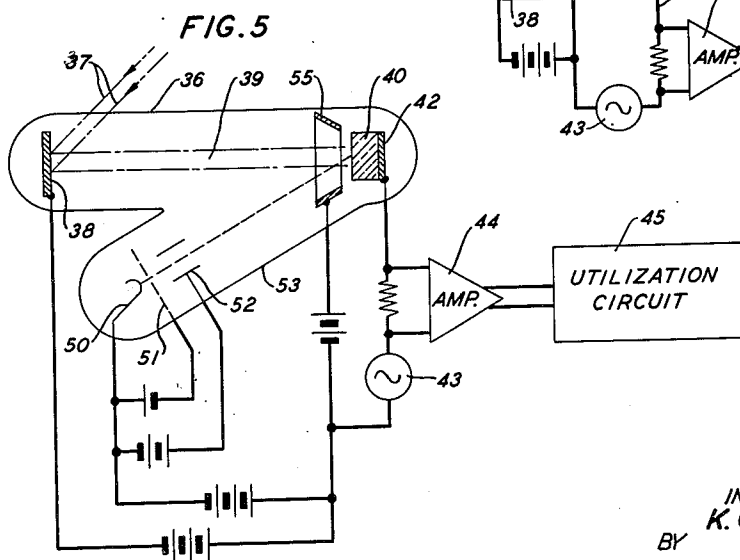
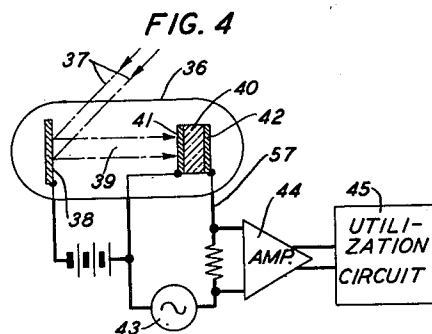
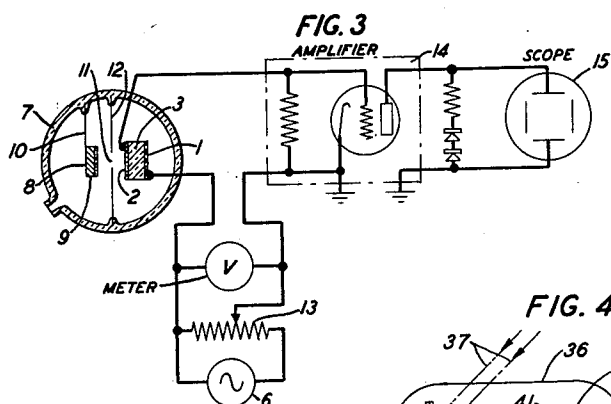
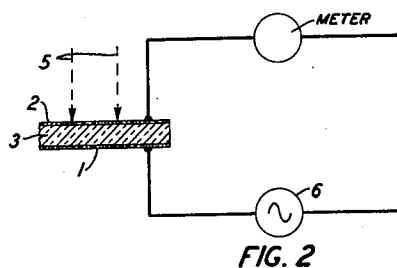
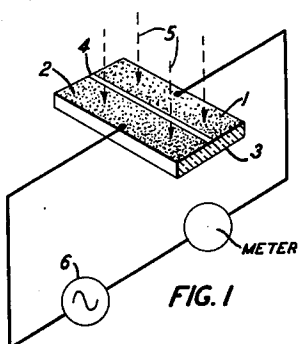


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PHOTOMULTIPLIER UTILIZING BOMBARDMENT
INDUCED CONDUCTIVITY
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PHOTOMULTIPLIER UTILIZING BOMBARDMENT INDUCED CONDUCTIVITY

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This invention relates to bombardment induced conductivity in solid insulators and more particularly to electrical photomultipliers. This application is in part a continuation of application Serial No. 789,667, filed December 4, 1947, issued February 27, 1951 as Patent No. 2,543,039 and it is filed pursuant to a requirement for division in the latter application. In the parent application, Serial No. 789,667, I disclose an improvement consisting largely in the use of an alternating rather than a direct voltage field across a bombarded solid insulator, together with bombardment of said insulator during all, or a part, of both positive and negative half cycles of the alternating voltage; or alternatively for achieving a like effect the use of a very thin solid insulator in conjunction with a very high field across the same. The improvement is without regard to the particular kind of radiation concerned, so as therefore to be applicable to the use of alpha particles, beta particles, electrons, mesons, X-rays or gamma rays, among others.

