Jan. 9, 1951 | D. E. WOOLDRIDGE | 2,537,388

BEAM AMPLIFIER

Filed May 14, 1947

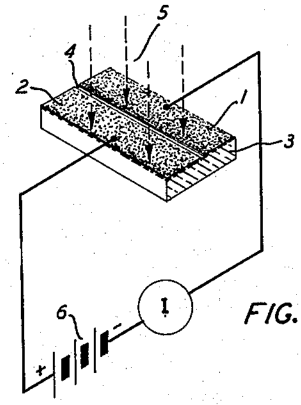



FIG. 1

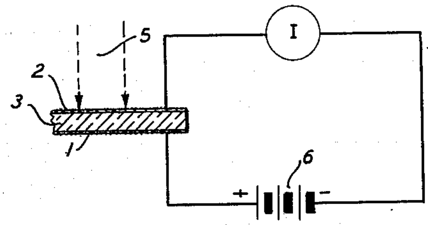



FIG. 2

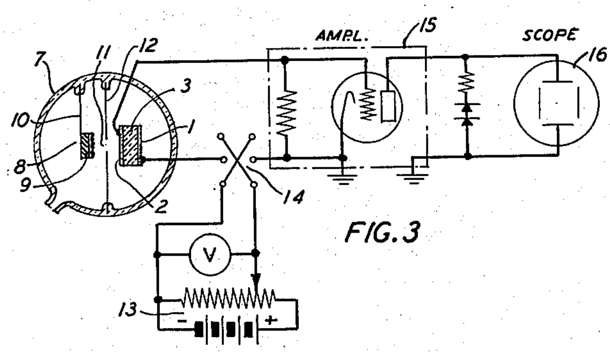



FIG. 3

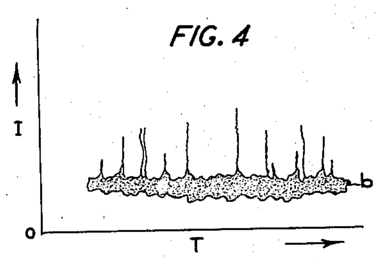



FIG. 4

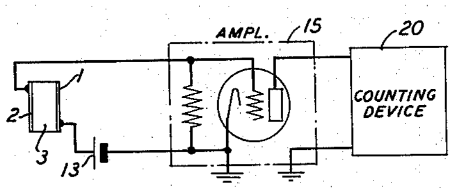



FIG. 5

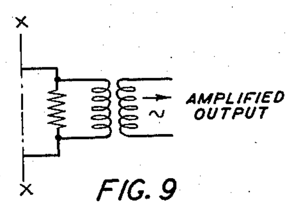
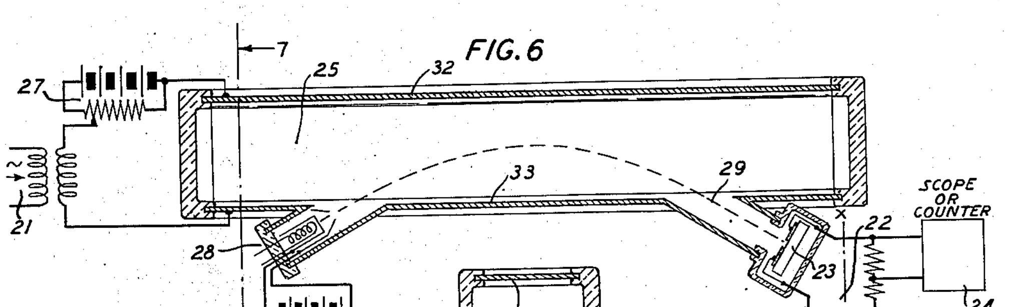



FIG. 9

FIG. 6



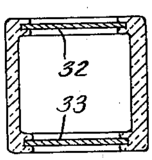
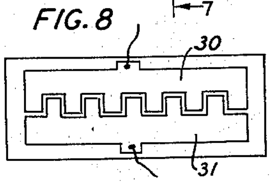




FIG. 7

FIG. 8

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# UNITED STATES PATENT OFFICE

2,537,388

## BEAM AMPLIFIER

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5 Claims. (Cl. 179—171)

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This invention relates to a process of inducing electrical conductivity in insulators and applications thereof in electrical apparatus.

