United States Patent [19]

Veith

[11] **3,902,181**

[45] **Aug. 26, 1975**

[54] **REPRODUCING SYSTEM EMPLOYING AN ELECTRON TUBE AS A CHARGE RECORDING TUBE**

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[22] Filed: **Jan. 24, 1973**

[21] Appl. No.: **326,291**

[30] **Foreign Application Priority Data**

Jan. 28, 1972 Germany 2204077

[52] **U.S. Cl.**...... **346/74 EB;** 346/74 CR; 178/6.6 A

[51] **Int. Cl.**[2] **G01D 15/08**

[58] **Field of Search** .... 346/74 EB, 74 CR; 340/173 CR; 179/100.2 CR; 178/6.6 A

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[57] **ABSTRACT**

A reproduction system has an electron tube for generating a beam of electrons which are accelerated toward a semiconducting or insulating window provided in a wall of the tube. The window is coated on its inner side with a conducting layer, and an electric field is established between the conducting layer of the semiconductor and an outer electrode spaced from the window outside the tube. A gas discharge between the outer electrode and the window is controlled by the electron beam, to apply a charge to a paper web in the space between the window and the outer electrode.

18 Claims, 3 Drawing Figures

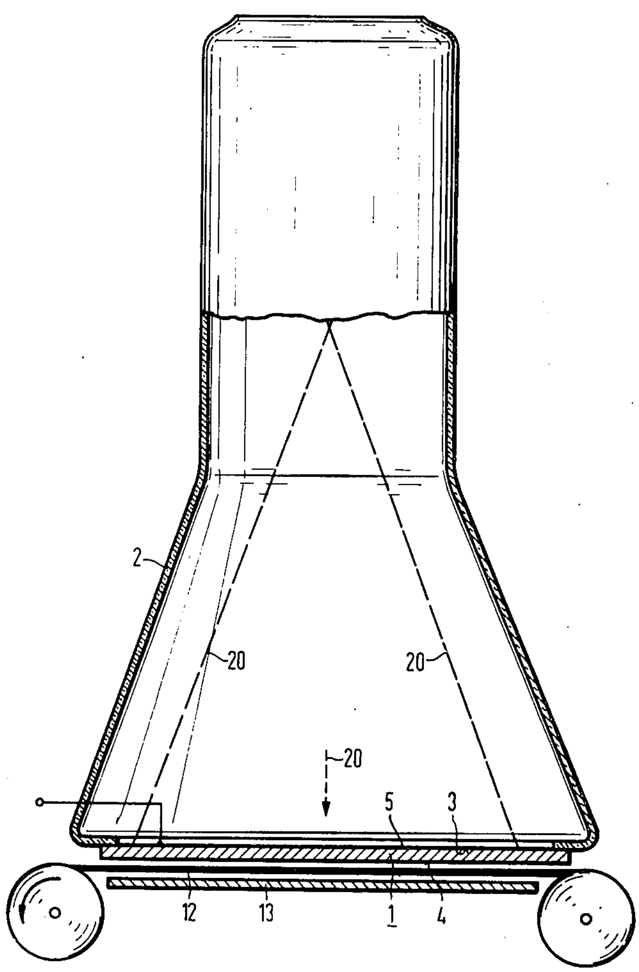


Fig.1

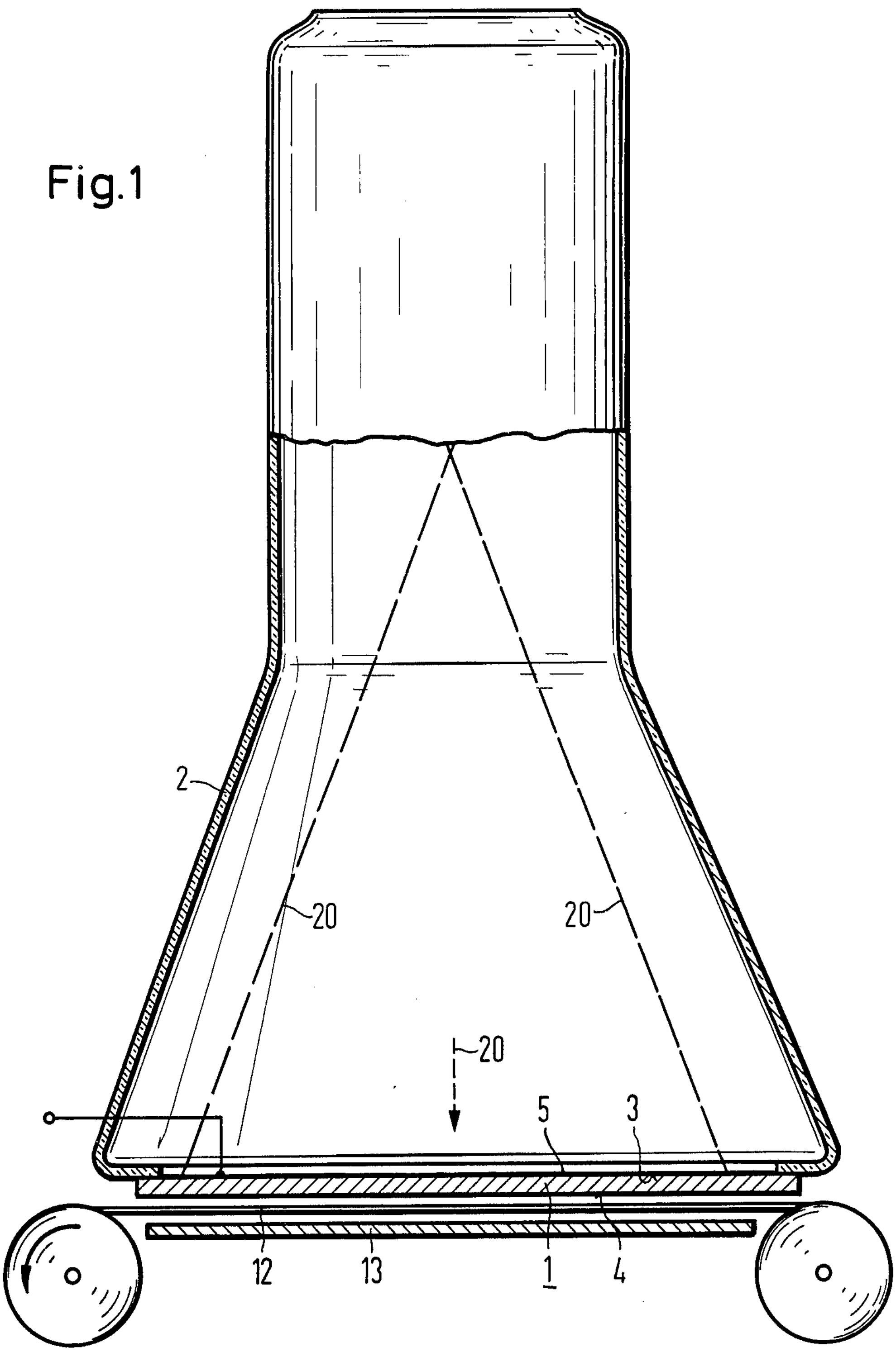


Fig.2

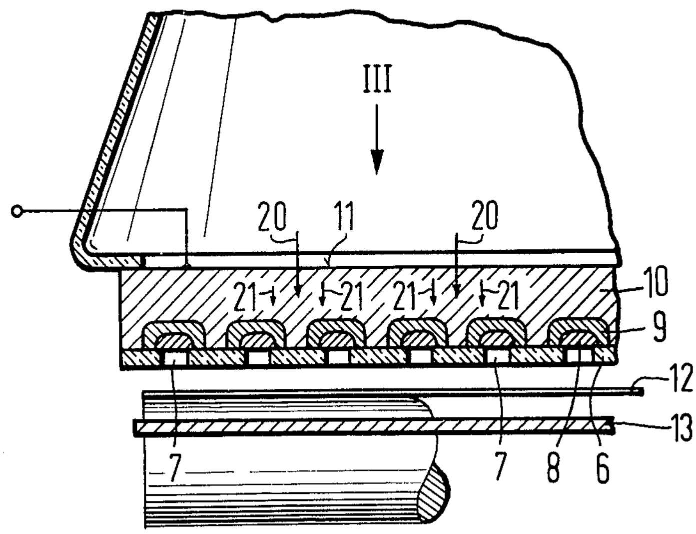
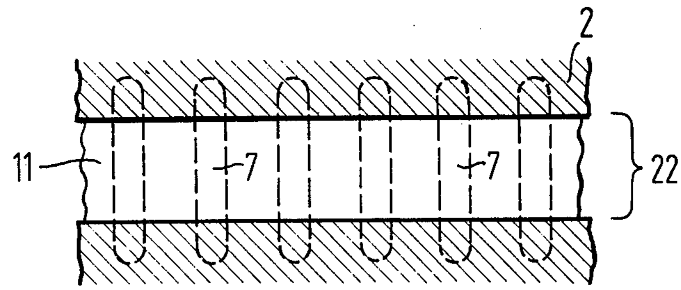


Fig.3



REPRODUCING SYSTEM EMPLOYING AN ELECTRON TUBE AS A CHARGE RECORDING TUBE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to recording apparatus and more particularly to apparatus employing an electron tube for producing a gas discharge to record a charge pattern on untreated paper.