The phenomenon of bombardment induced conductivity in solid insulators is an instance of valve action. Analogously as a vacuum tube is made conducting under the influence of electrical means independent of the voltage applied between the electrodes, in the present studied phenomena a normally insulating solid material is made conducting by the incidence of bombarding charged particles under control of conditions specific to the bombarding function rather than to the electric field induced by the electrodes bounding said solid insulator.

Similarly as a charged particle of a conventional type, as alpha, beta or electron particles, of sufficient energy can remove a valence electron from its bonds, so also units (photons) of electromagnetic radiation, as in X-rays and gamma rays, may possess sufficient energy to cause the removal of valence electrons from their bonds in such a way that the solid insulator is rendered temporarily conducting.

The bombarding particles penetrate the insulator, causing a disruptive separation of the positive and negative charges specific to the atoms which are affected by said bombarding particles. These charges are drawn toward the electrodes by the potential therebetween, which sets up an electric field in the insulator; this motion of charges constitutes a conduction current which may be suitably amplified and measured by conventional apparatus.

The material chosen for the solid insulator should have a high insulating characteristic so

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as to be most amenable, without ambiguity, to the conditions imposed by the type of phenomena being treated. To this end, and for other reasons as well which are not fully known at this time, the insulator should have preferably good insulating qualities, and also should be preferably of a single crystal type with a high degree of chemical purity and freedom from inelastic strain or other crystal defects. These considerations commend the use of diamond, quartz, zinc sulfide, the alkali halides (including potassium chloride and potassium bromide), magnesium oxide, calcium fluoride, sodium nitrate, topaz, silver chloride, orthoclase, beryl, calcite, apatite, selenite, tourmaline, emeralds, extremely pure silicon carbide, and stibnite. Several of these substances, notably diamond, zinc sulfide, magnesium oxide, silicon carbide, and stibnite, have been used in the basic studies of bombardment induced conductivity and there is every good reason to think that the feature of using an alternating voltage field, attributable to applicant, is applicable to each of them. This feature has been used with eminent success with a diamond insulator, using electrons as the bombarding particles. Alpha particle bombardment of diamond, zinc sulfide and magnesium oxide also has been used in the basic work in this art and applicant has found that the operation is improved by the use of the alternating voltage field of his invention, and has excellent reason to think that a similar improvement would be obtained under beta or meson particle bombardment, and under irradiation by X-rays and gamma rays.

Diamond is a favored solid insulator for this work because it can easily be obtained without sufficient impurities or imperfections to affect its high insulation resistance, or its conducting properties under bombardment. The carbon atoms therein consist each of a nucleus exhibiting fixed units of positive charge, to which two electrons are tightly bound. This core is surrounded by four valence electrons. The nucleus weighs twenty-two thousand times as much as an electron. The carbon atoms are held together by "electron pair bonds" between adjacent atoms. The insulation resistance is high because the electron bonds are very tight. As a result of this tightness very few electrons are displaced from their bonds by thermal agitation. This is not the case in, for example, metals, where a large number of electrons are continuously being displaced by thermal agitation and are relatively free to wander through the metal. This, under

adequate conditions, constitutes the usual current in a metallic conducting medium.

When charged particle bombardment removes a valence electron from its bond in an insulating target, producing a deficiency of one electron in the atomic structure immediately affected, this localized electron deficiency is called a "hole." Under an applied electric field the arrangement of the electrons is changed, and the location of any given hole will change. As a consequence, the hole may be conveniently regarded as a positive particle which is free to move, under the influence of the field. Similarly, the electron freed from the bond in question constitutes a negative particle which is free to move under the influence of the field. If there is no applied field, any free electron or positive pole moves in virtue of thermal agitation and consequently has a completely random motion. Under an applied electric field there is a directional motion superposed upon a random one. The order of mobility of the electrons in diamond is 1,000 centimeters per second for a field of one volt per centimeter. For a field of 104 volts per centimeter the velocity therefore is 107 centimeters per second. For a diamond crystal one millimeter thick the transit time therefore would be 10^{-8} seconds. The mobility of the electrons is affected by the number of "traps," that is the presence of foreign atoms or imperfections, in the crystal. If an electron gets into a trap, it takes a greater or less amount of time to get out, depending upon the thermal energy required. If the time which a free electron spends moving in the crystal before being trapped is, on the average, less than the transit time, many of the electrons freed by the bombarding particle will effectively move only part of the distance through the crystal and thus will not actually be collected on an electrode. Although this movement of charge through part of the crystal will contribute to the total observable conduction current, the contribution will be less than if the electrons had been collected on an electrode. Similar considerations concerning mobility and trapping also apply to conduction by positive holes. In order to minimize the number of effective traps in a given target, so as to realize a substantial conductive current, the length of path in the target, between the electrodes, should be made as small as possible.