In the field of nuclear physics there is a basic need for a device which yields a relatively large pulse of electrical current to correspond with each incidence on the device of a charged particle produced in the process of radioactive disintegration. Hitherto this need has been fulfilled by gas-filled devices such as the well-known Geiger-Mueller tube, which contains two or more electrodes across which an electrical voltage just insufficient to produce gas discharge is maintained. When an alpha or beta particle penetrates this gas, the ionization produced serves by a chain effect to cause local electrical breakdown of the gas. The pulse of electrical current flowing as a consequence of this breakdown serves to operate a counting device, which can be used to determine the intensity of the radiation of charged particles from the radioactive material or process under investigation. An alternative application of this principle is the ionization counter, in which true breakdown of the gas does not occur, but in which a pulse of current is produced whose magnitude corresponds to the number of ions produced by, and therefore to the energy of, the incident charged particle. Great advantages may accrue from a device in which similar pulses of electrical current are produced by the incidence of such charged particles on a solid rather than on a gaseous medium. Such a solid may substantially reduce the size of the apparatus required to count the products of radioactive disintegration.

An object of the invention is to facilitate the determination of kind and intensity of radiation, and more particularly, the radiation of charged particles.

A more specific object of the invention is to reduce substantially the size of apparatus employed in determining the kind and intensity of radiation of charged particles from radioactive materials.

Another object of this invention is to provide an external control for the flow of electrical current through a solid material across which an electrical field has been applied.

The basic feature of many electronic devices of great importance to the art is the control of the flow of electrical current between two electrodes in an evacuated or gas-filled space by electrical means independent of the voltage applied between these electrodes. Among the many applications of this principle are the amplifica-

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tion of electrical signals in the well-known evacuated triode and modifications thereof. All such apparatus hitherto devised for operation at normal temperatures have relied essentially on the control of the flow of electrons through a vacuum or a gas. Great advantages, especially by way of increased amplification accrue if such devices may be supplemented and in some cases replaced by a device in which the electron flow through a solid material is similarly subjected to independent external control.

Another object of this invention is to provide an amplifier of electrical signals whose amplification for a given interelectrode spacing is greater than that hitherto obtainble.

For the purpose of classifying substances in accordance with their electrical conductivities three designations are commonly employed. Electrical "conductors" connotes that class of substances which at room temperatures, that is, 15° C. to 25° C., have specific resistances of the order of $10^{-6}$ ohm-cm. Semiconductors include substances which under the same conditions have specific resistances of the order of 1 ohm-cm. Insulators are substances which under the same conditions have specific resistances of the order of $10^6$ ohm-cm. and higher.

The modern theory of the solid state satisfactorily accounts for the functioning of good electrical insulators. This theory is presented in the early part of a paper by W. Shockley, "The Quantum Physics of Solids," beginning on page 645, vol. XVIII (1939) of Bell System Technical Journal in which see especially pages 652 to 655. Such materials owe their non-conducting properties to an equilibrium distribution of the electrons of the solid among the available energy levels in such a way that an appreciable energy difference exists between the highest filled level and the lowest unoccupied level. This energy gap, which may be several electron volts wide, is an effective barrier that prevents the transition of electrons into higher states under the influence of a field. Since there are no empty levels below the forbidden energy region for electrons to move into, no change in the over-all electron distribution can be produced by an applied field; hence no current can flow.

The condition of equilibrium in an insulator can be upset in several known ways. For example, if the forbidden energy gap is sufficiently narrow or the temperature is sufficiently high, electrons occasionally can be thermally excited so as to occupy the unfilled band. Once arrived there, they are free to move into higher energy states under the influence of a field; in addition, the holes left in the normally filled band of levels make it possible for shifts to occur among this group of electrons when a field is applied. Both these effects manifest themselves as displacement of electric charge in the normally insulating material. Hence they may be regarded as evidence of induced electrical conductivity in the material.

