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Muntz et al.

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[45] **Nov. 20, 1973**

[54] **RADIOGRAPHIC SYSTEM WITH XEROGRAPHIC PRINTING**

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[22] Filed: **June 12, 1972**

[21] Appl. No.: **261,927**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 217,394, Jan. 12, 1972, abandoned, which is a continuation-in-part of Ser. No. 143,984, May 17, 1971, abandoned.

[52] **U.S. Cl.** **250/315**, 250/231

[51] **Int. Cl.** **G03b 41/16**

[58] **Field of Search** ..... 250/65 R, 65 ZE

[56] **References Cited**

UNITED STATES PATENTS

3,526,767 9/1970 Roth ..... 250/65 ZE

Primary Examiner—Archie R. Borchelt
Assistant Examiner—C. E. Church
Attorney—Ford W. Harris, Jr. et al.

[57] **ABSTRACT**

A system for making X-ray pictures by producing an electrostatic image on a dielectric sheet suitable for development by powder xerographic techniques. A pair of electrodes with a gas filled gap therebetween, with the dielectric sheet positioned at the anode or cathode and with the X rays directed past the object to the gas for producing electrons in the gap. An arrangement for increasing the quantity of electrons (or positive ions) moving toward the anode (or cathode) normal to the dielectric sheet and for providing high resolution images by enhancing the production of electrons in the gap and moderating the energy of the electrons, with superatmospheric high Z gas in the gap.

22 Claims, 7 Drawing Figures

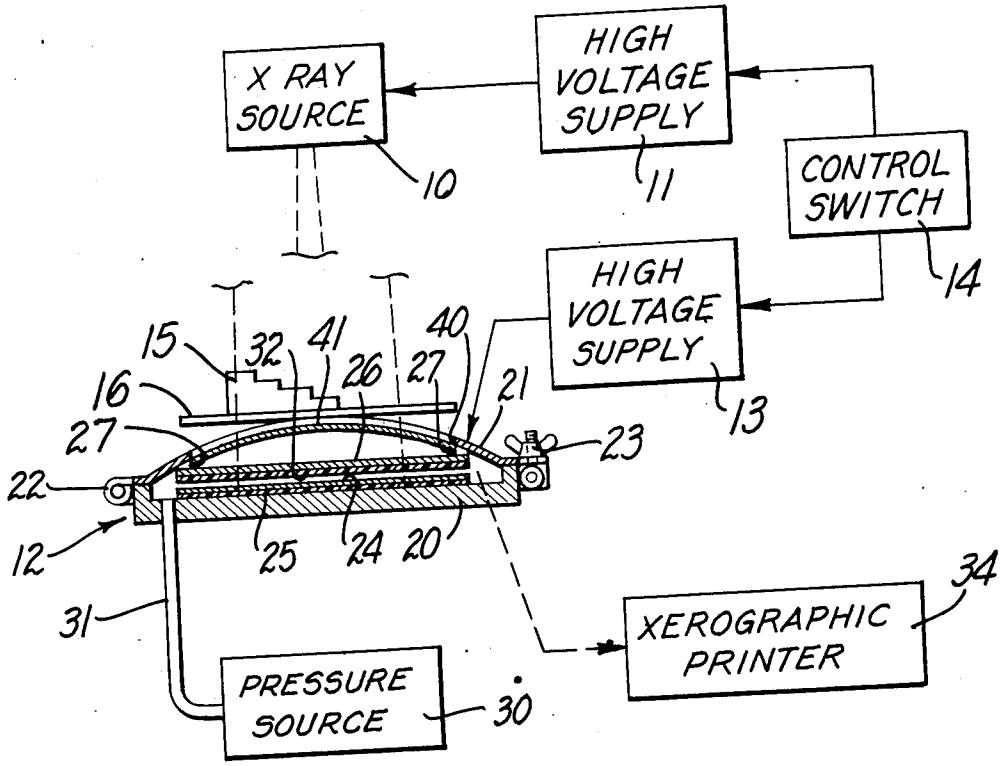


FIG. 1.