In accordance with the present invention, there is provided an improved photomultiplier of the bombardment induced conductivity type in which an alternating voltage is established across the insulator target, or in which alternatively, a very high electrical field is employed in conjunction with a very thin insulator target.

One embodiment of the invention described in detail hereinafter comprises an insulator having electrode connections coated or plated on its opposing surfaces, one of which is subject to bombardment by a stream of photoelectrons generated by a light beam impinging on a suitable photosensitive material. Across a pair of electrodes attached to the bombarded insulator is connected a circuit comprising an alternating voltage source; and an energy utilization circuit of some conventional form. Modulations impressed on the energy generated by the light source are highly multiplied in the output current derived across the bombarded insulator.

In accordance with a modification of the aforesaid embodiment, it has been found advantageous to replace the bombarded electrode contact by a low impedance conduction path provided by sec-

ondary electrons produced in the insulator target by a second beam and flowing to a collector electrode which is electrically coupled to the utilization circuit. For this purpose a low voltage high current beam is employed, which is broadly focussed in the inner target surface in addition to the beam of bombarding radiation.

A satisfactory theoretical picture explanatory of the advantages derived from the use of alternating, as compared with direct voltages, as in accordance with the invention, is not now completely available. It is, of course, recognized that such an explanation, or a physical picture of the operation in question, is not necessary to support the present specification and claims, under the patent statutes. However, it is evident that the adverse condition which tends to be, and is, remedied by the use of the alternating voltage across the solid insulator electrodes, is of the nature of a polarization or a space charge; that is, an accumulation of a net excess of either positive or negative electrical charge in a certain region or regions of the crystal. The following rough hypothesis, which is amply justified by observations so far, may be helpful.

Immediately after applying a steady voltage, as in the prototype organization disclosed in D. E. Woolridge Patent 2,537,388, January 9, 1951, most of the electrons which are freed by bombardment of the surface layer just beneath the thin cathode (negative electrode) move through the crystal from their point of origin near the cathode and are collected on the anode (the other electrode). However, some do not. Presumably these latter are trapped, and rendered temporarily immobile, by imperfections or impurity atoms in the body of the crystal. Electrons therefore tend to accumulate in regions of the crystal other than the very thin layer near the bombarded surface where they are freed. This is true, of course, without regard to whether the electrodes are in side-by-side presentation or in opposite presentation, with respect to the intervening crystal body. The crystal is then said to be polarized, that is, this accumulation of negative charges in the region between the source of the electrons and the anode opposes the force of the latter in attracting electrons away from this source. This effect is cumulative so that with the passage of time newly freed electrons are unable to move far from their source and only a small conduction current is observed. It is in this sense that the effective yield of internally freed electrons is observed to be relatively low with a steady voltage across the crystal.

This undesirable situation is disturbed if the applied voltage is reversed and the crystal is again bombarded. Now positive holes, instead of electrons as before, move across the crystal toward the back contact of the crystal which, before, constituted the anode but after reversal of the voltage would tend to function as the cathode. Some of these are trapped, similarly as the electrons in the earlier phase, thus setting up a positive space charge or polarization tending to neutralize the negative charge or polarization of the first phase, although some of the incomplete atoms which give rise to the positive holes may actually recombine with the trapped electrons. In either case, the negative space charge set up by the trapped electrons is greatly reduced or eliminated and the further reversal of applied voltage to restore the initial phase will thus cause newly freed electrons to move across the crystal until the opposing space charge again begins to form. Thus if an alter-

nating voltage of sufficiently high frequency be applied across the crystal in the bombardment, there is not time for an appreciable space charge to accumulate before the voltage is reversed and the space charge is partially or completely neutralized. Hence the effective yield of electrons is relatively large at all times when the applied voltage is such as to cause them to flow across all, or an appreciable part, of the crystal, providing this voltage alternates at a sufficiently high frequency. It has been determined that under certain experimental conditions a frequency of 20 cycles or greater is adequate.

