Oct. 5, 1954 A. R. MOORE ET AL 2,691,076

SEMICONDUCTOR SIGNAL TRANSLATING SYSTEM

Filed Jan. 18, 1951

Fig. 1.

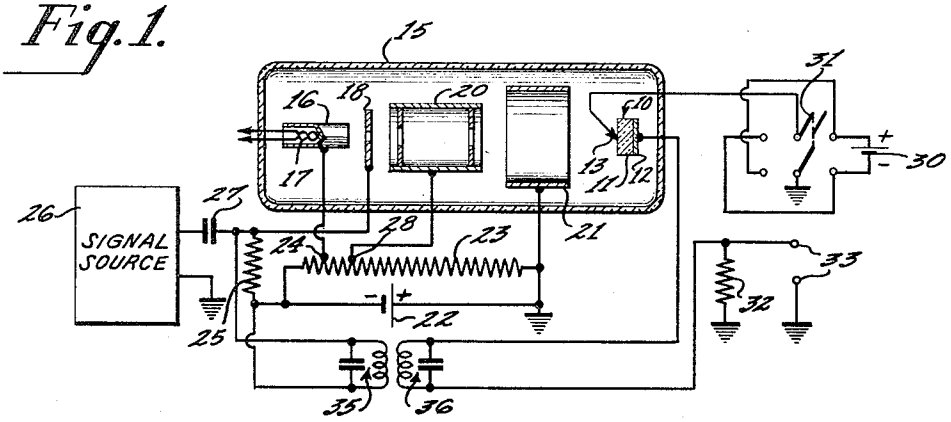



Fig. 2.

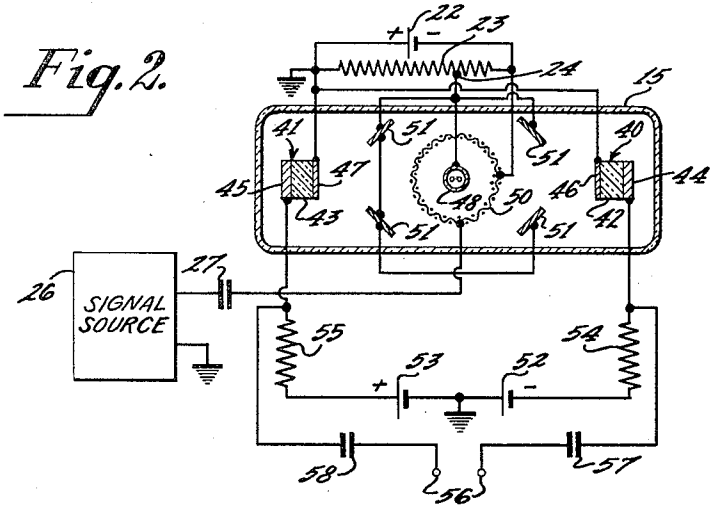



Fig. 6.

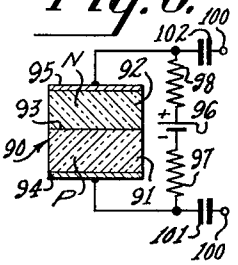



Fig. 4.

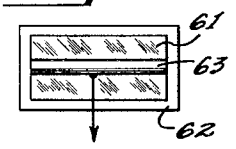
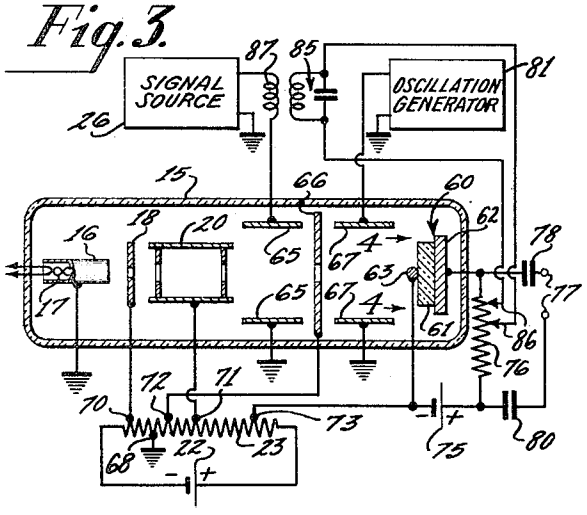



Fig. 3.



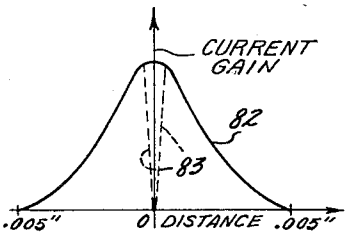




Fig. 5.

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# UNITED STATES PATENT OFFICE

2,691,076

## SEMICONDUCTOR SIGNAL TRANSLATING SYSTEM

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Application January 18, 1951, Serial No. 206,585

6 Claims. (Cl. 179—171)

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This invention relates generally to signal translating systems, and particularly relates to amplifier, modulator, oscillator or the like systems which incorporate a semi-conductor device, as well as to a method of controlling the current flow through such a device.