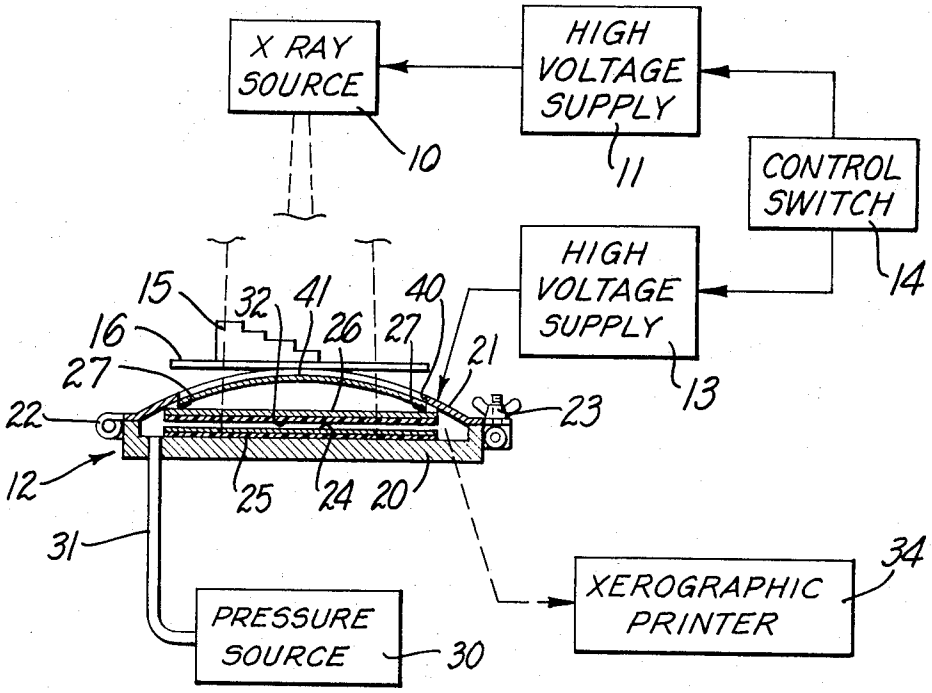


FIG. 2.

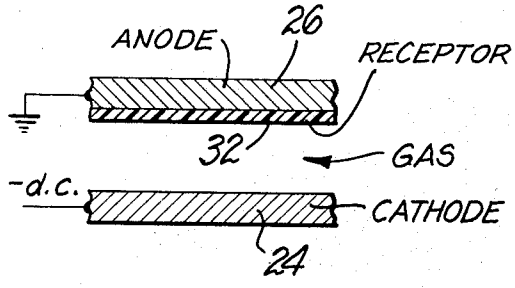


FIG. 3.

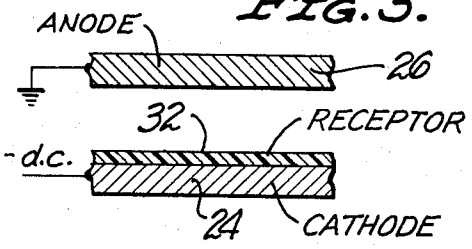


FIG. 4a.

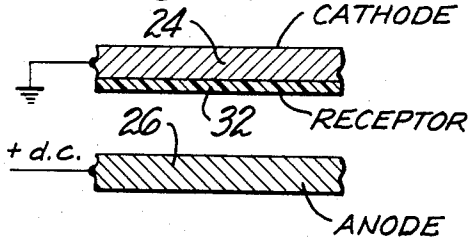


FIG. 4.

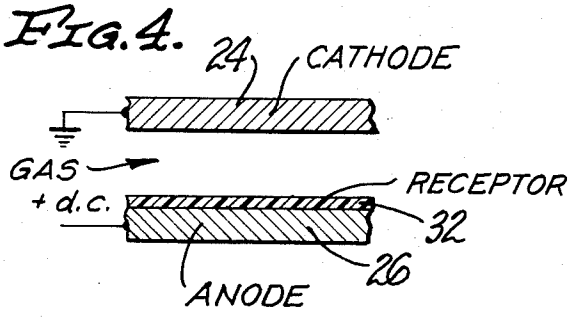


FIG. 5.