Considerable is known about the ionization produced by alpha particles in passing through a gas. For example, an alpha particle of radium produces about $1.4 \times 10^5$ free electrons and the same number of positive ions when it is completely stopped in air. It heretofore has not been possible to make a direct measurement of the number of ions produced in a solid, but the order of magnitude of that figure may be arrived at fairly simply. The argument is based on the assertion that the interaction between an alpha particle and an atom in a gas cannot be greatly different from the interaction between the alpha particle and a similar atom in a solid. This argument receives strong experimental support from measurements on the stopping power per atom of various elements, which increases smoothly with increasing atomic weight; a simple empirical relationship fits the observations, even though some elements are solid and some are gaseous. Therefore, it seems safe to conclude that the ratio of electrons knocked loose to atoms traversed will not be far different for the carbon atoms of diamond than for the nitrogen of the air; neither will the mean energy expended per electron be greatly different. Hence it has been inferred that an alpha particle of radium should raise about $10^5$ electrons into the conduction band on being stopped in a diamond crystal; i. e. should shift the electron from a condition where it cannot move in an electric field to a condition where it can.

When the alpha particle has transferred the electron out of its normal energy level and into the conduction band, the electron moves toward the anode and the "hole" in the filled band moves toward the cathode if an electric field is applied to the diamond. If suitable electrodes are provided on the crystal, so that an electric field can be applied, these electrons and "holes" move toward opposite electrodes; this gives rise to a conductivity pulse in an appropriate measuring circuit.

In a similar way, conductivity is observed in diamond crystals bombarded by beta rays or by electrons of moderate speeds when the measuring circuit is made appropriate to these observations.

Devices consisting of crystalline insulators having electrodes of gold, platinum or aluminum, deposited by evaporation from hot wires of these materials have been successfully used in producing bombardment induced conductivity. Apparently a very intimate contact between the diamond or other insulating body and the electrodes is desirable for the utilization of this induced conductivity.

In accordance with this invention when certain crystalline bodies of insulating material, as e. g., diamond are bombarded with either alpha particles, beta particles, electrons of moderate speeds, they temporarily become electrical conductors. Advantage may be taken of, for example, this phenomenon to detect the presence of streams of alpha particles, beta particles or electrons of moderate speeds and to measure their intensity. In certain embodiments of the invention the principle of bombardment induced electrical conductivity may be utilized by exposing a diamond crystal to an incident beam of electrically charged particles and simultaneously impressing on the diamond an electric field to produce a current through the diamond when the secondary electrons are released therein by the ionizing action of the incident particles. This current may be employed to actuate an oscilloscope to show the nature and intensity of the incident particles or it may be used to operate a counter to show the number of particles incident upon the diamond within a given period. If the insulator target in which electrical conductivity is to be induced by bombardment be placed in the path of an electron beam which is subjected to the control of weak electrical impulses to be amplified, the current resulting from the bombardment induced electrical conductivity may be very much larger than the weak electrical impulses, thus enabling the device to serve as an electric amplifier.

A further object of the invention is to increase the ratio attainable between the number of free charged particles released by bombardment and the number of primary (bombarding) electrons. A related object is to take advantage of the increased volume density of a solid insulator type of bombardment induced conductivity device as compared with the alternative device using a gaseous medium, in the interest of compactness and economy of space.

Other objects of the invention will be understood from the specification hereinafter following, with reference to the accompanying drawings in which:

Figs. 1 and 2 illustrate alternative methods of applying the necessary difference of potential to the surfaces of the insulators in question, with relation also to the incidence of the bombarding particles;

Fig. 3 illustrates a system of the invention for indicating the presence of conductivity in an insulator which is affected by the bombardment of charged particles;

Fig. 4 illustrates, to approximate scale, an actual oscillographic record of the inducement of conductivity in a diamond by means of a Fig. 3 type of circuit.