2. The Prior Art

In the reproduction and copying of images corresponding to documents and pictures, the apparatus which is currently available is unsatisfactory in that a continuous tone reproduction is not produced. Photographic methods are successful in producing continuous tone pictures and the like, but their cost is relatively high.

Several attempts have been made to develop electron tubes for the purpose of making more adequate reproductions, and one such system employs a tube constructed along the lines of the so-called pin tube. A charge image is applied to one side of a plurality of pins extending through the insulating envelope of the tube, resulting in a potential distribution corresponding to the image on the exterior of the tube. The pins effect the charging of a paper web juxtaposed with the outer ends of the pins, in a pattern corresponding to the pins which receive the charge from the electron beam.

In another system, a tube with a Lenard window is employed, having a very thin metal or mica window, through which the electron beam may effectively reach the outside of the tube with substantially its entire energy. This electron beam can place a charge on the paper web directly.

Another system employs a so-called indirect window, which is constructed of a thin sheet of a heavy metal, applied on both sides of a normal window which is transparent to X-radiation. In operation, the electron beam, which is directed toward the inner sheet, is converted into X-rays which penetrate the main part of the window, and they are then absorbed in the outer sheet of heavy metal where they are converted into electrons which are employed to place a charge on the paper web.

In all of the systems referred to above it is not possible to obtain any amplification in the electron beam at the window. The number of the electrons made available to charge the web are relatively few, however, and a charge image can be formed on the web only by repetitive operation of the apparatus, or operation of the apparatus at an extremely low rate of speed.

Accordingly, it is desirable to provide a system whereby the number of electrons available to charge the web may be amplified, to more effectively produce an image on the web.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to provide a system for amplifying the electrons of an electron beam to form a charge image on a paper web.

Another object of the present invention is to provide such a system for use with apparatus for electrostatic copying of images onto an unprepared paper web, to obtain the direct continuous reproduction of such images.

These and other objects and advantages of the present invention will become manifest upon an inspection of the following description and the accompanying drawings.

In one embodiment of the present invention there is provided a window constructed in the manner of an indirect window, consisting essentially of a self-supporting sheet of insulating or semiconducting material, the inner surface of which is provided with a conductive layer, the insulating properties of the semiconducting sheet being sufficiently great that the positive charge applied thereto by a gas discharge is maintained for at least the time required to record an individual image.

The present invention is based on the recognition that when an insulator or a semiconducting sheet is bombarded by electrons the impinging electrons produce up to **1,000** or more charge carrier pairs for each impinging electron, depending upon its intrinsic energy. When an electric field is established across the thickness of the semiconducting sheet and across a space outside the semiconducting sheet, the field gradient in the space is insufficient to support a gas discharge. In response to the electron beam striking the inner surface of the semiconducting sheet the field gradient within the sheet is reduced and that in the space is raised to produce a gas discharge in the space, placing a charge pattern on a paper web within the space in accordance with the pattern formed on the sheet by the beam. It is not necessary for the paper web to contact the semiconducting sheet. As a result of the gas discharge, positive ions are produced which raise the potential at the exterior surface of the sheet, to quench the discharge. The resistivity of the sheet is great enough to maintain the positive potential on the surface of the sheet until the electron beam moves away from the location opposite the site of the gas discharge.

The amplifying effect of the semiconducting sheet, is producing multiple charge carrier pairs for each electron striking the sheet, greatly amplifies the charge applied to the paper web.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made to the accompanying drawings in which:

FIG. **1** is a schematic view of an electron tube incorporating an illustrative embodiment of the present invention;

FIG. **2** is a cross-section, on an enlarged scale, of the portion of the apparatus similar to that shown in FIG. **1**, but incorporating an alternative embodiment of the present invention; and

FIG. **3** is an enlarged view of a portion of the apparatus illustrated in FIG. **2**, as viewed in the direction **III**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** illustrates an electron tube **2** constructed in the manner of a cathode ray tube, and adapted to produce a relatively narrow electron beam **20** which is swept across the face of the tube **2** in a regular rectangular array by deflection means, in the manner well known to those skilled in the art. The face of the tube, illustrated in the lower portion of FIG. **1**, comprises a self-supporting sheet **3** formed of insulating material, or semiconducting material, and the inner surface of the sheet **3** is provided with a metalic conductive coating

5. The coating 5 is connected via a terminal 23 to an external source of negative voltage.

The outer surface 4 of the sheet 3 is exposed to the atmosphere, and a space 26 is defined between the sheet 3 and an outer electrode 13 spaced therefrom and formed of a sheet of conductive material oriented generally parallel to the sheet 3.