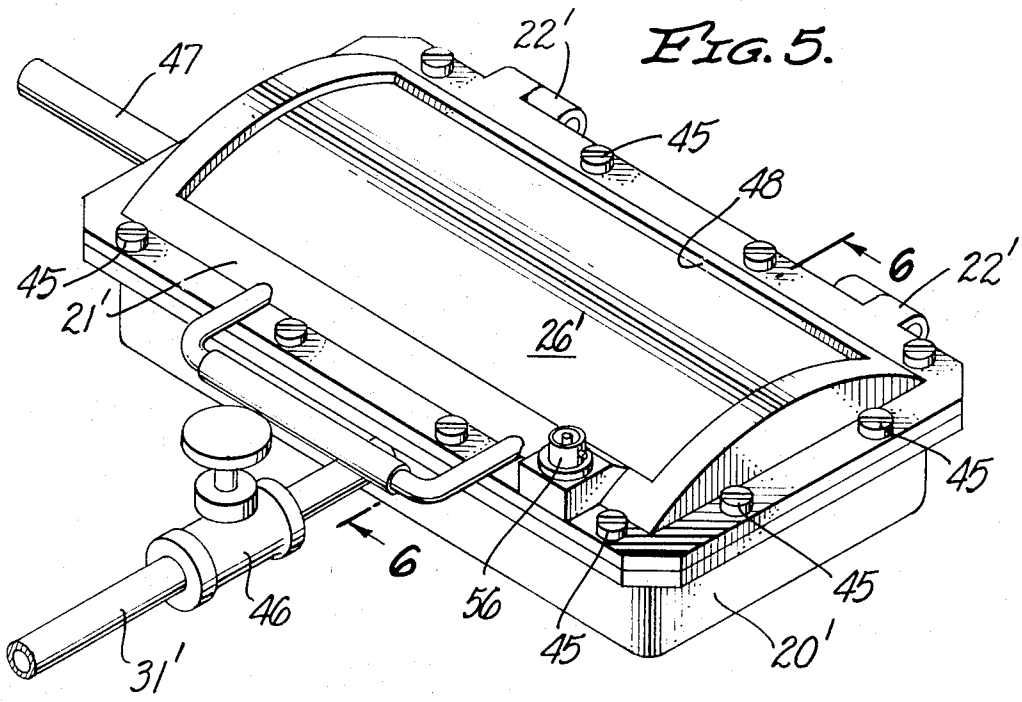
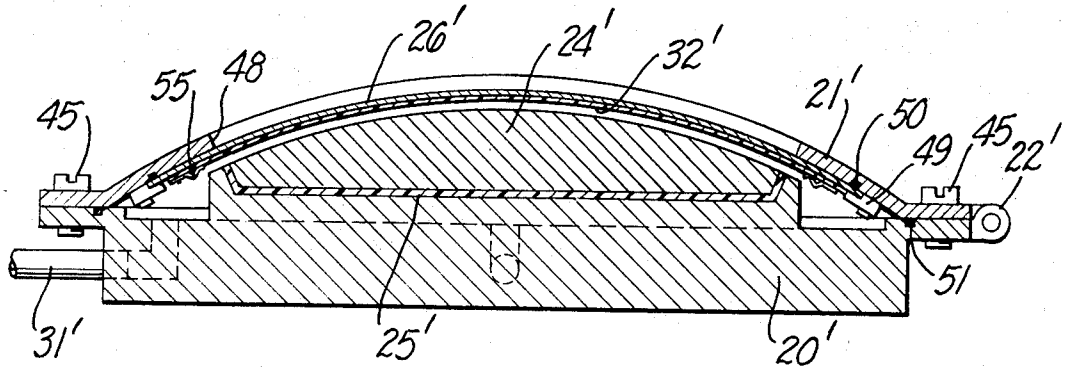


FIG. 6.



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RADIOGRAPHIC SYSTEM WITH XEROGRAPHIC PRINTING

This application is a continuation-in-part of copending application Ser. No. 217,394, filed Jan. 12, 1972, which is a continuation-in-part of application Ser. No. 143,984, filed May 17, 1971 both now abandoned.

This invention relates to radiographic systems providing images with an X-ray source producing electrons to form an electrostatic image suitable for printing, in place of photographic film. Conventional X-ray diagnostics of objects or tissue is performed by exposing appropriate silver halide emulsion film to X rays which have traversed the object to be diagnosed. The density variations in the object are translated into corresponding variations in the absorption of X rays traversing the various parts of the object, and consequently into corresponding variations of the exposure of the film. The "image" of the object is thus carried by the X rays in terms of a pattern of variable X-ray intensity. The film is the image receptor or imaging medium, in the case of conventional film radiography.

Film has some definite drawbacks as an image receptor. It is quite expensive, because of the high cost of silver, and its imaging properties are somewhat limited; it does not exhibit strong local contrast, so that small isolated absorption elements, such as minerals in soft tissue, are not readily detectible whereby X-ray diagonosis of breast cancer, for instance, is difficult; it is limited in sensitivity, particularly at high X-ray energies due to reduced quantum efficiency resulting from reduced absorption of X rays at the higher energies. Increases in sensitivity achieved by use of high quantum efficiency amplifying screens result in loss of resolution. Futhermore, film requires a wet development process and has a rather poor X-ray exposure latitude, with less than an order of magnitude between underexposure and overexposure dosages.