The interaction of radiation and matter, and the interaction of energized particles with the matter through which they pass, have been studied extensively in the past. It is found that the conducting properties of insulating and semiconducting materials are modified when subjected to irradiation or corpuscular bombardment. The changes in conducting properties may be transient, with the material returning to its normal condition very soon after the irradiation or bombardment ceases, or the changes in conducting properties are more lasting, though not permanent, and are found to be subsequently affected by heat treatment, or, finally, the changes in the conducting properties are of a permanent nature, being unaffected by heat treatment.

These effects have recently been utilized extensively in the development of crystal counters. The main emphasis has been on the development of materials and associated circuit means which enables the passage of a nuclear particle, such as an alpha, beta, or gamma ray, to be detected by the current pulse produced by the interaction of the nuclear particle or photon with the crystal through which it passes. Insulating crystals, semi-conductors and semi-conductor-point contact rectifiers (McKay) Phys. Rev., November 15, 1949, page 1537, vol. 76, have been used for this purpose.

The permanent changes in the material limit the useful life of crystal counters.

The effects of electron bombardment on thin insulating films using electrons in the kilovolt range have been studied by Pensak (Phys. Rev., vol. 75, February 1, 1949, pages 472–478). He finds that under the influence of the electron beam, the conductivity of the film is increased. It is believed that the increased conductivity can be attributed to the production of internal secondary electrons by the primary electron beam. The primary electron loses energy as it passes through the insulating film, and this energy is presumably used, in part, to raise electrons from the filled to the conduction band. Thus, the production of additional current carriers is reflected in an increased conductivity of the film.

McKay has bombarded diamond crystals with kilovolt electrons and observed electron bombardment induced conductivity. Here too, the

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production of internal secondary electrons by the action of the primary electron beam is believed to be, in part, responsible for the induced conductivity. The conductivity may also be enhanced by the production of holes, which result from the transfer of electrons from the filled to the conduction band. He also observed space charge effects due to the trapping of electrons and holes which reduced his electron bombardment conductivity after the initial excitation by the electron beam.

Thus we see that one method of varying the conducting properties of an insulating or semiconducting material may be regarded as due to the production of internal secondary electrons and of holes, which provide additional current carriers. Another method of varying the conducting properties of an insulating or semi-conducting material involves the interaction of electrons and holes with a potential barrier which may happen to exist in the material. A potential barrier may be described as a region, extending over many inter-atomic distances, which has a higher resistivity than the bulk material.

The larger resistance, or impediment to current flow, that a barrier provides, is caused by the fact that a charge carrier such as a hole or an electron possessing a certain amount of total energy gains potential energy and loses a corresponding amount of kinetic energy as it attempts to surmount the potential barrier; if all the kinetic energy is expended before the charge carrier reaches the peak of the barrier, it is unlikely that the charge carrier will pass through.

The potential barrier may be approximately symmetrical; that is, it may have the same shape as seen from either side. Such a symmetrical potential barrier does not exhibit rectifying properties. On the other hand, unsymmetrical barriers do exhibit rectifying properties. The resistance of a potential barrier can be changed by causing charge of sign opposite to that of the normal carriers to be introduced into the region of the barrier. The space charge produced by the introduced charge lowers the barrier, and enables more of the normal current carriers to pass through. Thus, the presence of the charge of opposite sign in the barrier region lowers the effective resistance of the barrier.

The variation or modulation of the conducting properties of a barrier in this manner is utilized in the transistor. In the type A transistor, using N type germanium, for example, the normal current carriers are electrons. The emitter point introduces holes, which diffuse to

the barrier existing at the germanium-collector point junction and modify the conductivity of the junction. In the photo-transistor, visible light or infrared radiation produces hole-electron pairs in the semi-conducting crystal. The quantum energy of light in the visible and infrared is such that not more than one electron-hole pair can be produced per incident light quantum or photon. If the semi-conducting crystal is N type for example, the holes produced by the irradiation in the neighborhood of the metallic point contact can migrate into the junction and modulate the conductivity of the junction.

It has also been suggested in the patent of Kock 2,522,521 that the conductivity of an intrinsic semi-conductor be modulated by changing the temperature of the semi-conductor, thus provided an electrothermal transducer.

It is the principal object of the present invention to provide novel signal translating systems including a semi-conductor device having a barrier such, for example, as a crystal rectifier.

A further object of the invention is to provide novel amplifier, oscillator, modulator, mixer or the like systems wherein a semi-conducting device having a barrier cooperates with an electron beam or stream which is modulated in accordance with a signal to increase the transconductance of the tube by a large factor, thereby obtaining high current and power gains.

Another object of the invention is to provide a novel amplifier system including one or two semi-conducting devices each having a potential barrier whereby a high-gain push-pull or balanced output signal may be obtained from an unbalanced or single-ended input signal.

Still a further object of the invention is to provide a novel system and method for modulating the effective resistance represented by the potential barrier of a semi-conducting material.

Still another object of the invention is to provide a novel amplifier system having a current or power gain higher than that which may be obtained with a conventional amplifier tube, with a cathode ray tube or with a beam deflection tube.

A still further object of the invention is to provide a signal translating system which has substantially no coupling between the input and output circuits thereof.

