Feb. 6, 1951 E. S. RITTNER 2,540,490

ELECTRON DEVICE WITH SEMICONDUCTIVE TARGET

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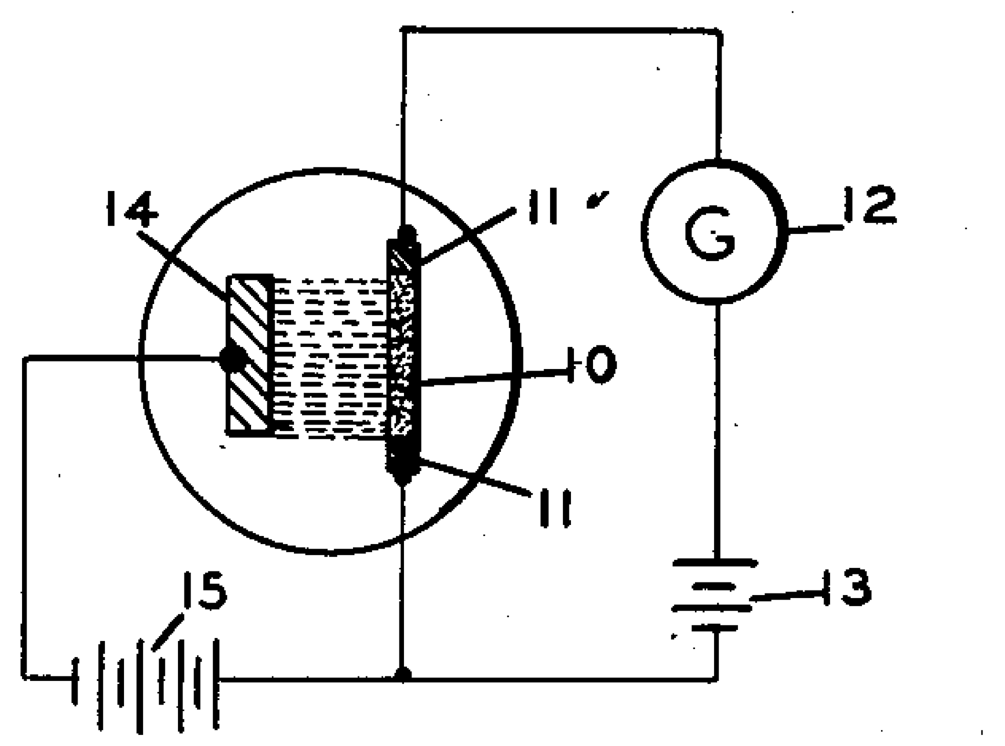