Alternative systems have been proposed or developed wherein the photographic film image is replaced by a charge image produced on an insulating or photoconducting surface, which functions as an image receptor, or wherein a discharge is produced which excites a sensitive surface, resulting in a visible detection of the X-ray flux.

In xeroradiography, such as is disclosed in U.S. Pat. No. 2,666,144 to Schaeffert et al., an electrostatic image is formed by exposure of a precharged photoconductive plate (e.g., selenium) to the X-ray "image" of a test subject, thereby producing conductivity in the photoconductor which is greater, the greater the incident X-ray flux, and thus draining off the original charge roughly in proportion to the X-ray flux and thereby producing an electrostatic charge depletion image on the photoconductor, which can then be developed and transferred to a suitable plastic or paper material as in ordinary xerography.

In a process called ionography, as described for instance in U.S. Pat. No. 2,900,515 to Criscuolo et al., the photoconductive material of xeroradiography is essentially replaced by an air or other gas gap, an insulating layer which is photoinsensitive is initially charged, and a wire mesh electrode is placed between it and the object to be radiographed. The X rays, after being differentially absorbed by the object to be radiographed, produce differential ionization of the gas gap between

the wire mesh electrode and the insulator, thereby providing differential conductivity in the gas which allows the charge on the insulator to drain off, differentially, from the insulator, thereby producing an electrostatic image, which can then be developed by xerographic printing or other means.

In another process described in U.S. Pat. No. 2,692,948 to Lion, an ionizable gas or other medium is also used, but in a different manner; no initial charging of an insulator or photo-conductor is used. A pair of plane electrodes, or a plane electrode facing a multiplicity of sharp needle like electrodes, is used. The image receptor, which is mounted on the plane receptor electrode, is separated from the facing electrode by a gas filled or liquid filled region which is the ionizable medium. The receptor may be a photographic film, a luminescent screen, a discharge sensitive paper or plate, or any similar discharge-responsive device.

A voltage or potential difference, just insufficient to cause breakdown in the ionizable medium is impressed between the electrode pair. When ionizing radiations, such as X rays, strike the ionzable medium, they trigger a discharge between the electrodes by providing the initial ionization required to initiate discharge. The film will respond to the discharge thus triggered by the radiations. The process disclosed in Lion thus detects X rays by having them serve as a trigger for a gas breakdown discharge. The type of image generated is of a 'half-tone' nature, in the sense that the intensity of the incident X rays is reflected in the number of discharge spots per unit area.

In still another system, (sometimes also referred to as ionography), which is described by K. H. Reiss, Zeitschrift fur Angewandte Physik, Vol. 19, page 1, Feb. 19, 1965, use is made of an arrangement of a pair of electrodes with a potential difference applied between them and with an intervening gas filled gap. A dielectric sheet is mounted on the anode, and the cathode is made of, or coated with a heavy electron absorbing metal, such as lead. A typical gap width or interelectrode spacing is 0.5 mm, with the gas at atmospheric pressure in the gap, giving a gap width-pressure product in the order of one/half. In operation, the differentially absorbed X-ray flux incident on the anode traverss the anode (made of a substance transparent to X rays, such as aluminum or beryllium), traverses the gas with very little attenuation, and impinges on the cathode, which acts as a photoemitter, emitting a current into the gas, the current density emitted from a given area being proportional to the incident X-ray flux density. The gas in the gap acts as a gaseous amplifier, the initial current being amplified by electron multiplication and avalanche in the presence of an accelerating potential difference. In this manner the initial photoelectric emission current from the cathode is magnified considerably, by as much as six orders of magnitude or possibly more.

The lead or other heavy metal or metal coating of the cathode, upon absorbing X rays, emits both primary photoelectrons (ejected from the tightly bound K or L or M shells) as well as secondary electrons caused by the ionizing effects of the primary electrons within the metal.

The primary electrons have high energy, typically tens of thousands of electron volts, and they create many secondary electrons within the cathode, and thereby lose their energy. Most of the primary elec-

trons lose so much energy in the process of secondary ionization that they are trapped inside the cathode. A very few primaries lose only a small amount of energy and are emitted into the gas filled gap between the cathode and anode (the gas being, for instance, argon with 10 percent ether, or a 50—50 freon propane mixture at atmospheric pressure). The secondary electrons created in the emitter material by the primaries are also mostly unable to exit from the emitter surface. Some secondaries, namely some of those created very close to the surface of the emitter, do exit into the gas.