In accordance with the present invention, use is made of a controlled or modulated electron stream to modulate or vary the effective resistance represented by the potential barrier of a semi-conducting material. Such a barrier is present, for example, in a crystal rectifier which has one electrode in low-resistance contact with the body and another electrode in rectifying contact therewith. Such a barrier is also present in the boundary region separating a semi-conductor from a metal which may serve as an electrode. The metal electrode may be of many forms, including that represented by a thin film, a point-contact, or a surface contact with a bulk metal and it is immaterial whether the junction rectifies or not. Such a barrier is also present in the region of a crystal grain boundary, and may also be present in any region which differs in structural form from the bulk material.

The electron stream or beam is caused to impinge on the semi-conductor in the neighborhood of the potential barrier. Each primary electron, in penetrating the semi-conductor, loses its energy, and produces a great many electron-hole pairs. The actual number of electron-hole pairs or secondary particles produced per incident primary electron depends upon such factors as the primary energy of the beam and the semi-conductor material used. If the potential barrier exists mainly near the surface, such as that at a metallic point semi-conductor junction, an electron beam would be used with energy so adjusted that the major part of the energy loss of the beam would occur near the surface barrier.

For the sake of illustration, let it be assumed that the semi-conductor is N type. Then the electrons and holes produced will both contribute to the conductivity of the region where they are produced and migrate by increasing the number of available current carriers in these regions. In addition, the holes will migrate into the potential barrier, and, as described previously, modulate the conductivity of the barrier. Thus, by directing the electron beam to impinge in the neighborhood of the potential barrier, the conductivity of the semi-conductor is modulated in two distinct ways: first, by increasing the number of available current carriers, and, secondly, by modifying the space charge existing at the potential barrier and therefore modulating its effective height.

Thus, the electron beam, by modulating the conductivity of the semi-conductor, can modulate the current passing through the semi-conductor. The electron beam itself can be modulated by varying its current density, its voltage, or by deflecting it with respect to the region of the potential barrier. It will be evident that such a system may be utilized in an amplifier, modulator, mixer, or oscillator circuit.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawing, in which:

Figure 1 is a sectional view and circuit diagram of an amplifier or oscillator system embodying the present invention;

Figure 2 is a sectional view and circuit diagram of an amplifier system in accordance with the invention having a push-pull output;

Figure 3 is a sectional view and circuit diagram of an amplifier, modulator or oscillator system including a beam deflection tube;

Figure 4 is a side elevational view taken in the direction of arrows 4, 4 in Figure 3 of the target of the deflection tube of Figure 3;

Figure 5 is a graph showing the current gain of the device of Figure 3 as a function of the beam deflection; and

Figure 6 is a sectional view of a semi-conductor device and circuit diagram which may be used in accordance with the invention as the target of the tubes shown in Figures 1 and 3.

Referring now to the drawing, in which like components have been designated by the same reference numerals throughout the figures, and particularly to Figure 1, there is illustrated a signal translating system including a semi-conductor device 10 which may, for example, be a crystal rectifier. Device 10 includes a semi-conducting body 11 which may consist of any suitable semi-conducting crystal such, for example, as silicon or preferably germanium. As is

conventional for a crystal rectifier, the device 10 has two electrodes 12 and 13. Electrode 12 is in low-resistance contact with crystal 11 and may, for example, consist of a plate or sheet of metal soldered to the crystal. Electrode 13 is in rectifying contact with crystal 11 and may, for example, be a point electrode as shown in Figure 1. Thus, electrode 13 may consist of a fine wire of tungsten or Phosphor bronze, for example, having a sharp point in contact with the crystal. As will be explained later in connection with Figures 2 and 3 rectifying electrode 13 may also be in large-area contact or in line contact with the crystal.

In accordance with the present invention crystal rectifier 10 represents the target for an electron beam. To this end crystal rectifier 10 is enclosed in an evacuated envelope 15 within which is provided a cathode ray tube. The cathode ray tube includes a cathode 16 which may be indirectly heated by a filament 17, a control grid 18, a first anode or focussing electrode 20 and a second anode 21.

The electrodes of the cathode ray beam are energized by a source of voltage such as battery 22 which may have its positive terminal grounded as shown. A potentiometer resistor 23 is connected across battery 22. By means of tap 24, cathode 16 is maintained at a negative potential. Control grid 18 is connected to the negative terminal of battery 22 through grid resistor 25. A signal developed by signal source 26 may be impressed across grid resistor 25, the source being coupled to the junction point between control grid 18 and resistor 25 by coupling capacitor 27. Anode 20 is maintained at a positive potential with respect to cathode 16 by tap 28, and anode 21 may be connected to the positive terminal of battery 22.

Accordingly, an electron beam is developed and is directed to impinge on crystal 11 in the vicinity of rectifying electrode 13 of crystal rectifier 10. The electron beam preferably has a circular cross section and impinges on the surface of crystal 11 which faces cathode 16. The electron beam preferably has a distance from rectifying electrode 13 which is no more than a few mils and may be less than one mil.

In accordance with the present invention, the electron beam is modulated. To this end, the intensity of the beam may be modulated in accordance with the signal developed by source 26.