FIG. 1

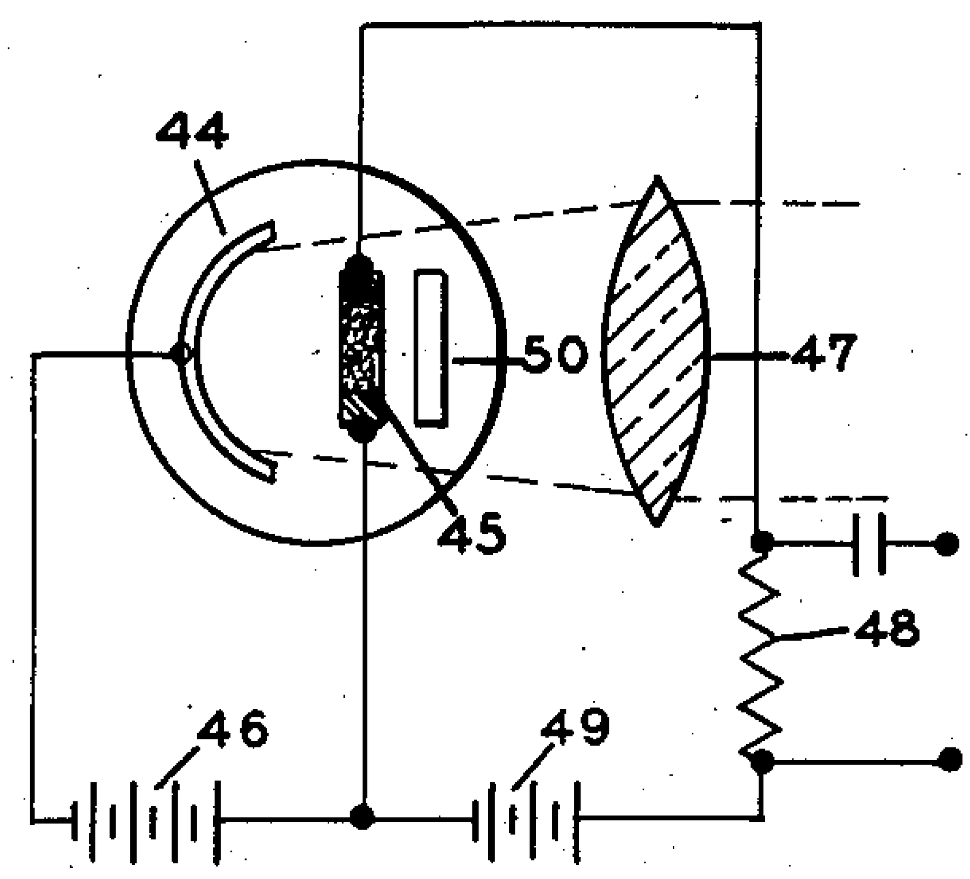

FIG. 4

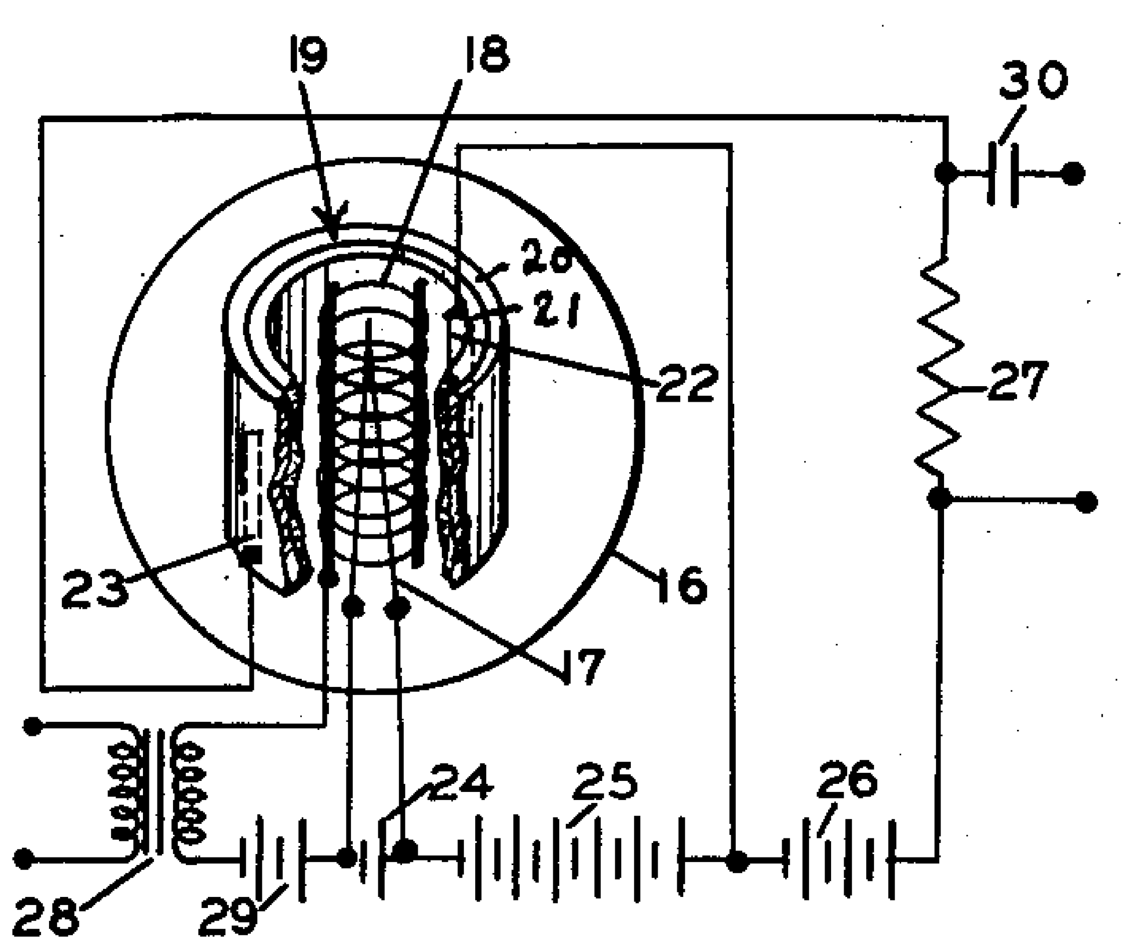

FIG. 2

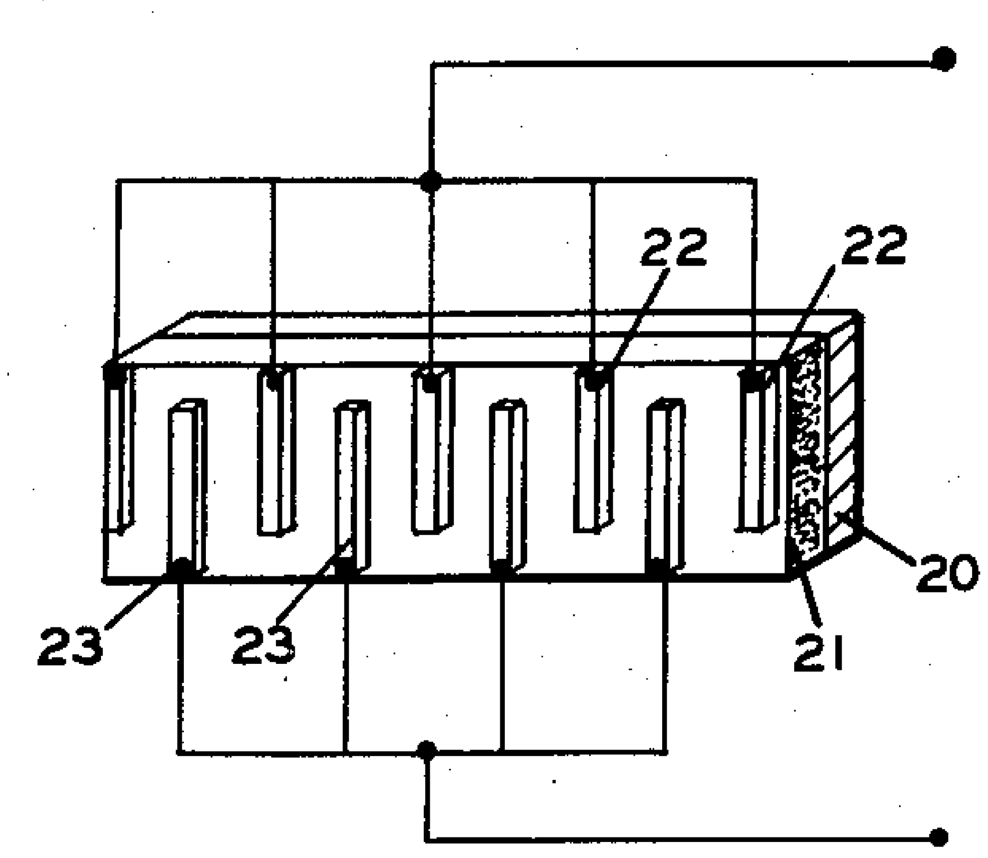

FIG. 5

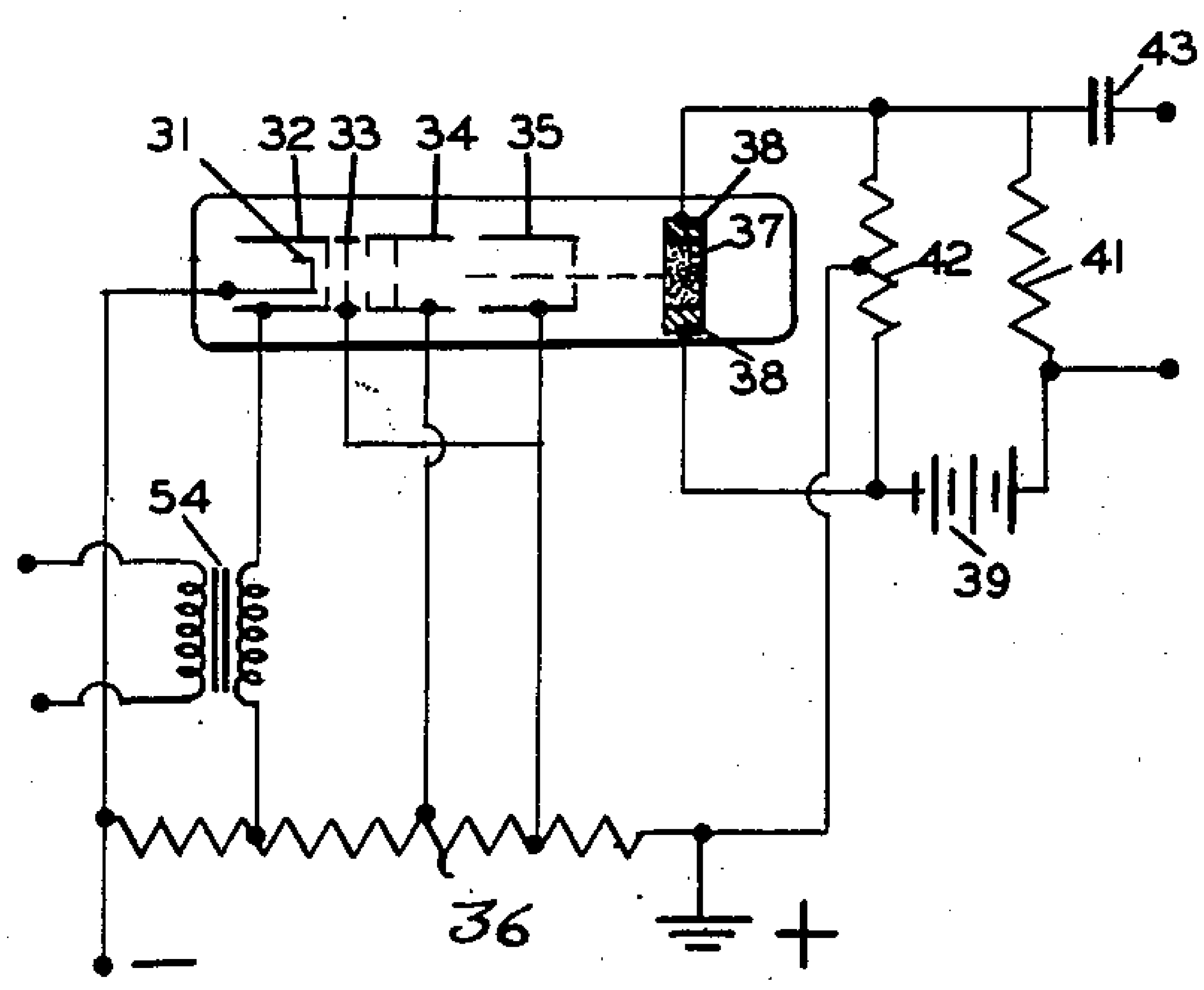

FIG. 3

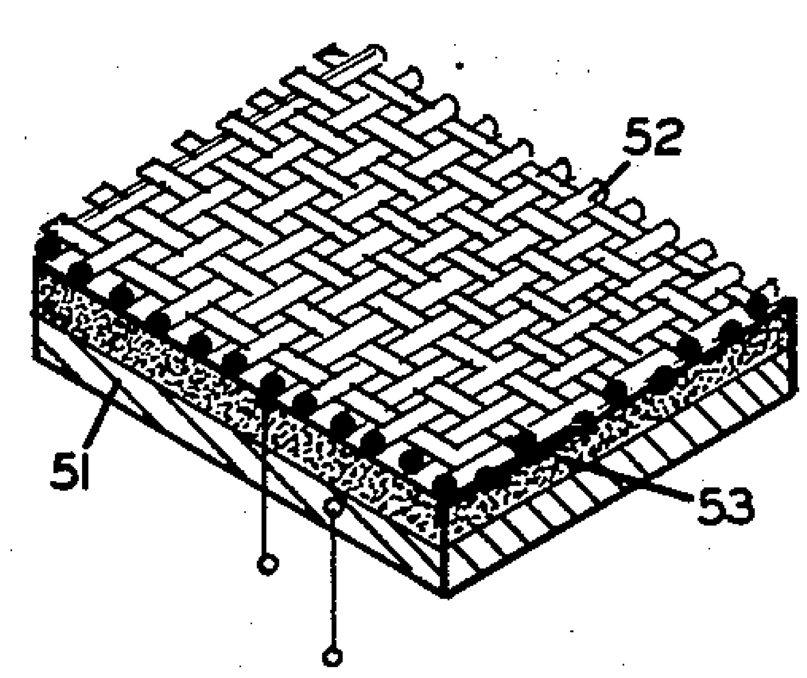

FIG. 6

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ELECTRON DEVICE WITH SEMICONDUCTIVE TARGET

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8 Claims. (Cl. 250—153)

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The present invention relates to an electron device in which a stream of electrons is directed at a target whose internal impedance varies as a function of the intensity or velocity of the stream, and more particularly to a device of this type wherein the active element of the target is fabricated of a semi-conductive substance having photoconductive properties.