Fig. 5 illustrates a system similar to that of Fig. 3 for indicating the presence of bombardment induced conductivity in an insulator, here specifically an apparatus for actually counting the incident charged particles, not restricted to a particular type of source of bombarding particles;

Fig. 6 illustrates an amplifier embodying the invention.

Fig. 7 illustrates a cross-section of the structure of Fig. 6 along the line 7—7;

Fig. 8 shows a detail of the quartz target of Fig. 6; and

Fig. 9 shows a modification of the portion of the output circuit of Fig. 6 at the right of line X—X.

It should be understood, in what follows, that, with reference to any particular system for demonstrating or measuring the bombardment induced conductivity of a diamond or the like, the incident ray or beam may almost impartially be made up of various common types of charged particles. Applicable types of charged particles include ordinary electrons as typified by the cathode emanations in the usual electronic devices, beta particles, which are essentially high speed electrons, and alpha particles which are positively charged particles. Alpha and beta particles usually, and as contemplated by the present disclosure, emanate from radio-active materials. It should be understood also that circuits or systems for evidencing the facts of bombardment induced conductivity do not differ in concept depending on whether the ultimate result is a graphical showing of the conductivity, as on the oscillograph screen, or an audible response in a device for obtaining a quantitative measure of the incidence of the beam of charged particles. This is true although certain figures of the drawings are so differentiated in order to indicate such choice of means in the interest of special considerations.

The foregoing generalization also applies to the particular electrode systems and Figs. 1 and 2 illustrate two kinds of system that may be almost impartially used in any of the systems being described, although a particular choice may be urged by particular practical considerations. These two systems differ in the nature of the coupling of the electrodes to the solid dielectric substance on which they are superposed. In Fig. 1 the two electrodes are mounted on the same surface of the diamond in a side-by-side presentation, and therefore so that the bombarding particles need only affect the diamond more or less superficially, whereas in Fig. 2 the electrodes are mounted on opposed surfaces of the diamond so that the conduction current represents a phenomenon existing throughout the mass of the diamond, thus implying that in the system of Fig 2 the bombarding particles and the particles released by the bombardment likewise affect the whole mass of the diamond

Referring to Fig. 1 more specifically two conducting metal film electrodes 1 and 2 are mounted on one surface of the insulator 3. The gap 4, separating the electrodes, is relatively small and various widths from .001 to .008 inch have been successfully used.

These electrodes may be prepared by dividing the diamond surface roughly in half by stretching a wire of appropriate diameter across and in close contact with the diamond surface and then evaporating a conducting metal layer, in vacuum, onto said surface. The shadow cast by the wire provides a gap when the wire is removed, of constant width across which the resistance is high.

The charged particles are assumed to conform to a ray or beam indicated generally by the reference numeral 5 which is incident on the diamond surface. Of course, the beam is most effective where it is incident on the diamond surface at the gap, but, depending on the type of charged particle, the electrodes would not necessarily impose a substantial barrier. Later numbered figures will show, more specifically and in detail, organizations including the elements which are here shown to a large extent diagrammatically. The angle of incidence is not critical.

Moderate electromotive forces applied between these electrodes by source 6 produce relatively high electric fields in the top surface layers of the diamond and the resultant induced conductivity pulses observed in the meter I, diagrammatically indicated, pass across only these surface layers. In the more specific disclosures related to other drawing figures, quantitative values will be given for certain physical and electrical dimensions shown or indicated in Figs. 1 and 2.

Fig. 2 presents the second type of electrode placement. Here the electrodes 1 and 2 are placed on opposite surfaces of the diamond 3. A typical diamond specimen for this purpose might be about ¼ inch in diameter (if circular. If the specimen is similar to that of Fig. 1, as it might well be, this could be very approximately either one or both of its principal dimensions.) and about .020 inch thick. Thus a potential difference of 100 volts from source 6, across these electrodes, would produce a uniform electric field of about 2000 volts per centimeter throughout the body of the diamond. In this type of electrode placement the induced conductivity pulses observed in the indicator I pass from front to back through the body of the diamond as distinguished from the alternative of Fig. 1 in which the pulses pass in the region of the front surface and in a direction along the surface.

