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METHOD AND SYSTEM FOR ELECTRON IRRADIATION OF MATERIALS

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Fig. 1.

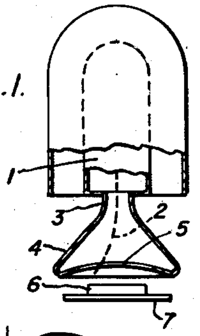


Fig. 2.

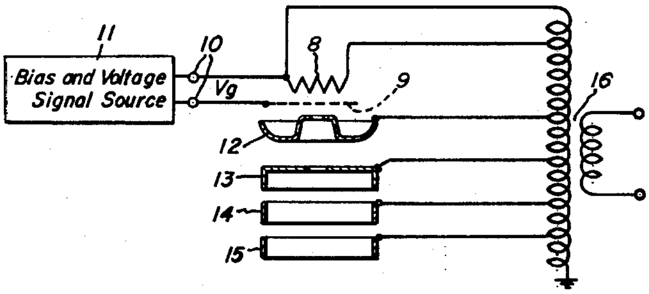


Fig. 3.

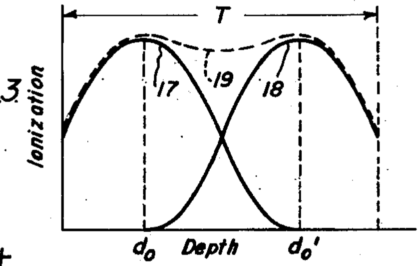


Fig. 4.

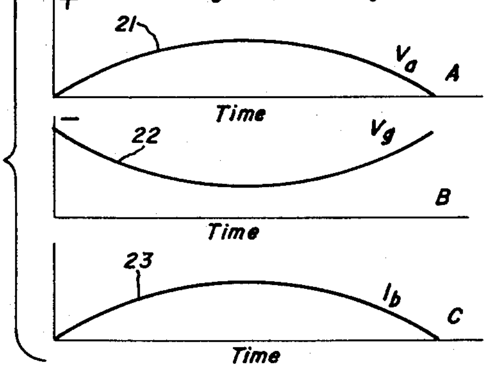


Fig. 5.

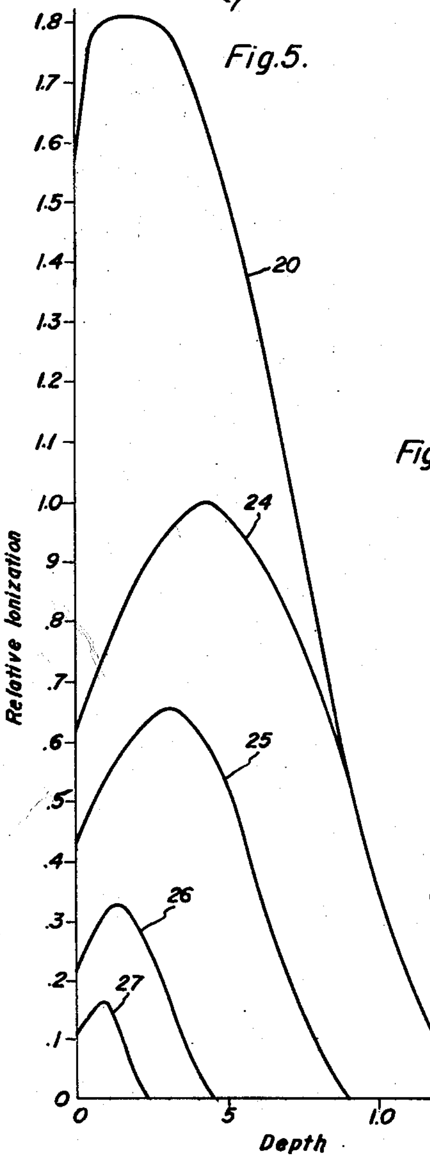
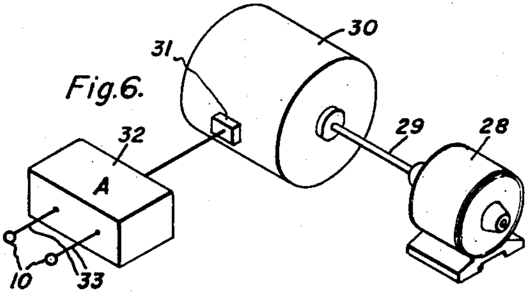


Fig. 6.