Further in accordance with the invention a source of bias voltage such as battery 30 is connected between the electrodes 12 and 13 of crystal rectifier 10. Rectifying electrode 13 may be made either positive or negative. Thus when double-pole double-throw switch 31 is moved to the right, electrode 13 will be connected to the positive pole of battery 30, while its negative pole is grounded. If switch 31 is moved to the left, the negative pole of battery 30 is connected to rectifying electrode 13, while the positive pole of the battery is grounded. A load impedance element such as resistor 32 is connected in series with battery 30 and electrodes 12, 13. One of the terminals of load resistor 32 may be grounded as shown. The output signal may be obtained from output terminals 33 connected across load resistor 32.

The device of Figure 1 as described herein functions as an amplifier and its operation is believed to be as follows. For the following discussion it will be assumed that crystal 11 is of the N type and may be an N type germanium crystal. Furthermore, it will be assumed that switch 31 is moved to the left so that rectifying electrode 13 is negative with respect to the low-resistance electrode 12. The rectifier is accordingly biased in the reverse or back direction. In order to bias the crystal in the forward direction, the rectifying electrode 13 should be positive with respect to the low-resistance electrode 12. If crystal 11 were a P type crystal, the rectifying electrode 13 must be positive or negative to bias the rectifier respectively in either the reverse or the forward direction.

The electron beam developed in tube 15 impinges in the immediate vicinity of rectifying electrode 13 and creates internal secondary electrons in crystal 11 and an equal number of holes which may be considered as charge carriers having a positive charge and a mobility slightly less than that of the electrons in the crystal. It has been found that an electron beam having a voltage of 10,000 volts will create approximately 1000 pairs of electrons and holes. Some of the excess electrons induced or created by the electron beam are dissipated rapidly over the electrical circuit. The holes start to travel in the direction of the electric field, that is, they are attracted by the negatively biased rectifying electrode 13. The holes accordingly form a space charge cloud which surrounds itself with negative charge carriers, that is, electrons to maintain statistical neutrality over a relatively large volume of the solid. It will be understood that both excess electrons and excess holes create excess conductivity.

The holes which drift with the electrical field eventually arrive in the barrier layer which exists in the crystal rectifier 10 so that a positive charge is provided at the barrier. As explained hereinbefore, it is believed that this positive charge reduces the barrier height which in turn permits more electrons to pass through the lowered potential of the barrier. Eventually the holes are collected by the rectifying electrode 13. Thus, the lowering of the barrier height caused by the holes will permit an additional multiplication of the current which is similar to the secondary photo effect above referred to.

It will now be obvious why it is essential that the primary electron beam impinges in the immediate vicinity of the rectifying electrode 13. Thus, if the holes created in the crystal are not close to the rectifying electrode, they will not be able to move into the barrier. Nevertheless, since the holes still travel a certain distance determined by the recombination time and by their mobility, they will still be able to induce a current, but the additional current multiplication caused by the lowering of the barrier is not present if the holes cannot reach the barrier.

The explanation of the operation of the device of Figure 1 will be similar if the crystal 11 is of the P type. In that case, the function of the holes and electrons is reversed. Otherwise, the current multiplication for a P type crystal is substantially the same as that for an N type crystal. However, the frequency response of a P type rectifier is slightly better than for an N type rectifier because the current flow in a P type rectifier is essentially due to the electrons which have a slightly higher mobility than the holes.

For maximum current multiplication the voltage of battery 30 should be of the order of 10 volts. When rectifying electrode 13 is biased

in the back or reverse direction, the current multiplication is higher than if the rectifying electrode were biased in the forward direction. For a smaller bias voltage the current multiplication is reduced.

The electron beam may have any accelerating voltage below an upper limit which is determined by that of an electron beam having such a high accelerating voltage that it will cause changes of the crystal lattice as explained hereinbefore. This is due to collisions of the beam electrons with the lattice atoms or molecules which produce lattice defects. These give rise to the same effects as does a change of the impurity concentrations. An electron beam having an accelerating voltage of the order of 500,000 volts or more will cause changes of the crystal lattice of a germanium crystal. For crystals of different materials, the minimum accelerating voltage of the electron beam which will cause lattice changes will, of course, have different values.

It may also be pointed out that when the velocity of the primary beam becomes too high, the specific ionization of the electrons is smaller than that of the electrons of a beam having a lower velocity. When the primary electron beam has too high an energy, it penetrates very far into the crystal so that not enough pairs of holes and electrons are created in the immediate vicinity of the barrier. Accordingly, the current multiplication decreases when the accelerating voltage of the primary beam exceeds an optimum value.

With a primary electron beam having a current of 0.05 microamperes and a voltage of 10,000 volts, an output current multiplication of 20,000 has been observed experimentally. When the primary beam has a still higher accelerating voltage and a lower beam current, output current multiplications as high as 50,000 have been obtained. The primary beam currents which were used experimentally are between .001 microampere and .5 microampere. For these primary beam currents, the output current obtained across load resistor 32 was between 50 microamperes and 5 milliamperes. The accelerating voltage of the primary beam which has been used experimentally was of the order of several kilovolts.