A paper web 12, supported between a supply roll 24 and a take-up roll 25, passes through the space 26 between the sheet 3 and the electrode 13. The electrode 13 is connected to a source of positive electric potential, in order to establish an electric field between the conductive layer 5 and the electrode 13. The gradient of this field is normally higher in the sheet 3 than in the space 26, because of the relatively high resistivity of the semiconducting material of which the sheet 3 is formed. Normally the outer surface 4 of the conductive sheet 3 becomes positively charged, and holds the field gradient in the space 26 below the level at which a gas discharge can occur.

The cathode ray tube 2 is operated by controlling the potential on the control grid in such a way as to cause the beam 20 to be modulated in intensity in accordance with the information desired to be reproduced or copied, as it scans the surface of the sheet 3. Alternatively, the tube 2 may be provided with a photo cathode exposed to light derived from the image to be reproduced by optical scanning of the image in synchronism with the scanning of the sheet 3 by the beam 20.

During operation of the tube 2, as the electrons in the beam 20 strike the inner surface of the sheet 3, they each produce a large number of charge carrier pairs. This process is known as the Ebic effect. The electrons produced thereby flow toward the outer surface 4 of the sheet 3, and lower the level of the positive charge present on the surface 4. In this way the potential difference across the space 26 increases, and a gas discharge is produced, which results in applying a charge to the paper 12. As the result of the gas discharge the surface 4 regains its positive charge, and thereby quenches the gas discharge almost immediately.

The resistivity of the sheet 3 is sufficiently high that the positive charges applied to the surface 4 as the result of the gas discharge are maintained for the time duration of the recording process of the individual image. This time duration is the interval required for the beam to move away from the location of the gas discharge. The charge carrier pairs recombine within the sheet 3, at a decay rate which is a constant of the material of which the window is formed. This rate is sufficiently rapid that the charge carrier pairs produced by the Ebic effect decay substantially to zero by the time required for the electron beam 20 to complete a cycle of its scanning.

When the semiconducting material of which the layer 3 is composed does not have a sufficiently high resistivity to maintain the outer surface 4 at a positive potential following the gas discharge, it is preferable to employ an alternative form of the present invention, which is illustrated in FIGS. 2 and 3.

FIG. 2 shows in cross section a portion of the apparatus provided at the face of a cathode ray tube 27. The semiconducting sheet 3 of the tube 2 is replaced by a sheet of p-conductive silicon substrate 10, and the sheet 10 has an inner surface 11 which is rendered conductive by means of a metalic coating or the like. This conductive layer is connected to a source of negative potential at a terminal 23, just as in FIG. 1. The outer surface of the sheet 10 is provided with a perforated insulating oxide coating 6 having apertures 7 which is preferably formed of SiO_2. Diodes 8 are formed at the locations of the apertures 7 by diffusing n-conductive material through the apertures 7, of the layer 10 in the vicinity of the opening 6 within small end material. Due to the depletion zones formed in the vicinity of the pn junctions 9, a high value of insulation is provided for each diode so that a potential difference up to approximately 2,000 volts can be maintained across the sheet 10 without substantial conduction.

Because of the potential difference between the inner layer of the sheet 10 and the outer electrode 13, the lower surface of the sheet 10 charges positive sufficiently to prevent a gas discharge in the space 26. The electrons of the electron beam 20, which is controlled in the same manner as the beam of the tube 2, produce charge carrier pairs, including electrons 21 which diffuse toward the outer surface of the sheet 10 and the result is an increase in the field gradient across the space 26. The increase in the gradient results in a gas discharge in the space 26, between one of the apertures 7 and the electrode 13, which discharge continues until the lower surface of the sheet 10 again becomes positively charged, thereby quenching the gas discharge.