In Fig. 3, illustrating a practical embodiment of a system operating according to the principles enuciated with respect to Figs. 1 and 2, especially Fig. 2, similar elements are, again, designated by like reference characters. The diamond 3 is coated with metallic electrodes 1 and 2 as in Fig. 2. The whole is mounted in an evacuated receptacle 7. The charged particle source 8, first assumed as a source of alpha particles, may consist of a small piece of silver sheet 9 on which is deposited a layer of radium sulphate having a given surface density of the radium component (in a typical instance, twelve micrograms of radium per square inch). The reference character 10 indicates diagrammatically the support for the silver sheet. In the prior art there are adequate teachings of mountings similar to this and other elements here disclosed in an evacuated container. Other facilities, likewise taught by the prior art could be used to advantage such as a magnetic control means to determine the particular direction of incidence of the particles on the diamond or even to adjust the position of the alpha particle source opposite the aperture 11 in a diaphragm-like element 12 for further determining and limiting the precise coaction of the beam of charged particles and the diamond.

The same illustration is applicable to the use of a beta particle source. In this instance the element 9 could have the form of a piece of glass on which a minute quantity of artificially radio active strontium has been deposited.

An adjusted potential, the value of which may be indicated by device V may be applied across the diamond, that is, between the electrodes thereof, by primary source and potentiometer, together indicated by 13. The bombarded surface of the diamond may be made either positive or negative, with relation to the opposite surface, by means of the reversing switch 14. Of course, in the specific instance of Fig. 3, the bombarding particles penetrate the exposed electrode before affecting the diamond. This action does not represent a significant departure from an alternative in which the diamond is directly bombarded. The detecting circuit comprises amplifier 15 and cathode ray oscilloscope 16, both shown diagrammatically to suggest the comparatively impartial choice of specific means to achieve these functions.

It is not a rigid requirement that the container be evacuated. In practice, a rough vacuum is produced merely to eliminate small induced conductivity pulses caused by ionization of the air produced by the charged particles in their transit to the diamond. These small effects may alternatively, or in cooperation with the use of a vacuum, be largely eliminated by mounting the particle source as close as practicable to the diamond, this therefore requiring that the diamond 3, source 8, and diaphragm 12 all be very closely interspaced.

Fig. 4 illustrates graphically, to approximate scale, the operation of an embodiment of the invention in a circuit similar to that of Fig. 3 in which alpha particles emitted by the radium component of radium sulphate constitute the charged particles. The drawing shows an actual sequence of traces on an oscilloscope field, the ordinates representing the current through the diamond, as induced by the bombardment by the charged particles, and the horizontal axis indicating time. The oscilloscope pattern represented by said Fig. 4 was reproduced from a photograph of one-twentieth second exposure. A potential of one or two hundred volts was applied between the electrodes, the bombarded electrode being connected to the negative side of the battery. Each one of the pronounced vertical cusps (displacement of the cathode ray) represents an induced conductivity pulse produced in the diamond by bombardment with a single alpha particle and lasting an exceedingly small fraction of a second. These alpha particle emanations occur at random along the horizontal trace in conformity with the well-known fact that alpha particles are emitted randomly in time from radium. These pulses are shown to vary in height. A calibration of the particular detector circuit used revealed that the maximum pulse height corresponded to a charge of at least $5 \times 10^5$ electrons. It was determined, at the same time, that a reversal of the relative polarity of the diamond electrodes caused a reversal of the Fig. 4 pattern, the displacements then occurring in a downwardly direction.

