May 18, 1965 F. A. WHITE ETAL 3,184,633

SEMICONDUCTIVE ELECTRON MULTIPLIER

Filed Nov. 3, 1960

FIG. 1

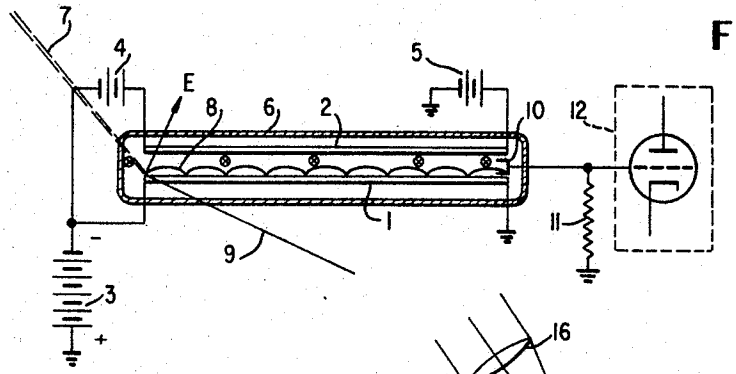


FIG. 2

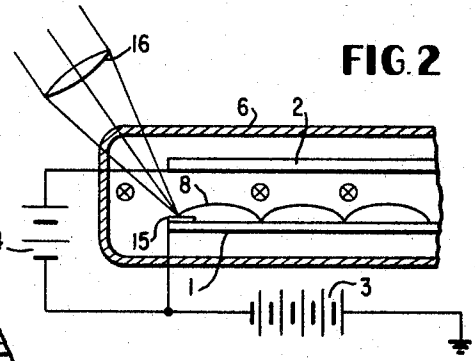


FIG. 3

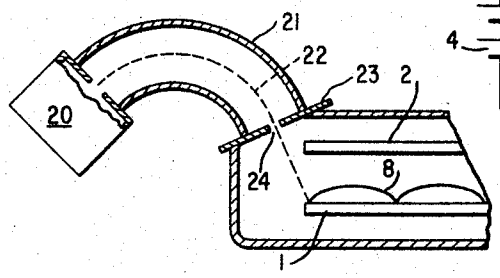


FIG. 4

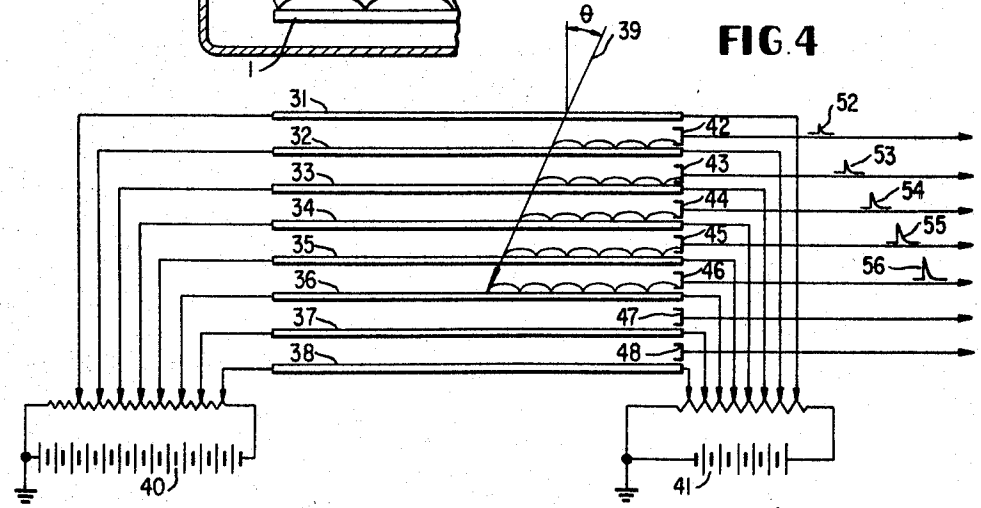
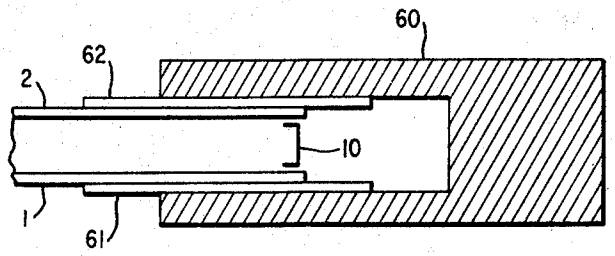


FIG. 5



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United States Patent Office 3,184,633 Patented May 18, 1965

3,184,633

SEMICONDUCTIVE ELECTRON MULTIPLIER

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Filed Nov. 3, 1960, Ser. No. 67,002
3 Claims. (Cl. 315—12)

This invention relates to electron multipliers and more particularly to a magnetic electron multiplier in which a slab of semi-conductive material is used for the secondary emissive material.