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METHOD AND SYSTEM FOR ELECTRON IRRADIATION OF MATERIALS

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The present invention relates to a system and method for irradiating materials with electrons.

When some materials are subjected to a beam of high energy electrons, the resulting ionization energy absorbed in the materials may produce beneficial results such as sterilization and de-infestation of foods and drugs, acceleration of chemical reactions, coloration of glass, treatment of skin diseases, etc. Usually, best results are obtained when the ionization is substantially uniform throughout the thickness of material being irradiated.

Accordingly, an object of the present invention is to provide a method for producing more uniform ionization by electrons throughout the thicknesses of irradiated materials.

Another object is to provide an electron beam system for producing more uniform ionization distributions throughout the thicknesses of irradiated materials.

An electron beam system provides more uniform ionization distribution when the electron beam is made up of a range of energies, from low to high, such as can be realized with an accelerating voltage which varies with time. On the other hand, when varying accelerating voltages are used, the low magnitude portions of these voltages result in a greater energy loss in the vacuum window provided at the beam exit area of the system. The window may absorb so much energy that it is destroyed by the resulting heat. Consequently, electron beam systems are usually operated with nearly constant high accelerating voltages to avoid overheating of the window even though better ionization distribution would be obtained throughout the thicknesses of the material with a varying accelerating voltage.

Therefore, an object of the present invention is to provide an improved electron beam system in which the beam accelerating voltage varies with time but in which the window heating is not destructive.

A still further object of the present invention is to provide a method of operating an electron beam system to obtain more uniform ionization distribution without destructive window heating.

These and other objects are achieved in a preferred embodiment of our invention in which the electron beam current magnitude in an electron beam generator, operated under space charge limited conditions, is varied in phase with the beam voltage to produce substantially uniform ionization distribution.

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, together with further objects and advantages thereof may best be understood by reference to the following description, taken in connection with the accompanying drawing in which:

FIG. 1 is a partially sectioned side view of an electron beam generator with which the present invention can be practiced,

FIG. 2 is a schematic diagram of the electron gun in the electron beam generator of FIG. 1,

FIG. 3 comprises graphs illustrating the ionization distribution produced by conventional operation of an electron beam generator,

FIG. 4 comprises graphs A, B and C illustrating electrical waveforms of operation when the electron beam generator of FIG. 1 is operated in a preferred manner,

FIG. 5 is a graph illustrating the synthesis of an ionization distribution resulting from a sine wave electron beam whose current is in phase with a sine wave acceleration voltage, and

FIG. 6 is a block diagram of one possible system for producing a control voltage for the grid electrode of the electron gun of FIG. 2.

Referring now to FIG. 1, we have illustrated an electron beam generator that, except for the electron gun, may be conventional. In this generator a tube **1** contains components (not shown) for producing and accelerating an electron beam **2** that then passes through a neck **3** of tube **1** having a terminating flared portion **4**. By way of example, at the bottom of portion **4** a long narrow slot is covered by a vacuum-tight thin metallic foil **5**, called a window, that is bowed due to the pressure difference caused by the high vacuum inside portion **4** and the atmospheric pressure outside. Other shapes of windows could be used. The high energy electrons in beam **2** readily pass through thin window **5** to irradiate a material **6** which may be moved by a belt **7** normal to the long dimension of the flared portion **4**. Beam **2**, which may be deflected parallel to the long dimension of portion **4**, as well as transversely, irradiates substantially the total volume of material **6**.