In an existing device for controlling the flow and amplification of electric current, a beam of electrons is caused to impinge on an insulator (such as a diamond crystal) across which an electrostatic field is established, thereby producing a flow of current in the insulator which is large relative to the original beam current. The bombardment of the insulator by the primary electrons of the beam gives rise to the production of secondary electrons within the insulator and results in a current flow.

However, there are several factors which contribute to impede current flow in such existing devices. The accumulation of primary electrons on the insulator creates a space charge thereon and, in addition, some of the internal secondary electrons produced are trapped within the substance and set up a negatively charged cloud which inhibits any flow beyond the momentary current surge occuring at the instant the beam strikes the insulator. To obviate these difficulties, the insulator is bombarded with sucessive pulses of electrons to allow the charge on the insulator to leak off in the intervals between pulses, and an alternating electric field is established across the insulator in order to draw off the electrons responsible for the space charge as well as the trapped electrons, thereby enabling an uninterrupted current flow.

The present invention is based on the discovery that by directing an electron stream toward a target having an electric field established thereacross and whose active element is constituted by semi-conductive material having a photoconductive characteristic, due to the nature of this material, secondary electrons are produced resulting in a continuous current flow. The flow of current in a target of this construction is not arrested by space charge effects or by reason of other current retarding effects, as is the case with an insulator. Moreover, loss of secondary electrons brought about by external emission is substantially less in semi-conductors than in insulators, hence this factor does not act so as to reduce the total yield of secondary electrons. Consequently the disadvantages inherent in an insulator target of the type heretofore employed are avoided by the present invention.

Of particular significance is the fact that the use of a photoconductive semi-conductor makes possible a far greater amplification factor than is obtainable with an insulator-type target. This

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follows from the fact that the number of secondary electrons released within the material per primary incident electron of a given energy is greater in a semi-conductor case than in an insulator case. Moreover the total number of electrons flowing through the semi-conductor per electron released by the incident energy is usually greater in the case of a semi-conductor than in the case of an insulator.

Accordingly, it is the principal object of the present invention to provide an electron device wherein an electron stream is generated and accelerated toward a target whose active element is defined by a semi-conductor having photoconductive properties.

More specifically, it is an object of this invention to provide an electron device of the above type adapted to operate as an amplifier having an exceptionally large amplification factor.

Still another object of this invention is to afford an electron tube wherein a concentrated electron beam is projected onto a target of the above-described type.

Another object of this invention is to provide an electron device having a photoemissive electrode, said electrode being responsive to incident light rays and being arranged to emit a stream of electrons which can be accelerated in the direction of a target of the above-described type.

A further object of this invention is to provide a target structure whose active element is formed by a photoconductive semi-conductor, said target being arranged to have a high sensitivity and a low internal impedance.

Briefly stated, in one embodiment of the invention, an electron device comprises an electron-emissive cathode member, a control grid and a target constituted by a photoconductive semi-conductor furnished with two spaced electrodes. The device is operated by applying a constant potential in series with an output circuit across the electrodes, and by applying an accelerating potential between the cathode and the target, whereby a stream of electrons emitted at the cathode is caused to be accelerated toward the target. By modulating the intensity of said stream with a signal voltage applied to the grid, the impedance of the target is correspondingly varied and an amplified signal is developed in the output circuit.

For a better understanding of the invention as well as other objects and further features thereof reference is had to the following detailed description of the invention which is to be read in connection with the attached drawing wherein:

Fig. 1 is a schematic diagram illustrative of the theory underlying the invention,

Fig. 2 is a schematic diagram showing a preferred embodiment of the invention,

Fig. 3 is a schematic diagram showing another preferred embodiment of the invention,

Fig. 4 is a schematic diagram of still another preferred embodiment of the invention,

Fig. 5 is a separate showing in a planar development of the cylindrical target structure of Fig. 2, and

Fig. 6 is a perspective showing of a modified form of target structure.

Before entering into the exposition of the invention in its several preferred constructions, the theory underlying the behavior of the active element of the target will be discussed briefly.

Semi-conductors are substances which possess electrical conductivities intermediate between those of insulators and those of metals. In accordance with the accepted theory of semi-conductors the possible energy levels of an electron in a crystal may be divided into bands which are separated by regions of forbidden energy. In a semi-conductor, as in an insulator, at the absolute zero of temperature all of the allowed bands are either entirely full or entirely vacant so that the crystal cannot conduct any current. In a semi-conductor, however, as distinguished from an insulator, as the temperature increases some electrons are raised into the lowest vacant band of allowed levels, said lowest band being the conduction band. These "free" electrons and the "positive holes" simultaneously created impart to the crystal its conductivity characteristic.