For optimum space charge neutralization, the extent of the primary bombardment, both in time and intensity, during the negative half cycle of the alternating voltage, must be adjusted with relation to the extent of the primary bombardment during the positive half cycle. It may be desirable to use a direct potential bias superimposed on the alternating voltage, since this would render the peak voltages of the positive and negative half cycle different in absolute magnitude; and that this tends to result in a more homogeneous neutralization of the space charge throughout the thickness of the crystal. The reason for such a bias, at least so far as concerns this latter effect, is of course based on the difference between electrons and positive holes in their probability of being trapped.

Throughout the above discussion it has been assumed that the penetration of the primary bombarding particles is negligible. However, in a sufficiently thin crystal, this is not true and the current flow from the point of origin back to the bombarded crystal face becomes important. The above argument still applies to this condition, however, except that account, of course, has to be taken of the current implied by the return of electrons or positive holes from their points of origin back to the bombarded face, and the corresponding neutralization of space-charge which brings this about.

The line of argument above is equally relevant to the specific applications to be disclosed in detail below. It must be emphasized that the use of the term "alternating voltage" should be interpreted in its broadest sense as applying not only to a sinusoidal wave form but also to other recurrent wave forms such as square waves or more complex forms. The principal requirement on the field appears to be that at a certain critical time the field across the crystal must be in a certain direction and that at some later critical time, the field should be in the opposite direction, these times being correlated with the extent of primary bombardment. The choice of types of alternating voltage wave forms becomes significant for example in the application of an alternating field to a crystal bombarded by alpha particles. Because of the random distribution in time of the alpha particles, sinusoidal modulation is not particularly applicable although square wave modulation is found to be very useful.

Another method of overcoming the affects of space charge is to use very thin crystals in conjunction with high fields applied across the same. As there disclosed for added effect the field may be an alternating voltage field. It is contemplated that an extremely high field across the thin crystals might actually nullify the effects of space charge, even when the field is a direct voltage field. For example, a field ranging as high as that which will cause dielectric breakdown under bombardment (of the order of 10^6 volts per

centimeter) might be applied between electrodes separated by from 10^{-4} to 10^{-3} centimeters. In this case such a field would be so large that, even if all the traps in the crystal were full, the resulting opposing space charge field would be small by comparison. Moreover, if the thickness of the crystal is of the same order of magnitude as the depth of penetration of the particles of the primary beam, currents of electrons and positive holes will accordingly be traveling in opposite directions in the same region in the crystal and will thereby tend to neutralize the accumulated space charge.

With reference to the use of alternating voltage with electron bombardment induced conductivity, it is desirable to estimate the order of magnitude of alternating voltage and frequency that can be applied across the crystal and be expected to yield useful results. The figure of 20 cycles per second suggested above is in contemplation of the use of diamond as the crystal substance, although there is reason to think that comparable values would pertain to other solid insulators adaptable for this purpose. The same is true of the figures now to be presented.

The limits to be imposed on the voltage and frequency tend to be functions of the bombarding current, the induced conduction current, and the geometry of the crystal. Nevertheless, it would appear feasible when using small values of the above currents to go down to frequencies of a few cycles per second, that is, considerably less than the above indicated 20 cycles per second. The upper frequency limit will probably be determined by the electron transit time between the electrodes. Thus frequencies of the order of 10^3 cycles per second are certainly practicable and probably frequencies of as large as 10^9 cycles per second could be used. Usable field strength across the crystal will probably have a lower limit of the order of 10^3 volts per centimeter. The upper limit will probably be set by dielectric breakdown of the crystal, which would tend to occur at around 10^6 volts per centimeter. In terms of practicable crystal electrode separation, the actual applied voltages should range from something less than 100 volts up to several thousand volts. The useful bombarding voltage range, that is, range of energies of primary electrons, will probably run from something less than 1,000 volts up to many kilovolts. Applicant and his confreres commonly used from 10 to 15 kilovolts, although there is reason to think that it would be practicable to go to very much higher voltages.

Other objects and teachings of the invention are derivable from the detailed description hereinafter following, with reference to the accompanying drawings, in which:

Figs. 1 and 2 illustrate two preferred methods of applying the necessary alternating difference of potential (alternating voltage) to the surfaces or parts of surfaces of the insulators in question, with relation to the incidence of the bombarding particle;

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

Fig. 4 illustrates a photomultiplier utilizing the bombardment induced conductivity principle in accordance with the invention; and

Fig. 5 is an alternative form of the photomultiplier circuit illustrated in Fig. 4 in which the inner contacting electrode of the bombarded in-

insulator is replaced by beam stimulated secondary radiation from the said insulator and a collector for the same.