The duration of the gas discharge during the recording process is extremely short, and its specific duration depends on the effective capacity of one of the diodes 8, and on the magnitude of the gas discharge current. The electron beam is aligned with one of the apertures 7 for only a relatively short time, which may be on the order of 10^{-6} to 10^{-7} seconds, and it is desirable to make the duration of the gas discharge approximately equal to the time interval during which the beam is aligned with a single diode 9 or aperture 7. Alternatively, the duration of the gas discharge is slightly longer than the interval during which the beam is aligned with a diode. The factors affecting the effective capacity of the diodes 9 and the magnitude of the gas discharge current are well known in the art, and therefore need not be described in detail.

Referring now to FIG. 3, a portion of the face of the tube 27 is shown, along with the upper surface 11 of the sheet 10. The shape of the window formed by the sheet 10 is preferably an elongate rectangle or slit, as shown in FIG. 3, and in one embodiment has a width 22 just sufficient to accommodate a single scanning line. The line preferably extends across the width of the paper web 12, so that movement of the web 12 from the supply roll 24 to the take-up roll 25 moves the window along the length of the web, scanning the entire surface thereof. The apertures 7 which are formed in the oxide coating 6 are illustrated in phantom form in FIG. 3, and are preferably longitudinal holes oriented in such a way as to have their major dimensions perpendicular to the width dimension 22. In one embodiment, the apertures 7 are approximately 0.006 mm in width, and a length which suffices to cover a gap with 22 of approximately .03 mm. The shape of the holes 7 illustrated in FIG. 3 is particularly advantageous for a narrow width 22 so that one line is recorded on the web 12 at a time. If, however, several lines are to be recorded simultaneously by means of the present invention, employing a wider window, a circular shape for the apertures 7 is more advantageous.

The apparatus illustrated in FIGS. 2 and 3 is more effective than the so-called pin tube described above, in that a more linear relation is obtained between the intensity of the gas discharge produced, and the intensity of the electron beam. The window of the present invention can be formed with the apertures 7 in a much more regular fashion, and with greater image resolution than can be achieved by the use of the pin tube construction. In addition, the outer surface of the present invention is entirely smooth in the embodiment of FIG. 1, and substantially smooth in the embodiments of FIGS. 2 and 3, being interrupted in the latter only by the apertures 7 in the oxide coating 6. As the coating 6 is only approximately 0.001 mm thick, it does not present the difficulties resulting from field inhomogeneities encountered with sharp and uneven pin edges.

It can be seen from the foregoing that by use of the present invention the quantity of electrons which are effective to produce the gas discharge are multiplied by action of the semiconductor sheet, and thus the amount of charge applied to the paper as a function of the intensity of the electron beam becomes much higher by a factor of 1,000 to 10,000 resulting in a much greater recording speed.

The semiconducting sheet 3 in the embodiment of FIG. 1 may be formed of any insulating or semiconducting material, including semiconductive glass material, providing that it has a sufficiently high resistivity in the dark state, i.e., when not exposed to the electron beam. The resistivity is preferably at least 10^{12} ohm cm, and may be formed of glass containing Te, As or Ge.

The sheet 10 in the embodiment of FIGS. 2 and 3 is preferably formed of silicon, doped with p-conductive material. Alternatively, a compound formed of elements from columns III and V of the periodic table, or even from columns II and VI, may be chosen, as long as the resistivity is sufficient.

The sheets 3 and 10 in the embodiments of FIGS. 1–3 are preferably formed so as to avoid the formation of so-called traps which are effective to capture, at least briefly, the charge carriers formed by the action of the electron beam. The number of traps is preferably as small as possible, and when traps are present in the material, they are such as to capture charge carriers for no longer than 10^{-9} seconds. Materials which have been found to be suitable are semiconductors with relatively large energy gaps. Examples of such semiconductors, with their energy gaps (where known) expressed in electron volts are: SiC (3.0), GaN (3.5), GaP (2.24), PbO, ZnO (3.2), ZnS (3.6) and ZnSe.

The sheets 3 and 10 formed with any of these semiconductor materials are formed in such a way that the compounds are as homopolar as possible, in order to permit the charge carriers to move easily within the sheet, through the part thereof which is not directly exposed to the electron beam.

The formation of a fixed space charge within the sheet, such as through the operation of traps and the like, is quite undesirable, as that interferes with the proper operation of the apparatus. When the material for the sheets 3 and 10 is selected in accordance with the desired characteristics discussed above, few charge carriers are found to form undesirable space charges, and those space charges that are formed decay during the scanning period before the electron beam returns to the same location on the sheet.