Semi-conductive substances fall into two general classes, in one class are those which are intrinsic semi-conductors and in the other are those which are extrinsic semi-conductors. An intrinsic semi-conductor is one which conducts in the pure state; electrons are raised into the conduction levels from the normally full band. Most semi-conductors, however, are conductive due to the presence of impurities in solid solution, and the actual value of the conductivity depends largely on the existing amount of these impurities. The energy required to bring an electron from an impurity center into the conduction band is considerably less than that required to bring it from the full band of the pure substance, so that conduction arises mainly from the electrons released from the impurities. For simplicity, a distinction between negative and positive charge carriers has not been made in the foregoing discussion, reference being made only to the former to illustrate the principles. A more detailed treatment of semi-conductors may be had by reference to "Electronic Processes in Ionic Crystal," Mott and Gurney (Oxford 1940).

Many semi-conductors exhibit photosensitivity, that is, they show increased conductivity on exposure to light. Such semi-conductors are termed photoconductive semi-conductors. The applicant has found that when photoconductive semi-conductors are bombarded by an electron stream, in lieu, of light radiation, a marked change in the internal resistance of the material is effected, which phenomenon may be utilized in various ways, such as for purposes of current amplification. The invention may be employed to improve such devices as electron tube amplifiers, photoelectric devices and the like.

The basic circuit of the invention is illustrated in Fig. 1 wherein a target is formed by a photoconductive semi-conductor 10 having a pair of electrodes 11 secured to either end thereof. Connected across electrodes 11 in series with a galvanometer 12 is a constant potential source 13. Electrons are emitted from a cathode member 14 and are drawn toward the target as a result of an accelerating potential derived from source 15 and applied between cathode 14 and one of electrodes 11, the target thereby acting as an anode with respect to the cathode.

The electron emission from cathode 14 may be accomplished in any manner known in the art. For example, cathode 14 may take the form of a thoriated filament or an oxide-coated, indirectly heated cathode. Cathode 14 may also be in the form of a photosensitive cathode which liberates electrons on exposure to light. Whatever the form of the electron emitter, the conductivity of the target will be controlled as a function of the intensity or velocity of the electron stream impinging thereon. This control may be effected by conventional means in accordance with any variable such as a signal voltage. For example by varying the accelerating potential in accordance with a signal voltage, the velocity of the electron stream will be correspondingly varied. The control means may also take the form of a control electrode interposed between the cathode and target, in which instance the behavior of the electron device would be similar in certain respects to a conventional triode vacuum tube.

It is to be noted that while in Fig. 1 the accelerating potential from source 15 is shown as connected to one end of the target, in actual practice it may be desirable to connect the accelerating potential to the electrical center of the target either by means of a third, centrally disposed electrode or through the center-tap of a resistance shunted across the end electrodes of the target.

Referring now to Fig. 2, there is shown a preferred construction of an electron device according to the invention, the device comprising an evacuated envelope 16 enclosing an emissive filament 17, a cylindrical control grid 18 and a cylindrical target 19, partially cut away to expose the structure. Grid 18 is arranged to surround filament 17 and target 19 is coaxially disposed about grid 18. As shown separately by Fig. 5, the target 19 is constituted by a tubular base 20, of nonconductive material such as glass, the inner wall of which is coated with a layer 21 of a semi-conductive substance having photoconductive properties, as for example selenium, silicon, germanium thallous sulfide, lead sulfide etc. Embedded in semi-conductive layer 21 are two intermeshing series of electrode members 22 and 23, the electrodes of each series being interconnected and serving as one terminal of the target.

The operating circuit of the electron device comprises an energizing source 24 for the filament, a source of accelerating potential 25 connected between one terminal of target 19 and one end of filament 17, and a source of potential 26 connected across electrodes 22 and 23 through an output resistor 27. A signal voltage is applied to the electron device by means of a step-up transformer 28 whose primary is connected to the source of incoming signal and whose secondary is connected at one end to grid 18 and at the other end through a bias source 29 to one end of filament 17. The varying output voltage developed across resistor 27 is derived therefrom through a coupling capacitor 30 which separates the output voltage from the direct-current component in resistor 27.

It is important to note that the total amplification factor of the device in Fig. 2 is still greater than that yielded by the target, per se, owing to the fact that the control action of the grid on the primary electron stream further augments the amplification of the device. While for the sake of simplicity the electron device in Fig. 2 has been shown as a triode, it will be obvious that the invention may be embodied as a multi-electrode structure, such as by the insertion of one or more grids intermediate the target and the control grid.