In FIG. 2 we have illustrated the electron gun for the accelerating tube **1** of the electron beam generator in FIG. 1. In this electron gun a filament **8** emits electrons that pass through a grid electrode **9** under the magnitude control of a voltage, which we shall identify as V_g, applied across two input terminals **10** from a source **11**. These electrons are then focused by voltages applied to a focusing electrode **12** and a high voltage electrode **13**; the voltage on the latter also acts with voltages on other electrodes **14**, **15**, etc., as a means for accelerating beam **2**. The cathode and grid structure may be such as set forth more fully and claimed in Patent No. 2,914,692, granted November 24, 1959, which patent is assigned to the assignee of the present application. The electron gun elements and electrodes can be energized by a resonant transformer **16** such as the type described and claimed in Patent No. 2,144,518, granted January 17, 1939, which patent is assigned to the assignee of the present application.

In some high energy electron beam generators, the electron gun is operated under emission limited conditions. In other words, the magnitude of current in the electron beam is usually all of the current that the filament electrode in the electron gun is capable of producing at the temperature at which it is operating. There is little control of current since all of the current emitted from the filament is used in the electron beam. In the present apparatus, grid electrode **9** is biased to provide space charge limited operation. In this type of operation a cloud of electrons is formed a short distance from filament 8, from which the number of electrons forming electron beam 2 is determined by a varying voltage V_g applied to the grid electrode **9**. The shape of this varying voltage is significant, as is explained below.

Referring now to FIG. 3, an ionization distribution graph **17** is illustrated for a relatively constant potential electron beam generator. The ordinate values correspond to relative ionization and the abcissa values to depth in the irradiated material **6**. Graph **17** illustrates that when a material is irradiated with high energy electrons of substantially constant potential, the distribution of the ionization throughout the thickness of material varies. The ionization is low near the surface and then increases to a maximum at a depth d_0. For depths greater than d_0 the ionization gradually decreases to zero. As perviously mentioned, uniform ionization distribution is desired. Thus, the ionization distribution corresponding to curve **17** is far from ideal. However, the uniformity of ionization beyond the depth d_0 can be improved by irradiating the material 6 from both sides. Graph 18 corresponds to the irradiation from the other side. As a result of this second irradiation the ionization distribution between depths d_0 and d_0' is more uniform. That is, the total ionization, as illustrated by curve 19, which can be found by adding the ordinate values of curves 17 and 18, is relatively constant within the interior of material 6, whose thickness is indicated by T, in FIG. 3.

Even though the ionization can be made more uniform near the interior by the irradiation from both siles of material 6, there still remains the large variation in ionization distribution near the two irradiated surfaces. This variation could be largely eliminated by the use of absorbers placed on the surfaces of material 6 or between the material 6 and the tube window. These absorbers, in effect, present a thickness to the irradiation, and thus the large variation in ionization distribution between the surface and depth d_0 occurs in the absorbers rather than in material 6. This, of course, is a very costly procedure as the fraction of the total energy of the electron beam that must be dissipated in the absorber is completely wasted as heat in the absorber. Thus, from the above it is seen that if a constant potential electron beam is utilized, the ionization distribution cannot be made substantially uniform without a large energy loss.

In the present invention, as is illustrated by curve 20 in FIG. 5, substantially uniform ionization distribution near the surface is obtained without the use of absorbers, and also without significant window heating. The electrical characteristics of operation that provides this result are illustrated in the graphs of FIGS. 4A, 4B, and 4C.

In FIG. 4A there is illustrated a half cycle, 21, of the acceleration voltage V_a for an electron beam generator in which the accelerating potential varies with time, for example, sinusoidally. V_a is the positive voltage on window 5 as compared to filament 8. Actually, window 5 is usually grounded and filament 8 maintained at a large negative potential below ground. Voltage V_a is the half of each cycle during which electrons leave filament 8. It contains all values of voltage from substantially zero to the maximum value.

In FIG. 4B there is illustrated a graph 22 of a preferred voltage V_g that is applied to the grid electrode 9 with respect to the filament 8. This voltage V_g is negative. With space charge limited operation, this voltage V_g causes the amplitude of the beam current I_b, represented by a curve 23 in FIG. 4C, to vary in phase with the acceleration voltage V_a such that there is low beam current for low beam voltage.