It is noted that these displacements are superposed on a background displacement b which appears as a zone with irregular boundaries in Fig. 4. This background effect is obtained with the potential removed from the diamond electrodes, the displacements making it up corresponding to the noise which is characteristic of the amplifier. It is evident from Fig. 4 that the circuit of Fig. 3 may be used in the quantitative measurements of the bombardment induced conductivity of the diamond, both as to the intensity of any given pulse and as to the number of pulses. By increasing the abscissa range representing a small interval of time and by sufficiently magnifying the pulse amplitudes, in accordance with conventional oscilloscope practices, it is quite practicable to count and appraise the effect of the incidence of single bombarding particles.

An applied field of 2,000 volts per centimeter, or even less, is sufficient to develop these current pulses. For example, such pulses have been obtained with only five volts applied to the electrodes of the Fig. 1 type, as embodied in the Fig. 3 circuits, and with an electrode saparation of .001 inch. Similarly, using the Fig. 2 type of electrode placement, these current pulses have been developed with less than 100 volts between the electrodes where the diamond thickness was about .020 inch.

Observation of these induced conductivity pulses, in which amplifier 15 had an extremely high speed characteristic, showed that the rise time of the pulse observed on the oscilloscope was about 0.15 microsecond. Since this figure represents a limitation in the amplifier itself, it is reasonable to conclude from this observation that the true rise of the pulse is less than 0.15 microsecond. Actually there is reason for believing that it may be very much less than this. Assuming that the recovery time of the insulator is of the same order as the rise time, this observation means that distinct and separately observable pulses occur in the diamond when the alpha particles that strike it are separated in time by only 0.15 microsecond or less. This means that the system of Fig. 3 is able to indicate the incidence of alpha particles at the rate of about seven million per second or more.

All of the described induced conductivity pulses were observed with the diamond at ordinary room temperature. This is important with relation to the prior art in which probably the closest approximation to this invention, although using quite different types of crystal and not the same variety of types of charged particles, required a temperature corresponding to that of liquid air or the like, and no practical result was achieved at room temperature.

It has been pointed out that the circuit of Fig. 3 may be used with beta particle bombardment, instead of with alpha particle bombardment. With beta particle bombardment observations similar to those illustrated by Fig. 4 have been made and which are similar in kind, although not in magnitude, to those of said Fig. 4. There was the same dependence of these pulses on the polarity of the applied potential. On the average the pulses were smaller than those of the alpha particles by a factor of 4 or 5, which is to be expected since the alpha particles had four or five times the maximum energy of the beta particles used.

Fig. 5 emphasizes the embodiment of the invention as a counter. Similar elements are similarly designated as in Fig. 3, the essential difference being the use of the counting device 20 in place of the oscilloscope 16 of Fig. 3, it being recognized that the prior art provides impulse (pulse) counters of a large variety and scope and having greater facility than the oscilloscope of Fig. 3. A potential of 200 or 300 volts may be applied across the diamond crystal. The structure of the crystal and its electrodes may be made to occupy a space each of whose dimensions is less than one-fourth of an inch. This structure is exposed to the desired source of radiation, the particles from which are to be counted. The current pulses, which flow through the diamond each time a charged particle penetrates it, are amplified as shown and the signals thus produced are counted by the counting device 20, which may be adjusted so that only pulses of a given amplitude or greater are selected for counting.

Fig. 6 illustrates an amplifier embodiment of the invention whereby a wave to be amplified originating in circuit 21 may be translated in amplified form to the output circuit 22 of the bombarded target 23 and thence may be utilized in oscilloscope or counter 24 similarly as in the modifications of Figs. 3 and 5, or, as taught by the alternative output circuit of Fig. 9, may be utilized for any other purpose normally served by an amplified wave. Of course, in the Fig. 6 circuit an amplifier may be inserted between the target 23 and the responsive means 24 similarly as in Figs. 3 and 5 as required to condition said responsive means 24 for most effective operation.