The behavior of the primary and secondary eletrons in the gas gap is quite different. The high energy primaries traverse the gas without significant energy loss, and create a trail of ion pairs in the gas. The electrons created in this process are then drawn to the collecting anode, and the Reiss device is operated with a sufficiently high voltage across the gap that they produce an electron avalanche, so that the gas acts as an electron amplifier. The electrons generated in the gas by ion pair formation from the primary photoelectrons are not useful for imaging purposes because they are created in the gap over distances comparable to or greater than the gas gap width (depending on the angle of emergence of the generating primary), and therefore lead to image diffusion. The primary electrons are therefore a source of background fog, in effect.

The secondary electrons, with energies below about 100 electron volts, have an extremely short means free path in the gas, much less than the gap width and attain energies comparable to the ionization energy of the atoms or molecules of the amplifier gas in a few collisions. They may produce a few ion pairs, depending on their energy, and they then participate in the electron avalanche process which leads to the high gain behavior of the gas gap. The useful image is created by collection on the dielectric receptor of those secondary electrons and of the electrons created by those secondaries in the avalanche process, and the resultant image resolution is limited by lateral diffusion of those electrons, which is much less than a gap width.

In the Reiss system, the gas in the gap absorbs a negligible fraction of the incident X-ray flux, by reason of the low absorptivity of the gases used, and by virtue of the near atmospheric pressure in the gas gap. The source of electrons in the Reiss system is thus the cathode, and the gas serves only as an avalanche electron multiplier. The arriving electrons are stored on the nonconducting surface of the dielectric sheet at the anode. If some of the X rays are absorbed in an object between the X-ray source and the emitter, such as for example a metal casting or a portion of the human body, then the charge build-up on the surface of the dielectric sheet varies with position and forms an electrostatic image of the object being "x-rayed." This image may be made visible by powder development techniques similar to those used in xerographic copier machines.

After the image of the dielectric sheet has been fixed, the X-ray image may be read and stored in a similar way to a silver halide film. A major advantage of the Reiss method is the low cost of the materials and the comparative ease of one-setp machine processing of the image as compared to the cost of silver halide film and the problems of film development.

The limitations of the Reiss system incude: (i) low X-ray sensitivity because of the low escape probability of the electrons generated in the photoemissive cathode, and the consequent poor photoelectric quantum efficiency; (ii) very stringent electrode parallelism requirements, due to the need for operating the device at very high values of grain the gap; and (iii) rapid 'saturation' of the image, due to buildup of retarding electric fields in regions of high charge density on the deielectric receptor, leading to drastic reduction of device 'gain' in those regions, and therefore, to limited contrast. This last limitation is due first, to the need to operate the Reiss device at very large values of gain, which is quite sensitive to electric field strength, and second, to the fact that the accelerating potentials in the device, operated at atmospheric or subatmospheric pressures, are relatively low (approximately one thousand volts or less) so that the retarding potentials represent a significant fraction of the initial potentials. By far the most serious limiatation of the Reiss device in terms of its usefulness for medical diagnostic X-ray application, is its low sensitivity, which in turn is directly related to the very poor photoelectric true quantum efficiency of all solid materials.

U.S. Pat. No. 3,526,767 to Roth et al. describes means for overcoming the image saturation limitation (item iii) by use of compensating charges. They describe no means for increasing significantly the main limitation of the device, i.e., its poor quantum efficiency. The system of the present invention overcomes all of the above limitations of the Reiss system.

The term quantum efficiency is defined as the fraction of X-ray photons absorbed by a device which lead to a detectable event, such as an electron avalanche or a gas breakdown discharge. A low quantium efficiency will lead to large quantum fluctuations, regardless of the means used to detect or amplify the signals produced by the samll fraction of effective absorbed incident photons. Thus, for instance, in the device of the Lion patent, any X-ray photon absorbed in the gas gap produces a large signal (a discharge), but the fluctuations in the number of absorbed X-ray photons will lead to large relative fluctuations (quantum noise) which severely limits the sensitivity of the device as an imaging device.