The significance of this shape of the beam current I_b relates to the proportion of the beam energy dissipated in window 5, which is greater for low than for high beam voltages. Consequently, by decreasing the beam current for low beam voltages the amount of energy lost in window 5 is decreased and overheating of window 5 is readily obviated. The beam current I_b should not be decreased to zero at low beam voltages since the resulting beam energies are very important in producing ionization near the surface of material 6 where, as is indicated by curve 17 in FIG. 3, there is insufficient ionization between the surface and a depth d_0. The ionization near the surface can be increased by allowing current to flow during the low voltage portions of the accelerating voltage V_a. However, this current must be compatible with permissible window heating. This current is obtained when the beam current I_b is in phase with the beam voltage V_a and has a shape similar to that of the voltage V_a. Then, when voltage V_a is at low magnitudes, at which there is danger of window overheating, the beam current I_b is at a low magnitude thereby avoiding window overheating. At higher voltages where there is less danger of window overheating, the beam current I_b is correspondingly larger.

In FIG. 5 we have illustrated the synthesis of the ionization curve 20 for a sine wave of beam current in phase with a sine wave of beam voltage of 3 megavolts maximum amplitude such as would be obtained using an in-phase sine wave biasing voltage, curve 22 of FIG. 4. The resultant curve 20 is obtained by adding the ordinates of curves 24, 25, 26 and 27, which represent the instantaneous ionization distributions occurring when the acceleration voltage sine wave has reached amplitudes of 3, 2, 1 and ½ megavolts, respectively. Actually curve 20 is taken to represent the curve obtained by summing the infinite number of ionization distributions occurring during each half cycle.

A different resultant distribution curve can be obtained by altering the relative beam current variation by controlling the shape of the bias voltage, V_g, which, in turn, changes the magnitude of the various curves 24, 25, 26 and 27. Thus, other shapes of ionization distribution can be obtained, but the illustrated one having the maximum amplitude near the material surface will be preferred in most applications. In many instances the sample of material will also be irradiated from the opposite side by a similar beam generator, or the material may be turned over, to provide for more uniform interior irradiation.

The voltage V_g can be produced electronically by, for example, a wave shaping or generating circuit energized in phase with V_a to produce V_g. Also V_g can be produced by the mechanical arrangement shown in FIG. 6 in which a synchronous motor 28 operates in synchronism with voltage V_a. Motor 28 has a shaft 29 to which a magnetic recording drum 30 is attached. Around approximately half of the periphery of drum 30 a magnetic signal is impressed having a magnitude corresponding to the magnitude of the voltage V_g such that when drum 30 is rotated past a magnetic transducer 31, this transducer 31 produces a signal corresponding to the wave V_g during the positive half cycle of voltage V_a, i.e. when electrons are emitted by filament 8. During the negative half cycles it need not produce a signal. The signal from transducer 31 is then amplified by an amplifier 32 and applied by leads 33 across terminal 10 thus supplying the bias voltage for grid electrode 9. It is noted that generator 29 and amplifier 31 operate at a high voltage level with respect to ground.

When electron beam 2 is deflected by electrostatic or electromagnetic deflection means (not shown), the rate of such deflection is desirably high in comparison to the frequency of V_a, the acceleration voltage.

It will be apparent to those skilled in the art that in the case of beam scanning, it is necessary, of course, to synchronize the deflection voltage and its magnitude with the beam voltage, V_a, so that deflection will be appropriate for the electron beam's energy.

In summary, an electron beam generator and a method of operation of this beam generator has been described for producing an ionization distribution within the thickness of an irradiated material, so that the ionization near the surface of this material is comparable with the maximum ionization below the surface. This is in contrast to a constant potential electron beam generator which produces an ionization distribution that is substantially less near the surface of the irradiated material than it is at some depths in the material.