More specifically the amplifier comprises an evacuated container 25 bounded by conductive plates 32 and 33, the cross-section for the tube being shown in Fig. 7. A critical difference of potential between said plates is determined by source and potentiometer 27, which causes the upper plate 32 in the figure to be negative with respect to the lower plate 33. Under these conditions electrons emitted by electron gun 28 are repelled from the upper plate so as to have a parabolic trajectory enabling the electrons eventually to be incident on the target 23. The wave from the source 21 affects the static electrical condition of the plates to the extent of varying the extent of the passage of the electrons to the opening 29 from which they are incident on said target 23. As has been before explained, the very fact of incidence of a beam of charged particles, such as the electron beam in the present instance, on the target 23 connotes an amplified response in the output of said target. By the variable difference of potential between plates 32 and 33 as superposed by source 21 on the steady difference of potential from source 27, this amplified response is made proportional to the waves to be amplified from source 21.

The electron gun 28 is disclosed diagrammatically only since its specific details, likewise diagrammatically indicated in the figure, may conform with the conventional practice which permits a considerable variety of choice of specific means.

In the organization of Fig. 6, as used by applicant, there were certain significant variants, as to the bombarded insulator or target, as compared with the earlier numbered figures. For instance, the insulating crystalline substance is quartz rather than diamond. A further variant related to the placement of the electrodes thereon, as illustrated best in Fig. 8. As indicated in this Fig. 8 the electrodes have the appearance of thin interlaced grids, as illustrated by elements 30 and 31. These electrodes may be, as they were in practice, constituted by thin sheets of gold, shaped as shown, and sputtered on the incident surface of the quartz. The electrode placement is therefore similar to that of Fig. 1 differing in detail as to the specific conformity of the opposed edges of the electrodes and as to their metallic constitution. The electrode placement of this Fig. 8 is believed to promote the bombardment induced conductivity of the material and its sensitivity to change.

The counter of this invention can be used wherever the conventional Geiger-Mueller gas tube counter is used in nuclear physics studies where radioactive radiations are to be measured. These solid insulator counters have been worked at as low as one or two volts applied across the electrodes, where the Fig. 1 type of electrode placement is used. This low voltage feature immediately suggests the possibility of the use of these counters in rockets, weather balloons, and the like where low battery weight, size and cost are important. The absence of electrical breakdown at high altitude is an advantage to be derived from the low voltage of operation of a counter embodying the present invention.

Because of its small size, the diamond counter can be inserted in small cavities to measure radioactive radiation therein. For instance, it is quite feasible to insert the diamond counter into the body cavities of an animal or a human being for radiation measurements and biological studies. Inherent in its small size is the further advantage that the diamond will give a low background count due to stray radiation.

Because the diamond insulator counter gives a sufficiently great response even when made as small as mechanical consideration will reasonably permit it effectively serves as a device of high resolving power to indicate variations of radiation strengths in space as the device is moved to explore the space point by point. Counters according to the invention have been successfully used in which the diamond area exposed to alpha particles was only 0.001 inch by 0.2 inch. The 0.001 inch width affords exceedingly high spatial resolving power.

The high density (that is, high absorbing power) of the diamond counter gives it an advantage over the Geiger-Mueller counter in measurements of very penetrating radiations, which on passing through a gas tube may not lose enough energy to actuate it. This advantage of the diamond is particularly important in measurements of feeble sources of penetrating radiation.

The diamond insulator counter has a high counting speed resulting from the small time required to collect electrons freed by the alpha particles. A test has shown that this collection time is at most 0.15 microsecond. There is reason to think that it may be as small as 0.01 microsecond or even 0.001 microsecond. This is much smaller than the corresponding time for the Geiger-Mueller type of counter. This is particularly important in measurements of strong radioactive sources because the diamond counts more accurately, at the higher speeds, than the Geiger-Mueller counter and the chance of a single count resulting from several nearly simultaneous alpha particles is much smaller than in the Geiger-Mueller counter.