While the prior art devices and processes differ in many respects, they are all alike in one respect, namely that they all exhibit very poor quantum efficiency, particularly with respect to X rays with energies in the range of 30 to 100 keV which are most important for the bulk of medical X-ray diagnoistic applications. In most of the devices, the quantum efficiency is poor (of order 1 percent or less) because the X-ray detecting medium absorbs only a small fraction of the incident X-ray photons. In the Reiss sytem, the effective quantum efficiency is low even though the X-ray photons are essentially all absorbed, because the fraction of absorbed X-ray photons whch lead to a detectable event (electron avalanche in the gap) is quite small, because most electrons created are trapped within the photocathode.

In contrast, the quantum efficiency of film with intensifying screens is around 20 to 40 percent. Thus, any device competing with film for medical diagnostics where dosages are kept as low as the quantum efficiency of the detector (film/screen) permits, must achieve comparable quantum efficiency.

Accordingly, it is an object of the invention to provide a new and improved electroradiographic system for making X-ray pictures, which system eliminates the

requirements of film and photoconductor plates, and which provides equal or superior quantium efficiency and sensitivity, improved resolution and contrast latitude of the resultant print. A further object is to provide such a system wherein the contrast of the image can be controlled to provide a very high local contrast or to provide a contrast similar to that obtained with present day film, depending upon the parameters selected in the development process.

These highly desirable results are obtained with the electroradiographic system of the present invention by discarding the emitting cathode of the Reiss system as a source of elections and replacing it by an x-ray-opaque gas in the gap which also exhibits a very short stopping distance for the resulting photoelectrons produced therein. This is done by resorting to a high atomic number gas, typically Krypton or Xenon, as the main component of the interelectrode gas, and by using sufficiently high pressure of the gas in the gap to assure complete or very substantial absorption of the incident X rays within the gap, as well as a very short means free path for the electrons. Thus, the problem of the low probability of escape of electrons from the solid emitter into the gas, which leads to very low photoelectric quantum efficiencies of the emitter, and therefore to low sensitivity of the device, is completely overcome, since the electrons are directly generated in the gas itself. The primary object of the gas gap is thus as an X-ray absorber, and the primary selection criteria for the gas are thus maximum opacity to X-rays, not discharge behavior. Indeed, because of the increased quantum efficiency, and thus the greater number of initial primary electrons, it becomes unnecessary and indeed undesirable, to operate the gas in the avalanche regime, and the only purpose of the accelerating potential is to insure full collection of the secondary ionization electron current.

When the gas pressure exceeds one or a very few atmospheres and/or the product pd of pressure times gap spacing exceeds 10 millimeter-atmospheres, the electron multiplication, avalanche and breakdown behavior of the gas becomes very unfavorable with respect to achieving high electron current gain. Thus, at low pressures and low values of pd, the device can be readily operated in an avalanche region (i.e., where the field induces additional ionization by imparting sufficient energy to electrons between collisions with gas molecules), and thus at gain values due to avalanche of up to 10^4 or perhaps higher without inducing undesired localized, voltage induced spontaneous breakdown. By contrast, at the higher pressures and pd values, the gas begins to exhibit unacceptably frequent localized discharges which obliterate the image in their vicinity, whenever one attempts to operate in the avalanche gain region of applied voltage. One should confine the impressed voltage to the so-called plateau region of the Townsend curve where essentially all the intial photoelectrons and those created by ion-pair formation by the energetic primary photoelectrons are collected, but no additional field induced electron ion-pairs are created. In the palteau regin, the collected current increases very little with increasing voltage, in contrat with the avalanche region where the collected current increases very sharply with increased voltage.

One beneficial side effect of operating in the plateau region is that the image formation is insensitive to charge buildup on the receptor, since any resultant counter voltage built up on the latter has little if any effect on the arriving current. No suppression of the induced voltage is thus needed. In addition, the total collected charge per unit area per unit of X-ray exposure is considerably less in operation of the device of the present invention than it is in the device as operated by Reiss or by Roth et al., so that the induced voltage on the receptor is quite small in any event. In fact, it must pointed out that the total current density, and the total number of electrons per unit area collected in normal operation of the Reiss system are greater than the corresponding current density and total number of electrons collected in the system of the present invention. However, as stated previously, it is not how much the initial effect of an absorbed X ray is amplified, but the total fraction of X rays absorbed and which lead to an observable event, that determines the device sensitivity. In other words, the effective quantum efficiency, not the subsequent gain, determines the device sensitivity. In electrical engineering parlance, the noise of the 'front end' preamplifier determinse sensitivity, and no amount of amplification behind the front end can improve sensitivity or shot-noise limited signal to noise.