The upper frequency limit of the device of Figure 1 is determined by the transit time dispersion or spread of the primary electron beam and particularly by the transit time dispersion of the electrons and holes created in crystal 11. The experimental evidence indicates that the upper frequency limit of the device of Figure 1 is above 10 megacycles and that it has a flat response at least up to a frequency of 10 megacycles.

It is also feasible to utilize the device of Figure 1 as an oscillation generator. To this end signal source 26 may be omitted and instead a parallel resonant circuit 35 may be connected across grid resistor 25. Another parallel resonant circuit 36 may be connected in the output circuit of the device, for example, between low-resistance electrode 12 and ground. Resistor 32 may also be omitted. Resonant circuits 35 and 36 are inductively coupled. Accordingly, a portion of the output energy is fed back to control grid 18 in such a phase as to sustain oscillations. The device will oscillate at the frequency to which resonant circuits 35 and 36 are tuned.

Figure 2 illustrates an amplifier in accordance with the present invention having a single-ended or unbalanced input and a push-pull or balanced output. The amplifier includes two crystal rectifiers 40 and 41. Each rectifier 40 and 41 has a semi-conducting body or crystal 42 and 43 and a low-resistance electrode 44 and 45 respectively. A rectifying electrode 46 and 47 is in contact with crystals 42 and 43 respectively. Rectifying electrodes 46 and 47 preferably are large-area electrodes which may cover substantially the entire opposed surfaces of the crystals 42 and 43. Rectifying electrodes 46 and 47 may, for example, consist of a very thin film of gold having a thickness of approximately 300 Angstrom units. The thickness of the gold film should be such that the electrodes are rectifying electrodes, and still permit transmission of electrons from the primary electron beam through the film. The gold films may, for example, be evaporated onto crystals 42 and 43. A photovoltaic device consisting of a germanium crystal having a low-resistance electrode and a thin metallic film such as a gold film has been disclosed and claimed in a copending application to Seymour Benzer filed on July 19, 1950, Serial No. 174,770, Patented December 16, 1952, No. 2,622,117.

In accordance with the present invention, a substantially unfocussed electron beam or stream is developed within the evacuated envelope 15. The electron stream is developed by cathode 48 which may be indirectly heated as indicated. A control grid 50 surrounds cathode 48 and a number of focussing plates 51 may be provided between control grid 50 and rectifiers 40, 41 to concentrate the electron stream on the electrodes 46, 47.

The cathode ray tube may again be energized by battery 22 having its positive terminal grounded. Potentiometer resistor 23 is connected across battery 22. Cathode 48 is maintained by tap 24 at a negative potential while control grid 50 may be connected to the negative terminal of battery 22 so as to have a potential which is negative with respect to that of cathode 48. A signal may be developed by signal source 26 which is coupled by a coupling capacitor 27 between control grid 50 and ground. Focussing plates 51 may be maintained at the potential of cathode 48 by tap 24. Rectifying electrodes 46, 47 may be connected to the positive terminal of battery 22 which is grounded. The electron stream impinging on electrodes 46, 47 should have sufficient energy to penetrate the metal films and create electrons and holes in crystals 42, and 43.

The low-resistance electrodes 44 and 45 of rectifiers 40 and 41 may be biased by battery 52 and 53 respectively. Battery 52 may have its positive terminal grounded while its negative terminal is connected to rectifying electrode 44 through load resistor 54. Similarly, battery 53 may have its negative terminal grounded while its positive terminal is connected to low-resistance electrode 45 through load resistor 55. An output signal may be developed across load resistors 54, 55 and may be obtained from output terminals 56 which are coupled to the load resistors by coupling capacitors 57 and 58 respectively.

Preferably crystals 42 and 43 are of opposite conductivity types. Thus, crystal 43 may be of the N type and crystal 42 of the P type. It will be observed that rectifying electrode 47 is negative with respect to low-resistance electrode 45. Since crystal 43 is of the N type, the electrodes are biased in the reverse direction. Rectifying

electrode 46 is positive with respect to low-resistance electrode 44 and since crystal 42 is of the P type, its two electrodes are also biased in the reverse direction.

Accordingly, a push-pull output signal will be obtained from output terminals 56. The amplifier of Figure 2 accordingly has a single-ended or unbalanced input and a balanced or push-pull output. The signals developed across load resistors 54, 55 have the polarities of the rectifying electrodes 46, 47. Thus a positive signal is developed across load resistor 54 and a negative signal across load resistor 55.

It is, of course, also feasible to utilize two crystal rectifiers 42 and 43 of the same conductivity type. Thus a push-pull output signal may also be obtained if both crystals 42, 43 are of the N type and if electrodes 45 and 47 are biased in the forward and reverse direction, respectively, as illustrated. However, since the current multiplication of a rectifier biased in the forward direction is smaller than that of a rectifier biased in the reverse direction, the bias voltages applied by batteries 52, 53 to the crystal rectifiers must be adjusted accordingly to obtain output signals of equal amplitudes. Since rectifier 41 is biased in the reverse direction battery 53 should impress a bias voltage of approximately —.2 volts between electrodes 47 and 45. Rectifier 40 is biased in the forward direction and its electrodes 46, 44 should be biased by battery 52 by a voltage of approximately +2 volts. Under these conditions two signals of substantially equal amplitudes are developed across load resistors 54, 55.

