.

In FIG. 1, the electron multiplying device has a layer 12 of an electrically conductive material, such as aluminum or gold. The layer 12 has a surface 14 to which incident electrons *e* of a relatively high energy level are applied thereto from an external source or from a previous stage of electron multipliers. The conducting layer 12 is made thin enough so that substantially all of the electrons irradiating the surface 14 will be transmitted through the layer 12 to an opposite surface 16 of the layer 12. Disposed next to the conducting layer 12 at the surface 16 is a semiconductive layer 18. The semiconductive layer 18 is of a p-type semiconductivity. An ohmic contact is formed

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at the interface surface 16 between the conducting layer 12 and the semiconductive layer 18 so that electrons transmitted through the layer 12 may penetrate into the p-type semiconductive material of the layer 18. The layer 12 may be fixed to the semiconductive layer 18 by evaporation or alloying in order to form an ohmic contact at the interface 16. An n-type semiconductive layer 20 joins the p-type semiconductive layer 18. A p-n junction 22 is formed between the semiconductive layers 18 and 20. The layers 18 and 20 may be formed from a single wafer with a p-type semiconductive wafer being diffused with an n-type impurity, or an n-type semiconductive wafer may be diffused with a p-type impurity. Both of these diffusion methods are well known in the art. Also epitaxial growth techniques could be utilized in order to form the p-n junction 22 between the two types of semiconductivities.

The n-type semiconductive layer 20 has a surface 24 disposed continuous to a vacuum area 26. The entire device or a plurality of devices is enclosed within a tube 28, which, for example, may be glass.

To reverse bias the p-n junction 22, a biasing source comprising the battery 30 and a resistor 32 is provided. The negative terminal of the battery terminal is connected ohmically to the conductive layer 12. The positive terminal of the battery 30 is connected to the resistor 32 with the other end of the resistor being connected ohmically to the periphery of the n-type semiconductive region 20 at the ohmic contact 34. The conducting layer 12 also serves as a terminal for a battery 36 which may serve as the inter-stage biasing source for subsequent stages of multiplying devices.

Referring now to FIG. 2, an incident electron *e*, being of a relatively high energy of the order of 10 kv., incident upon the surface 14 of the conducting layer 12 will pass through the thin metal film and penetrate into the p-type region 18. The thickness of the p-type layer 18 is chosen so that the excess energy of the electron is fully dissipated in the production of electron-hole pairs. This dissipation is approximately 3.7 electron volts per pair. In the energy diagram, the electron-hole pairs are shown by the small dashes in the conduction band and circles in the valence band of the p-type region 18. The pairs diffusing toward the p-n junction 22 are separated by the p-n junction electric field, which is established by the reverse bias of the battery 30. It should be noted that if the semiconductive device layers 18 and 20 are biased in the avalanche breakdown region, further carrier multiplication may be obtained. Due to the separation of the electron-hole pairs, excess electrons will be transmitted into the n-type region 20 with many of the electrons being at relatively high energy levels. By selecting the reverse bias on the p-n junction 22 of a sufficient magnitude and making the n-type region 20 thin enough, a substantial proportion of the excess electrons moving toward the surface 24 of the layer 20 will have sufficient energy to escape over the vacuum barrier 38 to provide a copious supply of electrons into the evacuated area 26. To lower the vacuum barrier, the surface 24 may be suitably treated, for example, cesiated. See, for instance, copending application Ser. No. 217,581, filed Aug. 17, 1962 and assigned to the same assignee as the present application which describes various structures for lowering the vacuum barrier at vacuum interfaces. The thickness of the n-type layer 20 may be reduced to a suitable value by a slow etch or by a jet etching process.

With incident electrons having energy levels of the order of 10 kv., the number of electron-hole pairs gen-

erated by a single electron may be several thousand. With avalanche multiplication, this factor can be increased by another order of magnitude. An electron transfer ratio of at least 0.1 may be expected through the n-type layer. Therefore, it can be seen that single stage gain of 1000 or better can be expected by the device as shown in FIG. 1.

The n-type region 20 is usually highly doped and an ohmic contact is made at 34 on the periphery of the layer. The highly doped n-type region, however, may excessively, in certain applications, reduce electron mobility. To avoid this problem, a structure such as shown in FIG. 3 may be utilized.

The embodiment of FIG. 3 is substantially the same as that of FIG. 1 with a metallic layer 12 being disposed adjacent a p-type semiconductive layer 18, forming a p-n junction 22 with an n-type semiconductive region 20. The difference between the embodiments of FIG. 3 and FIG. 1 lies in that an n-type region of low conductivity is used and a grid structure 40 is disposed on the surface 24 of the layer 20. The positive terminal of the battery 30 is connected through the resistor 32 to the grid structure 40 rather than at the ohmic contact 34 on the periphery of the n-type region 20 of FIG. 1. The grid structure 40 may be formed by evaporating a contact over the surface 24. The device of FIG. 3 functions in the same fashion as that of FIG. 1 with the energy diagram of FIG. 2 being equally applicable thereto.