Further, the high Z gas, at high pressure, results in very short mean free paths of the electrons in the gas, thus improving the resolution of the system. Beyond a certain pressure in the gap, the gains in X-ray absorption become minimal, as one approaches 100 percent absorption, while the difficulty of containing the high pressure gas becomes increasingly great. Accordingly, there is a limited range of pressures which is favorable for the purposes of the invention. Similarly, because of the shortened electron means free path, the interelectrode gap spacing may be increased to the values required for total or substantial X-ray absorption without significant loss of resolution (which would occur in the Reiss system), since electron diffusion is sharply curtailed in high pressure Krytpon or Argon. However, beyond a certain point, the X rays themselves, traversing the gap at some angle to the normal line to the planes of the electrodes, will eventually cause a diffuse primary electron path, and this limits the maximum useful gap width, together with the fact that beyond a certain gas thickness, little is gained in terms of added X-ray absorption with added thickness. The operating range of the device best suited for the relatively low X-ray dosages acceptable in medical practice, expressed in terms of the product of gas pressure times gap width (X-ray absoprtion efficiency depending only on this product and not on each factor separately), ranges between about 10 mm atmospheres and about 200 mm atmospheres. The more preferred range is about 20 to about 80 mm atmospheres. Satisfactory images are obtained today with film type X-ray systems at exposures producing a few milliroentgen at the film cassette. The system of the present invention will produce images of equal quality for this level of exposure.

The gas in the gap is chosen for high absorption of X rays per atom or molecule, high scattering cross-section for electrons (per atom), and low values of energy lost per ionization. The suitable gases are those of high Z, i.e., atomic numbers of at least 36, and preferably are Krypton and Xenon, possibily with minor components of up to 10 percent of some quenchant gas such as methane to avoid undesirable random discharges which can occur whenever an accelerating po-

tential (required to insure full collection of the secondary electrons created in the gas) is applied.

Other objects, advantages, features and results will more fully appear in the course of the following description. The drawings merely show and the description merely describes preferred embodiments of the present invention which are given by way of illustration or example.

In the drawings:

FIG. 1 is a diagrammatic illustration of an electroradiographic system incorporating the presently preferred embodiment of the invention;

FIG. 2 is an enlarged view of a portion of the electrode structure of the system of FIG. 1;

FIGS. 3, 4 and 4*a* are views similar to that of FIG. 2 showing alternative electrode and receptor arrangements;

FIG. 5 is a perspective view of an electrode unit showing an alternative embodiment of the invention; and

FIG. 6 is an enlarged sectional view taken along the line 6—6 of FIG. 5.

The electroradiographic system of FIG. 1 includes a conventional X-ray source **10**, a high voltage electrical power supply **11** for the source **10**, an electrode unit **12**, another high voltage electrical power supply **13** for the electrode unit, and a control switch **14** for actuating the supplies **11, 13.**

In a typical arrangement, the object **15** being "X-rayed" is supported on a table **16** of sheet plastic or other material exhibiting low X-ray attenuation, directly above the electrode unit **12**, with the X-ray source **10** spaced from the object, typically in the order of 3 feet.

The electrode unit **12** includes a closed container with a base **20** and a cover **21** which may be hinged to the base at **22** and clamped at **23.** A cathode **24** is carried on the base **20** and is electrically insulated from the base by an insulating sheet **25.** An anode **26** is carried on the cover **21** on brackets **27.** A seal (not shown) is provided between the base and cover so that a superatmospheric pressure can be maintained within the container of the electrode unit, and a pressure source **30** is connected to the interior of the container via a line **31.**

A receptor **32** for the electron charge image, which may be a dielectric sheet such as a flexible plastic, typically Mylar, is removably mounted at the anode. In operation, the cover **21** is opened, the receptor sheet is positioned on the anode, being held in place by conventional clips (not shown) or other suitable means, the cover is closed, and the electrode unit is placed in position for exposure. After the electron image is formed on the receptor, as will be described below, the cover is opened and the receptor is transferred to a xerographic printer **34** for producing the powder image in the conventional manner. In order to maintain the electron charge on the dielectric receptor, a site must be provided for the mirror charges if the receptor is moved from the anode. This may be accomplished by suistituting another conducting plate for the anode, or by providing a conducting layer in or on the receptor or by using a volatile conducting liquid such as alcohol to adhere the receptor to the anode.