If both crystals 42, 43 are of the P type, the bias voltages should be adjusted as follows to obtain output signals of equal amplitudes. Battery 52 should bias rectifying electrode 46 to a voltage of approximately +.2 volts which is the reverse bias voltage. Battery 53 should bias rectifying electrode 47 to approximately —2 volts which is the forward bias voltage. If crystals 43 and 42 are respectively of the N and P conductivity types, both rectifying electrodes 46 and 47 should be biased by approximately 10 volts for maximum current multiplication.

Figure 3 illustrates another signal translating system in accordance with the invention where the electron beam is modulated by deflecting it across the rectifying electrode of the crystal rectifier. The system of Figure 3 has been claimed in a copending application filed concurrently herewith for A. R. Moore. The theory of beam deflection tubes has been discussed in a paper by E. W. Herold and C. W. Mueller which appears in the May 1949 issue of "Electronics," pages 76–80, and which is entitled "Beam Deflection Mixer Tubes for UHF." It is well known that such beam deflection tubes are particularly advantageous at high and ultra-high frequencies due to their large transconductance. In the device of the present invention the already large transconductance of a beam deflection tube is multiplied by the very high current multiplication which may be obtained in accordance with the invention.

The beam deflection tube of Figure 3 again includes a crystal rectifier 60 having a semi-conducting body 61, a low-resistance electrode 62 and a rectifying electrode 63 which may be in line contact with body 61. As shown particularly in Figure 4 rectifying electrode 63 preferably consists of a fine wire which extends in a substantially straight line across the width of the upper surface of crystal 61.

The electron beam is again developed by cathode 16 which may be heated by filament 17. Grid 18 preferably has a rectangular aperture to pass a beam of substantially rectangular cross section. The beam may then be focussed by the first anode 20 and deflected by a first pair of deflection plates 65, 65. A screen or shield 66 with a rectangular aperture is interposed between the first pair of deflection plates 65 and a second pair of deflection plates 67, 67. The details of construction of such a beam deflection mixer tube may be obtained from the paper by Herold and Mueller above referred to.

Cathode 16 may be grounded as shown. Battery 22 may again be provided to supply the accelerating potentials for the deflection tube. Potentiometer resistor 23 is connected across battery 22 and an intermediate tap 68 on resistor 23 may be grounded. Grid 18 is maintained at a negative potential by tap 70. A first anode 20 is maintained at a positive potential by tap 71. One of the first pair of deflection plates 65, 65 may be grounded. Shield 66 is maintained at a positive potential by tap 72 on resistor 24 which, however, is less positive than that of first anode 20. One of the second pair of deflection plates 67, 67 may also be grounded. Rectifying electrode 63 is maintained at a high positive potential by tap 73 on resistor 23. The two electrodes 62 and 63 are connected through battery 75 and load resistor 76. The output signal may be obtained from output terminals 77 which are coupled across load resistor 76 by coupling capacitors 78 and 80.

A first signal is impressed on one of the deflection plates 65, 65 by signal source 26. A second signal which may be developed by oscillation generator 81 is impressed on one of the second pair of deflection plates 67, 67. It is, of course, to be understood that instead of impressing an oscillatory wave on deflection plates 67, 67 a second signal may be impressed thereon so as to mix the two signals impressed on deflection plates 65 and 67.

The operation of the frequency converter of Figure 3 may best be explained by reference to Figure 5. Curve 82 of Figure 5 indicates the current gain of the device of Figure 3 with respect to the distance of the electron beam from rectifying electrode 63. It will be observed that at a distance of 5 mils from either side of rectifying electrode 63, the current gain is substantially zero. Dotted lines 83 indicate the reduction of the current gain which is caused when the electron beam impinges on electrode 63. If electrode 63 should be a point electrode of negligible area with respect to the area of the electron beam, the gain of the device of Figure 3 will substantially follow the full line curve 82.

The current flowing through output load resistor 76 is accordingly determined by the distance of the electron beam from rectifying electrode 63. This distance in turn is a function of the signal developed by source 26 and of that developed by generator 81. Thus the device of Figure 3 may be used as a frequency converter or signal mixer. It is, of course, to be understood that generator 81 and deflection plates 67, 67 may be omitted in which case the device of Figure 3 will function as an amplifier. In the latter case an oscillation generator may be connected in series with load resistor 76. It will also be observed that curve 82 is non-linear which is essential to obtain signal mixing or frequency conversion.

The device of Figure 3 may also be used as

an oscillation generator. To this end, parallel resonant circuit 85 may be tapped by taps 86 to load resistor 76. Resonant circuit 85 may be inductively coupled with inductor 87 provided in the circuit of deflection plates 65. Deflection plates 67 and generator 81 may be omitted. Accordingly, a portion of the output energy is fed back and impressed on deflection plates 65 in such a phase as to obtain sustained oscillations. The oscillatory frequency is determined by the resonant frequency of tuned circuit 85. The oscillatory output wave may be obtained from output terminals 77 or from resonant circuit 85.