Since the diamond counter does not need to be encased in a container there are not necessarily any absorption losses due to container walls. This is an important advantage particularly in the measurement of radiations of short range. For instance, the diamond counter can be immersed in a dielectric liquid to make radiation measurements of radioactive substance in a solution. An important characteristic of the diamond counter is its intrinsic sensitivity. It has been observed that in it one electron may be released for as little as each ten electron volts of energy of the alpha particle. In air the alpha particle expends about 35 electron volts of energy for each electron released by ionization. Thus the intrinsic sensitivity of the diamond counter may be several times as great as that of the ionization counter.

As a further aid to the practice of the invention, especially as relating to a choice of the solid insulator that might be used, within the spirit of the invention, alternatively to diamond, the following considerations are offered. Theoretical considerations would suggest the desirability of such an insulator being of the single crystal type, having a specific resistance greater than perhaps $10^8$ ohm-cm. and with a high degree of chemical purity and freedom from inelastic strain or other crystal defects. These considerations suggest the possible use for this purpose of some or more of the following insulators: Zinc sulfide, the alkali halides (particularly potassium chloride), magnesium oxide, calcium fluoride, quartz, sodium nitrate, topaz, silver chloride, orthoclase, beryl, calcite, apatite, selenite, tourmaline and emerald of which applicant has worked with zinc sulfide, magnesium oxide, calcium fluoride, and quartz.

It will be apparent that the invention provides a useful tool for measuring a wide variety of incident electrical radiation ranging from the relatively slow electrons in the beam of a low voltage cathode ray device to the high velocity beta ray negative particles, which electrons and particles respectively are emitted at speeds corresponding to energies of the order of 500 to 5,000,000 electron volts. It will also be appreciated that the invention is useful in a wide range of circumstances since it is highly effective at room temperatures and may be embodied in very compact structures.

What is claimed is:

1. An amplifier comprising in combination, an electrically insulating crystal having electrodes mounted thereon in juxtaposed relation thereto together with a difference of potential means for causing a conductive current to flow therebetween and therefore through the crystalline structure responsively to the incidence of electrically charged particles on said crystal, means comprising a source of electrically charged particles and electrostatic beam conforming means for directing a beam of said particles in a curvilinear path on said crystal, a source of waves to be amplified, and means responsive to the waves from said last-mentioned source for varying the curvature of said path to thereby proportionally vary the number of charged particles in said beam that are incident on said crystal.

2. An amplifier comprising in combination a source of electrodes, means constraining said electrodes to follow a prescribed curvilinear path, an electrically insulating crystal in said path, a source of electrical variations to be amplified, means whereby said last source is adapted to vary the curvature of said path as in accordance with said electrical variations so as to correspondingly vary the number of electrons incident on a surface of the crystal, two conductive electrodes on said crystal in juxtaposed relation thereto together with a difference of potential means for causing a conductive current to flow therebetween and therefore through the crystalline structure responsively to the incidence of electrons on said surface and electric circuit means coupled to said electrodes to utilize the resulting wave corresponding, in amplified form, to said variations to be amplified.

3. The combination specified in claim 2 in which said crystal is quartz.

4. The combination specified in claim 2 in which said electrodes comprise grid-like gold sheets on a common surface of said crystal and having serrated interlaced opposed edges.

5. An amplifier comprising in combination a pair of conductive plates, means for potentially biasing one said plate negatively with respect to the other plate, a source of electric potential variations to be amplified connected to said plates to superpose its potential variations on the potential impressed thereon from said biasing means, means for injecting a beam of electrons in the direction of said negative plate and into the space between said plates wherein the electrons are constrained by the electrical condition of said plates to follow a given curved trajectory, an electrically insulating crystal mounted in the trajectory path of said electron beam, means whereby the number of electrons incident on said crystal from said beam is responsive to said trajectory as affected proportionally by the net difference of potential between said plates, two conductive electrodes on said crystal in juxtaposed relation thereto together with a difference of potential means for causing a conductive current to flow therebetween and therefore through the crystalline structure responsively to the incidence of electrons on said crystal and electric circuit means coupled to said electrodes to utilize the resulting wave corresponding, in amplified form, to said variations to be amplified.

DEAN E. WOOLDRIDGE.


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