In the past, most magnetic electron multipliers have had limited application due to the multiplicity of dynodes and resultant complexities and relatively bulky size. In addition, proper magnetic focusing has been exceedingly difficult to obtain and as a result, it has been virtually impossible to utilize all of the secondary electrons emitted from the dynodes due to the variation of the kinetic energy of the secondary electrons and the random directions of emission before acceleration.

In previous models of single surface electron multipliers, a plate of glass or other insulating material has been coated with a high resistance film. These films are usually of metallic oxide and are exceedingly thin. Such an electron multiplier is shown in U.S. Patent 2,841,729. The thin film in this type of electron multiplier has allowed only moderate potential gradients to be applied to it and it is difficult to achieve a uniform electrical gradient of desired stability. In addition, these thin films are frequently subject to burn out from excessive voltage gradients or from environmental disturbances.

It is, accordingly, an object of this invention to provide an improved and simplified magnetic electron multiplier.

It is a further object of this invention to provide an improved single surface magnetic electron multiplier.

It is a further object of this invention to provide a single surface electron multiplier, the surface of which can be subjected to a high potential gradient.

It is a further object of this invention to provide a single surface electron multiplier, the surface of which is not subject to burn out.

It is a further object of this invention to provide an electron multiplier useful as an ion detector which will measure beam currents of exceedingly small magnitude.

It is a further object of this invention to provide an electron multiplier which has a negligible background noise.

It is a still further object of this invention to provide an electron multiplier which is compact in size and of rugged assembly.

In accordance with one aspect of the invention, two semiconductive slabs are mounted in a spaced parallel relationship and a longitudinal voltage gradient is provided along each of the semiconductive slabs. A biasing field is provided between the two slabs and a magnetic field is provided which is transverse to the electric fields caused by the previously mentioned voltage gradient and biasing field. An initial electron disturbance, such as by ion bombardment, is caused at the relative negative potential end of one of the semiconductive slabs. The electrons disturbed from the end of the slab will leave the slab and, under the influence of the electric fields and the magnetic field will follow a cycloidic path and will strike the semiconductive slab from whence it came a spaced distance along the semiconductive slab. This electron strikage will cause secondary emission of a number of electrons from the semiconductive slabs and each of the secondarily emitted electrons will also follow a cycloidic path and re-strike the semiconductive slab. This series of cycloidic paths will continue along the length of the semiconductive slab, with each of the succeeding cycloidic

loops having a greater number of electrons than the cycloidic loop preceding it. A collector electrode is provided at the relative positive potential end of the semiconductor slab to collect the electrons in the final cycloidic loop. This collector electrode may then be connected to any suitable utilization device, such as an amplifier or a pulse counter.

For a better understanding of the invention, reference may be had to the accompanying drawings in which:

FIG. 1 is a schematic illustration of an electron multiplier embodying the subject invention.

FIG. 2 is a view of a portion of the electron multiplier of FIG. 1 being used as a photon or light detector.

FIG. 3 is a view of a portion of an electron multiplier utilizing the subject invention and being used as an ion detector in conjunction with a mass spectrometer.

FIG. 4 shows one embodiment of the subject invention being used to detect the velocity of a charged particle.

FIG. 5 shows an electron multiplier embodying the subject invention and being mounted in a block which also serves as a heat reservoir for the device.

FIG. 1 shows a schematic representation of an electron multiplier in which two slabs of semiconductive material **1** and **2** are mounted in a spaced, generally parallel relation. A longitudinal voltage gradient is provided along each of the slabs **1** and **2** by the voltage source **3**. A biasing field between the two slabs **1** and **2** is provided by the voltage sources **4** and **5**. The electric field resulting from these voltage sources at any point on the slab **1** is represented by the vector E. A magnetic field is provided from any suitable source (not shown) which is transverse to the voltage gradient in the semiconductive slabs and the electric field between the slabs caused by the biasing sources **4** and **5**. In the embodiment shown in FIG. 1, the magnetic lines of flux would pass into a sheet of paper. The entire assembly may be maintained in a vacuum by a suitable envelope **6**.