As has been said, the incident ray or beam which produces, by bombardment thereof, induced conductivity in a solid insulator (diamond or the like), may almost impartially be made up of any one of various common types of radiation. This includes ordinary electrons as typified by 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 radioactive material.

Figs. 1 and 2 illustrate two kinds of electrode systems that may be almost impartially used in any of the systems above 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 in a side-by-side presentation on the same surface of the solid insulator in question, which will be here assumed to be a diamond as in other figures unless specific notice is given to the contrary. In this arrangement, the conduction current flows only near the bombarded surface of the diamond, 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.

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 .003 inch have been successfully used in bombardment induced conductivity tests.

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 surface and then evaporating a conducting metal layer, in vacuum, onto said surface. This layer can be made so thin as to be semitransparent, provided its electrical resistance is so low as not to affect its electrical performance unfavorably. The shadow cast by the wire provides a gap when the wire is removed. This gap would have constant width and represent a uniformly high resistance thereacross at any point.

The charged particles are assumed to conform to a ray or beam indicated generally by reference numeral 5, which beam is incident on the diamond surface. Of course, the beam tends to be most effective where it is incident on the diamond surface at the gap but, depending on the type of charged particles, the electrodes would not necessarily impose a substantial barrier; however, the electrode system of Fig. 1 requires that the bombarding particles strike the gap or very closely adjacent thereto. Later numbered figures will show, most 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 alternating voltages applied between these electrodes by source 6 produce relatively high alternating electric fields in the top surface layers of the diamond and the resultant induced conductivity pulses observed in the indicating

means, which is diagrammatically indicated as a meter, pass across only these surface layers. In the statement of invention above, certain quantitative values, or their criteria, have been indicated, this applying not only to this figure but to the other figures as well.

Fig. 2 presents a second type of electrode placement. Here the electrodes 1 and 2 are placed on opposite sides of the diamond 3. A typical diamond specimen for this purpose might be about one-quarter inch in either principal dimension and about .020 inch thick. Thus a potential difference of 100 volts from alternating voltage source 6, across these electrodes, will produce a uniform electric field of about 2,000 volts per centimeter throughout the body of the diamond. In this type of electrode placement the induced conductivity pulses, observed in the meter indicating device shown, pass in alternate directions through the body of the diamond as distinguished from the Fig. 1 placement in which the pulses pass in the region of the front surface and alternately in directions along said surface.

In Fig. 3, illustrating a practical embodiment of a system operating according to the principles enunciated with respect to Figs. 1 and 2, like 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 the source of alpha particles, may consist of a silver sheet 9 on which is deposited a layer of radium sulfate having a given density of radium atoms (in a typical instance, 12 micrograms of radium per square inch). Of course other sources of alpha particle emanations are well known in the art and may impartially be used in the Fig. 3 organization. In fact said organization may well be used to explore the possibilities as to new sources of said emanations. The reference numeral 10 indicates diagrammatically a support for the silver sheet. In the prior art there are adequate teachings of mountings similar to this and the 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 in apposition to the aperture 11 in 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 and in this instance the element 9 could have the form of a piece of glass on which a minute quantity of artificially radioactive strontium has been deposited. The same teaching extends, of course, to other sources of charged particles or electromagnetic radiation such as gamma or X-rays.

In this figure the alternating current source 6 functions similarly as the like numbered source in Figs. 1 and 2 to apply the desired voltage across the diamond, that is, between the electrodes thereof. To suit the teaching of this figure, which discloses a more elaborate and complete organization than that of Figs. 1 and 2, the potentiometer 13 may be used as shown to determine a desired fractional part of the voltage of the primary source, the voltage impressed therefrom being indicated by the voltmeter V. Of course in the specific instance of Fig. 3, the bombarding

particles penetrate the exposed electrode before affecting the diamond, this of course not representing a significant departure from the alternative in which the diamond is directly bombarded, providing this electrode be sufficiently thin. The detecting circuit may comprise amplifier 14 and cathode-ray oscilloscope or the like 15, 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. Vertical cusps in the oscilloscope provide a measure of the intensity of any given pulse when the bombarded electrode is connected to the negative side of the source and a reversal of the relative polarity of the electrodes causes a reversal of the pattern. The reversal of polarity at an adequate rate, thus implying the use of an alternating voltage source results in the improved qualities of the organization that have been pointed out in the statement of invention.