For some instances it is desirable to establish a potential gradient in the space 26 with an opposite polarity to that described above, with the terminal 23 connected to a positive source of potential and the electrode 13 connected to a negative source of potential. In such a case, an n-conductive semiconducting material such as n-conductive silicon is preferred. The thickness of the sheet forming the window in the present invention is selected to be approximately 0.03 mm to 0.15 mm. The construction of the remainder of the tubes 2 and 27 depends upon whether an optical pattern and photo cathode is used, or whether a succession of electric signals is used, to originate the image.

What is claimed is:

1. A method of producing a charge image on an untreated paper web employing a cathode ray tube having a window formed of insulating material having a conductive inner surface and having an electrode disposed on the inner surface of said window, comprising the steps of applying a potential difference between the conductive inner surface of said window and an outer electrode spaced from said window, to produce a potential gradient across said window and across the space between said window and said outer electrode, said field being normally below the value required to sustain a gas discharge, placing said web in said space, and scanning the inner surface of said window with an electron beam to reduce the potential gradient within said window and to cause a gas discharge in said space.

2. The method according to claim 1, including the step of moving said beam at a speed, relative to the time interval required by said gas discharge, so that said interval is approximately equal to the time that the electron beam remains upon an individual point of said window.

3. The method according to claim 1, including the step of moving said beam at a speed, relative to the time interval required by said gas discharge, so that said interval is slightly greater than the time that the electron beam remains upon an individual point of said window.

4. The method according to claim 1, including the step of repetitively scanning a line on the inner surface of said window at a speed, relative to the time interval required for the decay of charges produced within said window by said beam, so that said interval is less than the period of the repetitive scanning.

5. The method according to claim 1, including the step of advancing said paper web synchronously with said scanning.

6. In recording apparatus employing a cathode ray tube for controlling a gas discharge in a space adjacent to the exterior of a window in said tube for application of an electrostatic charge to a paper web, the combination comprising, a window disposed in the face of said tube in position to be scanned by an electron beam generated within said tube, said window being formed of a sheet of semiconducting material having a conductive inner surface, an outer electrode spaced from the exterior of said window, a paper web being disposed in the space between said window and said outer electrode, and means for establishing an electric field between said conductive inner surface and said outer electrode, the gradient of said field being normally below the value required to sustain a gas discharge, said sheet having a relatively large resistivity so that a charge applied to the exterior surface of said window by said gas

discharge is maintained there at least for the duration required to form a charge image on said paper web by said gas discharge.

7. Apparatus according to claim **6** wherein said window comprises a highly insulating semiconducting material with a resistivity of at least 10^{12} ohm centimeters, and is provided with a conductive coating on its inner surface.

8. Apparatus according to claim **7,** wherein said semiconducting material includes a component selected from the group containing Te, As and Ge.

9. Apparatus according to claim **6** wherein said window comprises a sheet of p-conductive silicon material, and including an oxide coating applied to the outer surface of said sheet, said oxide coating having a plurality of apertures therein, and a layer of n-conductive material applied to the outer surface of said sheet through each of said apertures.

10. Apparatus according to claim **9** wherein said window is elongate in form, and said apertures are elongate in form, having their major dimensions perpendicular to the major dimension of said window.

11. Apparatus according to claim **10** wherein said apertures are approximately **0.006** mm wide, and said window is approximately **0.030** mm wide.

12. Apparatus according to claim **9** wherein diodes are formed at the junctions of said p-conductive material and said n-conductive material, said diodes having a blocking voltage of at least **2,000** volts.

13. Apparatus according to claim **6,** wherein the thickness of said window is approximately **0.03** mm to **0.15** mm.

14. Apparatus according to claim **6,** including an outer electrode spaced from the outer surface of said window, and means for establishing a potential difference between the inner surface of said window and said outer electrode, whereby the potential gradient across the thickness of said window is normally sufficient to maintain the voltage gradient in the space between said window and said outer electrode below the level necessary to support a gas discharge.

15. Apparatus according to claim **14,** including means for connecting said inner surface to a source of negative potential and means connecting said outer electrode to a source of positive potential.

16. Apparatus according to claim **6,** wherein said window comprises a highly insulating semiconductor material having a relatively large energy gap.

17. Apparatus according to claim **16,** wherein said material has an energy gap of not less than **2.24** electron volts.

18. Apparatus according to claim **16,** wherein said material is selected from the group containing SiC GaN, GaP, PbO, ZnO, ZnS, and ZnSe.

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