The electron multiplier operates as follows: Energy **7** from any suitable source impinges upon the relative negative potential end of the semiconductor slab **1**. This energy may be in the form of charged particles such as ions or electrons or may be radiant energy such as light, ultra violet light, gamma rays, or any other form of energy which, when striking the semiconductor slab **1**, will cause at least one electron to be emitted therefrom. These electrons, upon entering the electric field as represented by the vector E, will be accelerated and, as they attain a velocity, will be deflected by the transverse magnetic field. The electron path **8** will follow a cycloidic loop whose base lies along the line **9**, which is normal to the vector E. When an electron following this path restrikes the slab **1** secondary emission will occur from the slab and a plurality of electrons will then traverse another cycloidic loop in a similar manner. With each succeeding loop, the number of electrons in the path will increase. After the final loop, the electrons are collected by the electron collector **10** which is connected to ground through the resistor **11**. An output signal will then appear across this resistor **11** and this signal may be applied to any desired utilization device **12**, which may be an amplifier, a pulse counter, or any other desired utilization device.

The output pulse on the resistor **11** for each initial excitation of the slab **1** will be approximately $K(X)^n$ where K is the average number of electrons ejected due to the primary excitation, X is the average number of secondary electrons caused to be emitted by each striking electron and n is the effective number of stages or loops which make up the electron path **8**. It is thus seen that the electron multiplier is relatively insensitive to variations in the magnetic field. This is because while an increase in magnetic field will increase the number of loops in the elec-

tron path, it will also decrease the potential gradient through which each loop passes and will thus decrease the number of secondarily emitted electrons in the following loop or stage. Conversely, while a decrease in magnetic field strength will decrease the number of loops in the path 8, it will also increase the potential gradient to which each loop passes and will increase the number of secondarily emitted electrons in each loop. Thus, the device shows a relatively broad maximum gain for a varying magnetic field strength.

The semiconductive slabs 1 and 2 may be made from either N type or P type semiconductive materials. They may be made from gold doped silicon, cadmium sulphide, intermetallic compounds such as gallium arsenide or any other suitable semiconductive material. The resistivity of the semiconductive material may be increased by cooling the assembly, if desired. This increased resistivity is desirable to reduce the longitudinal current flow in the semiconductive slabs. It has been found that when using gold doped silicon cooled to a temperature of about —80° C. with Dry Ice that a resistivity in the order of 10^9 ohms can be obtained.

Of course, the slab 2 need not necessarily be made of an electron emissive material, since it is never subject to electron bombardment, but instead establishes the electric field between the slabs 1 and 2. Thus, the slab 2 must only be made of a material sufficient to support a voltage gradient similar to that in the slab 1. However, in the preferred embodiment of the invention the slab 2 is made of the same material as is the semiconductive slab 1, thus assuring the same voltage gradient in each slab.

It has been found that a gain in the order of 10^8 can be obtained from a device of the type described in which the length of the semiconductor slabs is about two centimeters, the spacing between the slabs about one millimeter, the voltage gradient from the source 3 is about 3,000 volts, the bias voltage from the sources 4 and 5 is about 400 volts and the magnetic field is about 1,000 gauss. These values were obtained while using gold doped silicon for the semiconductor slabs and when the assembly was cooled with Dry Ice to a temperature of about —80° C.

FIG. 2 shows a portion of an electron multiplier such as has been previously described being used as a light detector or photo tube. Suitable focusing means 16 are provided to direct and focus incident light onto a photo cathode 15, which may be made of cesium antimony or any other suitable photo emissive material. When the photo cathode 15 has light impinging thereupon, electrons are emitted therefrom and, under the influence of the electrical and magnetic fields, the electrons follow a cycloidal path 8 and strike the semiconductive slab 1, whereupon secondary emission occurs. The operation of the device is then similar to that previously described.

FIG. 3 shows an electron multiplier according to the subject invention being used as an ion detector in conjunction with a mass spectrometer. A mass spectrometer 20 is generally shown including a curved portion of constant radius 21 which is joined to the electron multiplier by a member 23 that includes an opening 24 therein. The mass spectrometer 20, the arcuate region 21 and the electron multiplier are maintained in a common vacuum. Ions are accelerated by the mass spectrometer and a magnetic field (not shown) causes these ions to follow the arcuate path 22 and, if these ions are of proper predetermined mass, they will pass through the opening 24 and strike one of the ends of the semiconductive slab 1 of the electron multiplier. The ions striking the semiconductive slab 1 will cause electrons to be emitted therefrom and the electron multiplier will then operate in the manner hithertofore described. The electrical connections and magnetic field for the electron multiplier in this figure are not shown, but they will be made in a manner similar to that previously described.