Fig. 4 discloses diagrammatically a photomultiplier utilizing bombardment induced conductivity in a diamond across which is impressed an alternating voltage.

This is an important ingredient of the invention, as pointed out hereinbefore, providing a greatly increased yield over prior disclosed devices of the bombardment conductivity type. It should be understood that no particular alternating voltage wave form is specified, since it may take the form of a sinusoidal wave, square wave or some other form of which there is a wide choice.

Alternatively, as described in the earlier parts of the specification, the arrangement described in the preceding paragraph may be replaced by a very thin insulator crystal used in conjunction with a high field strength across the same.

The photomultiplier shown in Fig. 4 is somewhat similar to the apparatus disclosed in the earlier numbered figures, the essential elements being enclosed in evacuated envelope 36. The significant particles are photoelectrons, as distinguished from electrons emitted from a heated cathode, as in the earlier figures. A light beam, from whatever available source, is represented in the drawing by the two lines or rays 37 which are incident on a conventional photoemissive target 38 adapted for the efficient emission of photoelectrons under such conditions. Reference numeral 39 indicates the path of two typical photoelectrons emitted from said surface and which impinge on the exposed surface of the diamond crystal 40, having electrodes 41 and 42. The photoelectrons are accelerated by the voltage indicated between the emitter 38 and electrode 41 of said diamond crystal so as to bombard the diamond with an energy of a thousand electron volts or more. In a particular experiment by applicant, a diamond was used which was coated with two narrowly separated electrodes constituted by evaporated gold on the diamond face presented to the incident photoelectron beam

which were interconnected so as effectively to constitute a single electrode, together with one similar electrode on the opposite face of the diamond. Alternatively, other arrangements of dielectric and electrodes may be used within the teachings of the earlier numbered figures and, in addition, there is a wide choice of solid insulator material.

To the outer electrode 42 of the insulator 40 is connected a load resistor, across the terminals of which is connected an output circuit, including, for example, the amplifier 43 and some type of utilization circuit 45, which may take the form of a cathode-ray oscilloscope. The load resistance is connected in series to the alternating current source 43 to the other electrode 41, to which is also connected the positive terminals of the biasing source for the photoelectron source 38.

The conditions specific to the diamond are similar to those relative to the diamonds described in connection with other applications of bombardment induced conductivity. That is, the conductivity induced therein by the alternating voltage field derived from the source 43 is about one hundred times the bombarding current of photoelectrons. This current flows through the output circuit, here indicated diagrammatically by the amplifier 44 and utilization circuit 45. In extent it is the equivalent to what would be expected of a secondary emission surface twenty times more efficient than those employed in conventional photomultiplier tubes.

A modification of the improved form of bombardment conduction photomultiplier described in the preceding paragraphs with reference to Fig. 4 is shown in Fig. 5 of the drawings, which has as its principal feature of difference from the former the replacement of the inner electrode of the crystal insulator target 40 by a low impedance conduction path provided by secondary emission emanating from the target and flowing to a collector electrode. The said secondary emission is induced in the target by means of low voltage high current beam of electrons focussed broadly thereon by a second electron gun included in an extended portion of the envelope enclosing the gun which produces the bombarding beam, the target, and the other elements of the system.

Referring in detail to Fig. 5, the electron gun producing the beam which is directed to induce secondary radiation in the target 40, and which will be known hereinafter as the "holding beam" as differentiated from the bombarding beam, comprises a cathode 50, a control grid 51, and a cylindrical focussing electrode 52, all of which are enclosed in the extending portion 53 which extends obliquely outward from the evacuated glass envelope 36, at such an angle as to enable irradiation of the inner surface of target 40 without presenting interference to the bombarding beam. Such an electron gun may assume any one of a number of forms well known in the art, such as for example, one of the arrangements described in detail in Patent 2,458,652 to R. W. Sears, January 11, 1949.

The beam from the cathode 50 is so focussed by the positively biased focussing electrode 52 as to broadly cover the inner surface of the insulator element 40. The electrons emanating from the cathode 50, which is usually biased a few thousand volts negative with respect to the insulator 40, provides electrons of sufficient energy to induce secondary emission in the target having a coefficient of the order of unity. Optimum operation is obtained at what is known as the "second cross-

over point," referring to a graphical representation of secondary radiation. The meaning of this phrase may be explained as follows. As the potential applied to the primary electrons of the "holding" beam is gradually increased from zero, the number of secondary electrons emitted by the target also increases reaching a maximum at which the coefficient of secondary emission is somewhat in excess of unity, and then gradually decreases passing a second time through a point at which the coefficient is unity. The "second cross-over point" is preferred to the first since operation of the latter is unstable.