It can thus be seen that an electron multiplying device is provided. Incident electrons pass through a metal layer and penetrate into a semiconductive layer of one type semiconductivity and produce electron-hole pairs. The pairs drift toward a p-n junction under the effect of a biasing source. Electrons are separated at the junction to provide excess electrons which pass through a semiconductive region of another type semiconductivity with sufficient energy to be emitted into a vacuum.

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 that 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 multiplier operative with incident electrons comprising, a first layer comprising an electrically conductive material transmissive to irradiating electrons, a second layer comprising a semiconductive material of one type of semiconductivity, said second layer being disposed adjacent said first layer, said second layer producing a copious number of electron-hole pairs in response to each incident electron penetrating said second semiconductive layer, a third layer comprising a semiconductive material of another type of semiconductivity from said second layer, said third layer being adjacent said second layer and forming a p-n junction therewith, the electron-hole pairs being separated at said p-n junction, and biasing means to reverse bias said p-n junction so that the separated electrons may pass through said third layer.

2. A solid state electron multiplier operative with incident electrons comprising, a first layer comprising an electrically conductive material transmissive to irradiating electrons, a second layer comprising a semiconductive material of one type of semiconductivity, said second layer being disposed adjacent said first layer, said second layer producing a copious number of electron-hole pairs in response to each incident electron penetrating said second layer, a third layer comprising a semiconductive material of another type of semiconductivity from said second layer, said third layer being adjacent said second layer and forming a p-n junction therewith, the electron-

hole pairs being separated at said p-n junction, and biasing means connected ohmically to said first and third layers to reverse bias said p-n junction between said second and third layers so that the separated electrons may pass through said third layer and be emitted into vacuum.

3. A solid state electron multiplier operative with incident electrons comprising, a contact layer comprising an electrically conductive material transmissive to irradiating electrons, a first semiconductive layer comprising a p-type semiconductive material, said first layer being disposed adjacent said contact layer and forming an ohmic contact therebetween, said first layer producing a copious number of electron-hole pairs in response to each incident electron penetrating said first semiconductive layer, a second semiconductive layer comprising an n-type semiconductive material, said second layer being adjacent said first layer and forming a p-n junction therewith, the electron-hole pairs being separated at said p-n junction and biasing means to reverse bias said p-n junction between said semiconductive layers so that the separated electrons may pass through said second layer and be emitted into vacuum.

4. A solid state electron multiplier operative with incident electrons comprising, a contact layer comprising an electrically conductive material transmissive to irradiating electrons, a first semiconductive layer comprising a p-type semiconductive material, said first layer being disposed adjacent said contact layer and forming an ohmic contact therebetween, said first layer producing a copious number of electron-hole pairs in response to each incident electron penetrating said second semiconductive layer, a second semiconductive layer comprising an n-type semiconductive material, said second layer being adjacent said first layer and forming a p-n junction therewith, the electron-hole pairs being separated at said p-n junction, and biasing means connected ohmically to said contact layer and said second layer to reverse bias said p-n junction between said semiconductive layers so that the separated electrons may pass through said second layer and be emitted into vacuum.

5. An electron multiplier operative with incident electrons comprising, a first contact layer comprising an electrically conductive material transmissive to irradiating electrons, a second layer comprising a semiconductive material of one type of semiconductivity, said second layer being disposed adjacent said first layer, said second layer producing a copious number of electron-hole pairs in response to each incident electron penetrating said second semiconductive layer, a third layer comprising a semiconductive material of another type of semiconductivity from said second semiconductive layer, said third layer being adjacent said second layer and forming a p-n junction therewith, the electron-hole pairs being separated at said p-n junction, a grid matrix disposed adjacent said third layer, and biasing means connected to said first layer and said grid matrix to reverse bias said p-n junction between said second and third layers so that the separated electrons may pass through said third layer and said grid matrix and be emitted into vacuum.

6. A solid state electron multiplier operative with incident electrons comprising, a first layer comprising an electrically conductive material transmissive to irradiating electrons, a second layer comprising a p-type semiconductive material, said second layer being disposed adjacent said first layer and forming an ohmic contact therebetween, said second layer producing a copious number of electron-hole pairs in response to each incident electron penetrating said second layer, a third layer comprising an n-type semiconductive material, said third layer being adjacent said second layer and forming a p-n junction therewith, the electron-hole pairs being separated at said p-n junction, a grid matrix disposed adjacent said third layer and having openings therein to permit the passage of electrons, and biasing means connected to said first layer and said grid matrix to reverse bias said p-n junction.

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tion between said second and third layers so that the separated electrons may pass through said third layer and said grid matrix and be emitted into vacuum.

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