In the target structure 19 of Fig. 2, the active layer of semi-conductive material assumes a polycrystalline configuration. When the primary electrons impinge on the active layer the conductivity of the layer increases as a result of the "free" electrons produced therein, a condition which persists until the newly released electrons disappear by passage into the electrodes, by recombination with positive holes, or by other means. Inasmuch as one high energy electron is capable of releasing many "free" electrons within the substance and as the total number of electrons passing through the semi-conductor is usually greater than the number of electrons released by the action of incident energy, the above-described electron device behaves as an amplifier.

The accelerating potential impressed between the cathode and the target should be as high as is feasible or convenient for a particular application. For a given magnitude of accelerating potential, optimum results will be obtained when the active element of the target is made of such thickness as to be substantially equal to the penetration depth of the incident electrons. For highest efficiency the electron device should also be designed with a view to affording incident radiation over the entire surface of the active element of the target.

The magnitude of the constant voltage impressed across the electrodes of the target should be as large as possible in order to attain maximum amplification; however this voltage is limited to values below those causing excessive heating of the active element due to the current flow therein. Moreover care should be taken to avoid deflection of the primary beam onto one of the electrodes. This can be accomplished either by appropriate geometrical configuration of the target or a suitable alignment of the beam with respect to the target. The impedance of the target should be such as to provide a proper impedance match with its associated circuits. This factor will be treated in greater detail in connection with Fig. 6.

In certain applications it is desirable to employ as the active element of the target a single crystal of a photoconductive semi-conductor rather than a polycrystal as in the target of Fig. 2. A single crystal exhibits the above-described conductive effect to a greater degree by reason of its extremely high electron mobility. However as a single crystal of the desired thickness will probably be of relatively small dimensions it is of advantage to concentrate the electrons in a single beam so as to irradiate substantially the entire area of the crystal. This may be accomplished, as shown in Fig. 3, by generating an electron beam in a cathode-ray gun of conventional design.

The gun comprises a cathode 31, a control electrode 32, a first accelerating anode 33, a focusing electrode 34 and a second accelerating anode 35. Operating potentials for the electron device are obtained from spaced taps along a voltage dividing resistor 36 connected across a source of potential. The first and second accelerating anodes 33 and 35, respectively, are both connected to the same point of high potential on resistor 36, the focusing electrode 34 being connected at a point of lower potential and the control grid 32 at a still lower potential point. The convergent focusing action on the beam occurs between the focusing electrode 34 and the second anode 35, the action between the first anode 33 and the focusing electrode 34 being divergent as is also the action between the first anode 33 and the control electrode 32.

The focused electron beam is projected onto the target which is formed by a single crystal 37 of semi-conductive photo-conductive material mounted between two electrodes 38. The target is connected to the point of highest potential on resistor 36 by means of a center-tapped resistor 42 shunted across electrodes 38, the center tap being connected to the positive extremity of resistor 36. A constant voltage is applied between electrodes 38 from a source 39 in series with an output resistor 41. In operation the intensity of the beam is controlled by applying a control voltage through transformer 54 to the control electrode 32, and the amplified output votlage developed across resistor 41 is derived through capacitor 43.

While the construction of Fig. 3 is especially adapted to operate in conjunction with single crystal targets it may also be successfully employed in connection with polycrystalline targets of small size.

Referring now to Fig. 4, there is illustrated a photo-electric device in accordance with the invention, said device comprising a photoemissive electrode 44 and a target 45 constituted by a photoconductive semi-conductor held between two electrodes. When an accelerating potential source 46 is connected between electrode 44 and target 45, and light radiation falls on electrode 44 either directly or through a concentrating lens 47, electrons are emitted which are drawn toward the target. The electrodes of target 45 are connected through an output resistor 48 to a constant potential source 49. To prevent light radiation from striking target 45, a baffle member 50 is provided, said member being arranged to shield the target from incident light. The operation of this device is similar to the devices disclosed in the preceding figures excepting that the output voltage in this instance is varied in accordance with the intensity of light incident to the electrode 44, rather than to the amplitude of an input signal.

The static impedance of the targets disclosed in the several figures of the drawing is determined by the inherent resistance of the semi-conductor employed, the area of the electrodes in contact with the semi-conductor and the spacing between electrodes. In many electronic applications a low impedance target is desirable. A target structure adapted to present a low impedance and a high sensitivity is illustrated in Fig. 6 in which metal plate 51 acts as one electrode of the target and metal grid 52 acts as the other electrode. A thin layer 53 of photoconductive semi-conductive material is deposited on plate 51 and grid 52 is embedded in the layer, thus defining a sandwich construction. The interstices of the grid electrode 52 expose the active layer to incident electron radiation. At the same time a small electrode spacing and a large contact area is realized in this construction so that a low impedance value is attained.