The secondary emission emanating from the target 40 is collected by the electrode 55 which may, for example, take the form of a truncated hollow cone, the inner surface of which is disposed close to the inner face of the insulator 40 to receive secondary electrons emitted therefrom, but which has a sufficiently wide opening to be substantially out of the impinging path of the bombarding beam. The current density of the "holding" beam should be sufficient to provide an impedance between the target 40 and collector 55 which is low compared with the effective impedance set up through the crystal as the result of bombardment. For best operation the ratio of the current density in the holding beam to that of the bombarding beam should be of the order of 1000 to 1. For example, if the bombarding beam has a current density of the order of microamperes, the current density of the "holding" beam should be of the order of milliamperes. In order to maintain the flow of secondary electrons in the desired direction, the collector electrode 55 is biased positively with respect to the target. For example, the cathode 50 may be maintained at a potential of the order of a kilovolt negative with respect to the target 40; whereas the collector electrode is maintained at a potential of the order of a kilovolt positive relative to the said target. Connection is made from the collector 55 through the lead 57 to the output or load resistance, as in previously described embodiment.

It is apparent that the bombarding electron gun, the target, and other elements of the system are similar in structure and function to like numbered elements shown in Fig. 4 and described with reference thereto.

The system operates in a manner largely similar to the system described with reference to Fig. 4. When a current of electrons or holes is generated in the insulator 40, by a stream of photoelectrons directed thereon, the inner surface of the insulator 40 varies in potential in accordance with variations in the intensity of the light ray 37 and it also varies in accordance with the alternating voltage impressed from the source 43. In the presently described embodiment, due to the stimulation produced by the low voltage high current beam from the cathode 50, secondary electrons are emitted from the surface of insulator 40 and flow to the positively biased collector 55 until a stable energy state is established. This secondary electron current, which is proportional to potential variation across the insulator 40, and hence is an amplified replica of the variations in the light beam modulated by the alternating current from source 43 passes through the lead 57 into the output circuit.

Such an arrangement has several advantages over the arrangement previously described, namely, that the effect on the insulator due to the bombarding beam is more pronounced with

the removal of the inner electrode, which operated to absorb part of the bombarding radiation; and further, that it is technically simpler in some instances to irradiate the insulator uniformly with electrons than to evaporate or plate a uniform electrode film in contact with the surface.

What is claimed is:

1. A photomultiplier comprising in combination a solid electrical insulator, means for reducing the cumulative space charge in said insulator comprising a source of electrical biasing potential applied across at least a portion of said insulator, photoemissive target disposed to emit in response to an applied light beam a stream of photoelectrons which impinge on a photoelectron receiving surface of said insulator, and a circuit coupled to said insulator, said circuit responsive to the change of conductive current generated in said insulator by said photoelectrons.

2. A photomultiplier comprising in combination an electrically insulating crystal, means for reducing the cumulative space charge in said insulating crystal comprising a source of alternating-current biasing potential applied across at least a portion of said crystal, a photoemissive target disposed to emit in response to an applied light beam a stream of photoelectrons which impinge on a photoelectron receiving surface of said crystal, and a circuit comprising a pair of electrodes coupled to said insulating crystal, said circuit responsive to the change of conductive current generated in said crystal by said photoelectrons.

3. A photomultiplier comprising in combination an electrically insulating crystal, means for applying an electrical field across at least a portion of said crystal, a photoemissive target disposed to emit in response to an applied light beam a stream of photoelectrons which impinge on a photoelectron receiving surface of said crystal, and a circuit coupled to said insulating crystal which is responsive to the change of conductive current generated in said crystal by said photoelectrons, wherein the spacing between said field applying means is so small as to approach the depth of penetration of said photoelectrons causing the field thereacross to be extremely large.

4. A photomultiplier comprising in combination an electrically insulating crystal having electrodes mounted thereon together with means comprising a source of alternating voltage impressed across at least a portion of said crystal for causing a conductive current to flow between said electrodes responsively to the incidence of photoelectrons on said crystal, a light target having a photoemissive surface presented to incident light beams and in photoelectron radiation relation to a photoelectron receiving surface of said crystal, and current responsive means coupled to said electrodes and alternating voltage source for indicating a change of conductive current through the crystal responsive to the incidence of said photoelectrons.