FIG. 4 shows one embodiment of the invention being used to measure the velocity of a high energy particle. Since velocity is a vectoral quality, it has both magnitude and direction and the embodiment shown in FIG. 4 will determine both the direction and the magnitude of the velocity of a charged particle. A plurality of semiconductive slabs 31 through 38 are mounted in spaced, parallel relation. The potentiometer 40 provides a longitudinal voltage field gradient in each of the semiconductive slabs 31 through 38. The potentiometer 41 provides a biasing field potential between each of the adjacent ones of the semiconductive slabs 31 through 38. A magnetic field (not shown) is provided transverse to the electrical fields and is in a direction into the paper at FIG. 4. The arrow 39 represents the path of a charged particle having sufficient velocity to penetrate to the semiconductive slab 36. The direction of the particle is represented by the angle θ, which is the angle between the arrow 39 and a line normal to the surface of the semiconductive slabs.

As the charged particle passes through or strikes one of the semiconductive surfaces, it will create an electron multiplier action such as has been previously described. A series of pulses will then appear at the collector electrodes 42 through 46. The magnitude of the pulses appearing on these collector electrodes 42 through 46 will become increasingly larger, as is shown by pulses 52 through 56, since the electron paths associated with the semiconductive slabs 32 through 36 became increasingly longer, thus each surface showing a gain greater than the preceding surface.

Obviously, a particle of a given mass having a greater magnitude of velocity will penetrate a greater number of semiconductive slabs and thus the number of pulses which appear at the collector electrodes is indicative of the magnitude of the velocity of the particle striking the unit. Also, the difference in the magnitude of the succeeding pulses 52 through 56 is a measure of the angle θ, since for greater angle θ, the total path length on succeeding stages will be longer and the change in gain from progressive stages will be greater.

FIG. 5 shows a mounting arrangement for an electron multiplier according to the subject invention in which the spacings between the semiconductive slabs is accurately determined and which also removes any heat which may be developed in the electron multiplier. The semiconductive slabs 1 and 2 are supported at their collector ends in a block 60. Copper or any other suitable material of good heat conductivity may be used for the block 60. The semiconductive slabs 1 and 2 are separated from the block 60 by sheets 61 and 62, these sheets being of a material which is both electrically insulative and heat conductive, such as sapphire or ruby. Again, the assembly may be maintained in a suitable vacuum and suitable electrical and magnetic connections (not shown) similar to those previously discussed are provided.

While the invention is thus described and several applications of the invention are shown, the invention is obviously not limited to only these shown embodiments or applications. Numerous embodiments and changes will be obvious to those skilled in the art without departing from the spirit and scope of the invention. For example, the materials and magnitudes of values given are for illustrative purposes only and the invention is obviously not limited to only these materials or values. The invention is therefore to be limited only by the scope of the appended claims.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. In an electron multiplier having two spaced parallel electrode, means for establishing a biasing field between said electrodes, means for establishing a longitudinal potential gradient along each of said electrodes whereby each of said electrodes has a relative positive potential and a relative negative potential end, means for establishing a magnetic field transverse to said biasing field and said longitudinal potential gradient, means for causing an electron emission at the relative negative potential end of one of said electrodes, and an electron collector adja-

cent the relative positive potential end of said electrodes, the improvement wherein at least said one of said electrodes consists entirely of a self-supporting slab of homogeneous semiconductor material having a length of about two centimeters and a resistivity of the order of 10^9 ohm centimeters at a temperature of about −80° C., and said electrodes have a spacing of about one millimeter.

2. An electron multiplier according to claim 1 in which said one electrode is formed from high resistance gold-doped silicon semiconductive material.

3. In a device for determining the velocity and direction of travel of a charged particle, an assembly comprising a plurality of spaced parallel slabs of secondary electron emissive semiconductor material having a spacing of about one millimeter and adapted to be disposed in the path of a charged particle, means for establishing a longitudinal potential gradient along each of said slabs of semiconductor material, each of said slabs thereby having a relative positive potential end and a relative negative potential end, means for establishing a biasing electric field between each pair of adjacent slabs, means for establishing a magnetic field transverse to said biasing fields and said longitudinal potential gradients whereby secondary electrons emitted from each of said slabs follows a cycloidal path therealong, and collector electrode means

responsive to incidence of a charged particle on said slabs for generating pulses whose number is a measure of the velocity of the charged particle and whose relative magnitude is a measure of the direction of travel of said charged particle, said collector electrode means including a plurality of individual respective collector electrodes positioned respectively adjacent the relative positive potential end of the space between each pair of said slabs in the path of secondary electrons emitted from said slabs.

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