The current flowing through the output circuit of the signal translating system of the invention is not strictly proportional to the current of the primary electron beam. Thus when the current of the primary electron beam is small, the current developed in the semi-conducting body, and which flows through the output circuit, is proportionately larger than the output current obtained with a larger primary electron beam current.

Accordingly, if the swing or the amplitude of the signal developed by source 26 is sufficiently large, it may be desirable to provide a variable mu type grid particularly in the device of Figure 2 to obtain a linear relationship between the primary electron beam current and the amplified output current. In that case, the mutual conductance of the tube is a non-linear function of the signal voltage applied to control grid 50. Consequently, if a higher negative bias voltage is applied to the control grid 59 so that the current of the primary electron beam is reduced, the mu or the mutual conductance of the control grid 50 should be smaller. In other words, at lower primary beam currents the grid gain should be made correspondingly smaller. However, such an expedient will not be required unless the amplitude of the signal voltage is comparatively large.

As pointed out hereinabove the resistance represented by a barrier in a semi-conducting body is modulated in accordance with the present invention. Such a barrier may be obtained not only in a crystal rectifier such as illustrated, for example, at 10 in Figure 1, at 40 and 41 in Figure 2 and at 60 in Figure 3, but also by a semi-conducting body having a distinct N zone and a P zone which are separated from each other by a barrier. Such a semi-conducting device has been illustrated in Figure 6 to which reference is now made. The semi-conducting body 90 has a P zone 91 and an N zone 92 which are separated by a barrier indicated at 93. The same effect may also be obtained by utilizing a semi-conducting body provided with a suitable grain boundary which forms a barrier.

Two electrodes 94 and 95 are in low-resistance contact with P zone 91 and N zone 92 respectively. The output circuit includes a source of voltage such as battery 96 and may further include two load impedance elements such as resistors 97 and 98, each having one terminal connected to electrodes 94 and 95 respectively and its other terminal to one pole of battery 96. Preferably the positive pole of battery 96 is connected through resistor 98 and electrode 95 to N zone 92 and the negative terminal of the battery is connected through resistor 97 and electrode 94 to P zone 91. The output signal may be derived from output terminals 100 coupled by capacitors 101 and 102 respectively across load resistors 97 and 98. It will be obvious that a push-pull output signal is derived from output terminals 100. By omitting one of the resistors 97 or 98 a single-ended output signal may be obtained.

The device illustrated in Figure 6 may be substituted, for example, for the device 10 in the tube of Figure 1 or for the device 60 in the tube of Figure 3. If the device of Figure 6 is used in the tube of Figure 1, the electron beam preferably has a rectangular cross section and is focussed at the barrier 93. The operation of such a signal translating system is similar to those previously described.

It will also be obvious that the voltage developed by battery 30 (Figure 1), batteries 52, 53 (Figure 2) or battery 96 (Figure 6) may be modulated. In that case, systems illustrated in Figures 1, 2 or 6 may be used as mixer or converter circuits to mix the input signal with that modulating batteries 30, 52—53, 96 or to obtain a converted output signal.

The device of the invention may be considered essentially as a current amplifier. It may be applied particularly where secondary electron multipliers are now used. It has the advantage of greater simplicity and it requires but a small bias voltage, yet has a very large current gain which, when a high velocity primary electron beam is used, is comparable to that which may be obtained from a ten stage electron multiplier. The device of Figure 2 may, for example, be used to derive an output signal from a television pick-up tube such as the orthicon or image orthicon or from the vidicon. The device of Figure 3 may be used wherever beam deflection tubes are utilized. It has the advantage that its gain is a product of the transconductance of the beam deflection tube and the current multiplication obtained in the crystal rectifier. Furthermore, there is no inherent coupling between the input and output circuits.

What is claimed is:

1. A signal translating system comprising a first and a second semi-conducting body, each having a barrier, each of said barriers having the characteristic of providing a potential gradient thereacross, a first and a second electrode in contact with each of said bodies, each of said first and second electrodes being disposed to include the barrier of the associated body between them, means for developing an electron beam and directing it to impinge in the vicinity of both of said barriers thereby modifying said potential gradient, a source of potential, two load impedance elements, circuit means connected between said first electrodes, further circuit means including said load impedance elements and said source of potential connected in series relation between said second electrodes, whereby a closed circuit is provided including said barriers, said source of potential and said load impedance elements, means for modulating said electron stream, and means for deriving an output signal across said load impedance elements.

2. An amplifier system comprising a first semi-conducting body having a first and a second surface, a first electrode in low-resistance contact with the first surface of said first body, a second electrode in rectifying contact with the second surface of said first body thereby providing a static potential gradient in said first body adjacent said second electrode; a second semi-conducting body having a third and a fourth surface, a third electrode in low-resistance contact with the third surface of said second body, a fourth

electrode in rectifying contact with the fourth surface of said second body thereby providing a static potential gradient in said second body adjacent said fourth electrode; means for developing an electron beam and directing it simultaneously toward the second surface of said first body and the fourth surface of said second body, means for modulating said beam in accordance with a signal thereby modifying said potential gradients in accordance with the intensity of said beam, a source of voltage, two load impedance elements, each of said load impedance elements being connected respectively between one of the terminals of said source of voltage and one of said first and third electrodes, a connection between an intermediate point of said source of voltage and said second and fourth electrodes, and means for deriving an amplified output signal across said load impedance elements.