While the target electrodes in the figures of the drawing have been illustrated as metallic plates, it is to be understood that they may assume the form of any conductive means in conjunction with the active element of the target. For example, the electrodes may be formed by electrodeposition or coating of conductive material on the surface of the semi-conductor.

For a given photoconductive, semi-conductive substance the frequency response can be improved with an attendant loss of amplification by any means which will result in an increased concentration of charge carriers. This may be accomplished in various ways, for example by exposing the semi-conductor to steady background illumination, by raising its temperature, or by suitable incorporation of small amounts of impurities in the substance.

While there have been shown what at present are considered preferred embodiments of the invention it will be evident that many changes and modifications may be made therein without departing from the essence of the invention, and it is intended in the annexed claims to cover all such changes and modifications as fall within the scope and true spirit of the invention.

What I claim is:

1. An electron discharge tube comprising an electron-emissive cathode, a target electrode spaced from the cathode electrode and positioned for electron bombardment by electrons emitted from said cathode electrode, and a grid electrode interposed between the target electrode and the cathode electrode for controlling electron flow from the cathode electrode to the target electrode, said target electrode comprising a pair of spaced terminal electrodes and an active element therebetween constituted by an element selected from the group consisting of silicon and germanium.

2. An electron device comprising an electron-emissive cathode, a grid surrounding said cathode, and a cylindrical target surrounding said grid, said target being defined by a tubular non-conductive base, a layer of an element selected from the group consisting of germanium and silicon and secured to the inner wall of said base and two series of circumferentially arranged spaced electrodes disposed in intermeshing relationship on said layer, the electrodes of each series being interconnected to form a terminal of said target.

3. An electron device comprising an electron gun for generating an electron beam and including in successive arrangement a cathode, a control electrode, a first accelerating anode, a focusing electrode and a second accelerating anode, and a target disposed in the path of said beam, said target comprising a pair of spaced terminal electrodes and an active element therebetween constituted by an element selected from the group consisting of silicon and germanium.

4. An electron device comprising an electron gun for generating an electron beam and including in successive arrangement a cathode, a control electrode, a first accelerating anode, a focusing electrode and a second accelerating anode, and a target disposed in the path of said beam, said target comprising a pair of spaced terminal electrodes and an active element therebetween constituted by an element selected from the group consisting of silicon and germanium.

5. Electronic amplifying apparatus comprising an electron device including an electron gun for generating an electron beam and having in successive arrangement a cathode, a control electrode, a first accelerating anode, a focusing electrode and a second accelerating anode, and a target disposed in the path of said beam, said target comprising a pair of spaced terminal electrodes and an active element therebetween constituted by an element selected from the group consisting of silicon and germanium, a source of accelerating potential connected between said cathode and the center-tap of said resistor, said first and second anodes being connected to an intermediate point in said source, said focusing electrode being connected to a tap in said source between said cathode connection and said intermediate point, an input circuit connected between said control electrode and a point in said source between said tap and said cathode connection, an output circuit, and a source of constant voltage connected in series with said output circuit across said terminals.

6. An electron discharge tube comprising an electron-emissive cathode, a target electrode spaced from and positioned for electron bombardment by electrons emitted by said cathode electrode, and a grid electrode interposed between the target electrode and the cathode electrode for controlling electron flow from the cathode electrode to the target electrode, said target electrode comprising a pair of spaced terminal electrodes and an active element therebetween constituted by an element selected from the group consisting of silicon and germanium, said active element of said target electrode having a given thickness approximately equal to the depth of penetration of electrons impinging thereon.

7. An electron discharge tube comprising an electron-emissive cathode electrode, a target electrode spaced from and positioned for bombardment by electrons emitted from said cathode electrode, and a grid electrode interposed between the target electrode and the cathode electrode for controlling electron flow from the cathode electrode to the target electrode, said target electrode comprising a pair of spaced terminal electrodes and an active element therebetween constituted by germanium.

8. An electron discharge tube comprising an electron-emissive cathode electrode, a target electrode spaced from and positioned for bombardment by electrons emitted from said cathode electrode, and a grid electrode interposed between the target electrode and the cathode electrode for controlling electron flow from the cathode electrode to the target electrode, said target electrode comprising a pair of spaced terminal electrodes and an active element therebetween constituted by silicon.

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