The improved ionization distribution near the surface is obtained by varying the beam current in phase with the beam voltage such that the current is sufficiently low, at the low beam voltages, that destructive window heating is avoided. In this way the most ionization that is compatible with non-destructive window heating is obtained at the low beam voltages, which are the voltages that produce ionization near the surface of the irradiated material.

A sinusoidally shaped half-wave grid voltage is herein illustrated as occurring in phase with a similar acceleration voltage. It is understood these in-phase signals may assume other waveforms without departing from the present invention. Thus it should be understood that irradiation near the surface may be made greater than the interior in accordance with the present invention, for example, by selecting the proper wave shape for application to the grid electrode.

While the invention has been described with respect to certain specific embodiments, it will be appreciated by those skilled in the art that many other modifications and changes may be made by those skilled in the art without departing from the spirit of our invention. We intend, therefore, by the appended claims, to cover all such modifications and changes as fall within the true spirit and scope of our invention.

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

1. In an electron beam generator system for irradiating materials, an electron gun for producing an electron beam and including a grid electrode, an electron transmissive window separating said gun and said materials, means for applying a bias voltage to said grid electrode for producing space charge limited operation of said electron gun, means for accelerating said electron beam with a voltage whose magnitude varies as a function of time during substantially its entire period of operation, and means for applying a variable voltage to said grid electrode for causing the magnitude of the beam current to vary during substantially the same period and in proportion to the magnitude of said acceleration voltage.

2. In an electron beam generator system for irradiating material, an electron gun for producing an electron beam and including a grid electrode, a vacuum tight window between said electron gun and said material through which said electron beam passes, means for producing space charge limited operation of said electron gun, means for accelerating said electron beam with a voltage having substantially a sine wave shape, and means for applying a variable voltage to said grid electrode that causes the magnitude of the beam current to vary in accordance with a similar sine wave shape in phase with said voltage wave shape.

3. A method of operating an electron beam generator, having a grid electrode, to improve the uniformity of ionization within material that is impinged by an electron beam from the electron beam generator, comprising gradually varying the energy of said electron beam over a period of time, biasing the grid electrode to produce space charge limited operaiton of the electron beam generator, and applying a voltage to the gird electrode that causes the beam current to vary in magnitude substantially in proportion to the variations in the magnitude of the beam energy.

4. Apparatus for irradiating material comprising means for generating an electron beam directed to intercept said material, means for cyclically varying the energy of said electron beam, and means for simultaneously cyclically varying the electron beam current in phase with the cyclically varying energy to correspond in relative magnitude to the magnitude of said beam energy from near zero energy to near maximum energy.

5. Apparatus for irradiating material comprising means for generating an electron beam whose energy gradually assumes a plurality of different energy level values at different times during a given operating cycle, means for directing said beam at a material to be irradiated, and means for varying the beam current magnitude as the beam energy varies and in substantial proportion thereto, to produce selectably increased irradiation at the surface of said material relative to the interior thereof.

6. The method of irradiating material comprising generating an electron beam whose energy assumes a plurality of different energy level values at different times during an interval, directing said beam at a material to be irradiated, and varying the total radiation of said beam in relation to the energy thereof so that at said different times the current of said beam assumes values generally proportional to its energy, whereby the surface of the said material receives an amount of radiation comparable to the interior of said material.

7. The method of irradiating material comprising generating an electron beam, directing the beam at a material to be irradiated, gradually raising the energy of said beam from a lower value to a higher value and concurrently gradually raising the current represented by said beam from a lower value to a higher value.

8. In an electron beam generator system for irradiating material, an electron gun for producing an electron beam and including a grid electrode, an electron permeable window through which said electron beam is directed toward the material to be irradiated, means for accelerating said electron beam with a portion of an alternating voltage wave which varies as a function of time, and means for applying a variable bias voltage to said grid electrode which voltage is proportional to said alternating voltage wave and in phase therewith to cause the magnitude of the beam current to vary as said acceleration varies so that low values of beam acceleration will not subject said window to damaging radiation.

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RALPH G. NILSON, *Primary Examiner.*

ARTHUR GAUSS, *Examiner.*