5. A photomultiplier comprising in combination an electrically insulating crystal, means for reducing the cumulative space charge in said crystal comprising means for applying an electrical field across at least a portion of said crystal, a photoemissive target disposed to emit in response to an applied light beam a stream of photoelectrons which impinge on a photoelectron receiving surface of said crystal, a circuit for utilizing the

changes in conductive current generated in said crystal by said photoelectrons, and means for providing a current conductive path between the photoelectron receiving surface of said crystal and said current utilization circuit, said means comprising another source of a beam of electrons directed to impinge the photoelectron receiving surface of said crystal and to stimulate secondary emission from said crystal, and collecting means connected to said current utilization circuit and disposed to receive secondary electrons emitted from said crystal proportionately to the charge generated therein by said photoelectrons, wherein the spacing between said field applying means is so small as to approach the depth of penetration of said photoelectrons causing the field thereacross to be extremely large.

6. A photomultiplier comprising in combination an electrically insulating crystal, means for reducing the cumulative space charge in said crystal comprising an alternating current field impressed across at least a portion of said crystal, a photoemissive target disposed to emit in response to an applied light beam a stream of photoelectrons which impinge on a photoelectron receiving surface of said crystal, a circuit for utilizing the changes in conductive current generated in said crystal by said photoelectrons, means for providing a current conductive path between the photoelectron receiving surface of said crystal and said current utilization circuit, said means comprising another source of a beam of electrons directed to impinge the photoelectron receiving surface of said crystal and to stimulate secondary emission from said crystal, and collecting means connected to said current utilization circuit and disposed to receive secondary electrons emitted from said crystal proportionately to the charge generated therein by said photoelectrons.

7. A system comprising in combination a solid electrical insulating element, means for reducing the cumulative space charge in said insulating element comprising an electrical field applied across at least a portion of said element, a source of a beam of charged particles directed to impinge on a surface of said insulating element, means for modulating the intensity of said beam, a circuit for utilizing the changes in conductive current generated in said insulating element by said charged particles, means for providing a current conductive path between said insulating element surface and said current utilization circuit, said means comprising another source of a beam of electrons directed to impinge on said surface and to stimulate secondary emission from said insulating element, and collecting means connected to said current utilization circuit and disposed to receive secondary electrons emitted from said element proportionately to the charge generated therein by said charged particles.

8. A system comprising in combination a solid electrical insulating element, means for applying an electrical field across at least a portion of said element, a source of a beam of charged

particles directed to impinge on a surface of said insulating element, the spacing between the surfaces of said insulating element in the direction of said beam being so small as to approach the depth of penetration of said charged particles causing the field thereacross to be of the order of the dielectric breakdown potential of said insulator, means for modulating the intensity of said beam, a circuit for utilizing the changes in conductive current generated in said insulating element by said charged particles, and means for providing a current conductive path between a surface of said insulating element and said current utilization circuit, said means comprising another source of a beam of electrons directed to impinge on said surface and to stimulate secondary emission from said insulating element, and collecting means connected to said current utilization circuit and disposed to receive secondary electrons emitted from said element proportionately to the charge generated therein by said charged particles.

9. A system comprising in combination a solid electrical insulating element, means for reducing the cumulative space charge in said insulating element comprising an alternating voltage field impressed across at least a portion of said element, a source of a beam of charged particles directed to impinge on a surface of said insulating element means for modulating the intensity of said beam, a circuit for utilizing the changes in conductive current generated in said insulating element by said charged particles, means for providing a current conductive path between said insulating element surface and said current utilization circuit, said means comprising another source of a beam of electrons directed to impinge on said surface and to stimulate secondary emission from said insulating element, and collecting means connected to said current utilization circuit and disposed to receive secondary electrons emitted from said element proportionately to the charge generated therein by said charged particles.

10. In combination, a system comprising a target of insulating material in crystalline form, means to direct an intensity-modulated beam of charged particles to impinge a surface of said target, means to direct a second beam of charged particles to impinge on said surface with velocity sufficient to produce secondary emission therefrom, a collector electrode positioned adjacent said surface to receive the secondary emission therefrom, and an electrical circuit connecting said collector and another surface of said target, said circuit including a utilization device and an alternating voltage source.

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