3. An amplifier system comprising a first semiconducting body having a first and a second surface, a first electrode in low-resistance contact with the first surface of said first body, a second electrode in rectifying contact with the second surface of said first body thereby providing a static potential gradient in said first body adjacent said second electrode; a second semi-conducting body having a third and a fourth surface, a third electrode in low-resistance contact with the third surface of said second body, a fourth electrode in rectifying contact with the fourth surface of said second body thereby providing a static potential gradient in said second body adjacent said fourth electrode; means for developing an electron beam and directing it simultaneously toward the second surface of said first body and the fourth surface of said second body, means for modulating the intensity of said beam in accordance with a signal thereby modifying said potential gradients in accordance with the intensity of said beam, a first source of voltage and a first load impedance element connected serially between said first and second electrodes, a second source of voltage and a second load impedance element connected serially between said third and fourth electrodes, and means for deriving an amplified output signal across said load impedance elements.

4. An amplifier system comprising a first semiconducting body having a first and a second surface, a first electrode in low-resistance contact with the first surface of said first body, a second electrode in rectifying contact with the second surface of said first body thereby providing a static potential gradient in said first body adjacent said second electrode, said second electrode being in large-area contact with said second surface, a second semi-conducting body having a third and a fourth surface, a third electrode in low-resistance contact with the third surface of said second body, a fourth electrode in rectifying contact with the fourth surface of said second body thereby providing a static potential gradient in said second body adjacent said fourth electrode, said fourth electrode being in large-area contact with said fourth surface, said second surface and said fourth surface being disposed to face each other; means for developing an electron beam and directing it to impinge simultaneously on said second and fourth electrodes thereby modifying said potential gradients in accordance with the intensity of said beam, said second and fourth electrodes being permeable to said electron beam, means for modulating the intensity of said beam in accordance with a signal; first source of voltage and a first load impedance element connected serially between said first and second electrodes, a second source of voltage and a second load impedance element connected serially between said third and fourth electrodes, and means for deriving across said load impedance elements an amplified output signal.

5. An amplifier system comprising a first semiconducting body having a first and a second surface, a first electrode in low-resistance contact with the first surface of said first body, a second electrode in rectifying contact with the second surface of said first body thereby providing a static potential gradient in said first body adjacent said second electrode, said second electrode being in large-area contact with said second surface and covering substantially said second surface; a second semi-conducting body having a third and a fourth surface, a third electrode in low-resistance contact with the third surface of said second body, a fourth electrode in rectifying contact with the fourth surface of said second body, said fourth electrode being in large-area contact with said fourth surface and covering substantially said fourth surface thereby providing a static potential gradient in said second body adjacent said fourth electrode, said second surface and said fourth surface being disposed to face each other; means located between said second and fourth surfaces of said semi-conducting bodies for developing an electron beam and directing it to impinge simultaneously on said second and fourth electrodes thereby modifying said potential gradients in accordance with the intensity of said beam, said second and fourth electrodes being permeable to said electron beam, means for modulating the intensity of said beam in accordance with a signal; said first body being of the P type, said second body being of the N type, a first source of voltage and a first load impedance element connected serially between said first and second electrodes, a second source of voltage and a second load impedance element connected serially between said third and fourth electrodes, said sources being so poled as to bias said second and fourth electrodes in the reverse direction with respect to their associated bodies, and means for deriving across said load impedance elements an amplified push-pull output signal.

6. An amplifier system comprising a first semiconducting body having a first and a second surface, a first electrode in low-resistance contact with the first surface of said first body, a second electrode in rectifying contact with the second surface of said first body thereby providing a static potential gradient in said first body adjacent said second electrode, said second electrode being in large-area contact with said second surface and covering substantially said second surface; a second semi-conducting body having a third and a fourth surface, a third electrode in low-resistance contact with the third surface of said second body, a fourth electrode in rectifying contact with the fourth surface of said second body, said fourth electrode being in large-area contact with said fourth surface and covering substantially said fourth surface thereby providing a static potential gradient in said second body adjacent said fourth electrode, said second surface and said fourth surface being disposed to face each other; means located between said second and fourth surfaces of said semi-conducting bodies for developing an electron beam and directing it to impinge simultaneously on said second and fourth electrodes, said second and fourth

electrodes being permeable to said electron beam, means for modulating the intensity of said beam in accordance with a signal thereby modifying said potential gradients in accordance with the intensity of said beam; said bodies being of the same conductivity type, a first source of voltage and a first load impedance element connected serially between said first and second electrodes, a second source of voltage and a second load impedance element connected serially between said third and fourth electrodes, said sources being so poled to bias said second electrode in the reverse direction and said fourth electrode in the forward direction with respect to their associated bodies, and means for deriving across said load impedance elements an amplified push-pull output signal, the voltages developed by said sources being chosen so that the signals developed simultaneously across each of said load impedance elements are substantially equal in magnitude.

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