An X-ray absorber and electron and positive ion emitter is positioned in the gap between the anode and cathode. The electron and/or ion output produces the charge image on the dielectric receptor, being attracted to the respective electrodes by the electric field between the electrodes. The absorber and emitter in the gap is an X-ray opaque, high Z gas at superatmospheric pressure. The high Z gas should have an atomic number of at least 36 and preferred gases are Xenon and Krypton. A small amount of a quenching gas may be used with the high Z gas, such as 10 percent of methane.

In the preferred electrode arrangement of FIG. 2, the anode **26** is a thin sheet of a light metal, such as aluminum, magnesium or beryllium, or of carbon, such as a carbon fiber sheet, having low X-ray absorption. Typically the anode may be in the order of one/half mm. thick. The cathode **24** is a sheet or block of any electrical conductor, typically a low or medium atomic number material such as steel or aluminum, since the gap gas itself is used as the medium for absorbing X rays and emitting electrons. The gap for spacing between the electrodes is relatively small and typically may be in the order of one/fourth mm. to 5 mm.

The gas in the gap is maintained under a superatmospheric pressure, typically at least 10 atmospheres or higher. The system can be operated with pressures as low as 75 psig, but the X-ray dosage required is normally too high for medical usage, and the resolution is degraded. The preferred range for the pressure in the gap is about 150 psig to about 1,500 psig. The pressure desirably is function of the gap width, and as set out above, the product of gap width and pressure is preferably between about 10 mm atmospheres and about 200 mm atmospheres. The applied voltage is preferably at least a thousand volts and, with higher gas presures, the voltage across the electrodes can be made higher. By way of example with a gas pressure of 75 psig the electrode voltage may be in the range of 2,000 to 3,000 volts, and at 300 psig the voltage may be 4,000 to 8,000 volts. An electrode voltage as low as 1,000 volts is suitable for some applications, but there is less collected current and the image is weak, calling for higher X-ray dosage for an improved image.

In operation, a photon from the X-ray source passes through the anode and is absorbed by the gas in the gap, causing photoelectron emission from the gas atoms in the interelectrode space. The primary photelectrons produce secondary ion-electron pairs. The secondary electrons move toward the anode under the influence of the electric field, and the ions move towards the cathode. A charge image can be formed on a dielectric receptor on either electrode by the arriving electrons or ions. In the present system the nature of the gas and the gas pressure are such that the capture probability of an X-ray photon in the energy range of importance in medical diagnostics is of order unity, and the system quantum efficiency is of order unity (typically 50 percent).

In operation, the X rays produced by the X-ray source **10**, after traversing the object **15** and being differentially attenuated, impinge on the unit **12.** The X rays will traverse the electrode **21** and the insulating receptor **32**, with small (and in any event uniform) attenuation. The gas in the gap emits a current of electrons in proportion to the X-ray intensity and the receptor thus receives a charge density, which is an 'image' of the object **15** as seen by the X rays. Hence, a heavily absorbing portion of the object will produce a relatively low X-ray intensity at the corresponding image point in

the gas gap, and this current of electrons will produce a relatively lower charge density at the corresponding image point on the image receptor **32**, whereas a weakly absorbing point will induce a large current from the gap and a higher charge density at the corresponding point on the crecptor. The passage of the current to the insulating photoreceptor is aided by a potential difference of one to several thousand volts applied between the cathode and the anode by the power supply.

The gas filled interelectrode gap serves several purposes: (i) when a high Z gas such as Krypton and Xenon at high pressure is used, (e.g., at 300 psig for a typical gap) and for X-ray energies used in medical diagnostics, the gas will absorb a significant fraction (20 percent to 100 percent) of the X rays to produce photoelectrons. The choice of cathode material is unimportant insofar as affecting the sensitivity of the device. Any conductor, even one coated with an insulator will then do as a cathode. X rays incident on gas atmos result in the ejection of photolectrons, at angles ranging from zero to π (relative to the X-ray beam direction) and at energies typically of tens of kilovolts. (ii) The gas will amplify the electron current which flows from cathode to anode, due to secondary ionization produced in the gas, by a factor approximately equal to the ratio of primary electrons and the diffusion of the secondary electrons and ions so that electrons produced by a photoelectric absorption event at a point in the gas will tend to reach the insulating image receptor at points in the immediate neighborhood of one another, hence, improving the resolution and sharpness of the image. (iii) The gas reduces the electron energies so that electrons arriving at the receptor will attach to the surface rather than bounce off or penetrate too far into the receptor lattice, or produce undesirable secondary emission.

The requirements of increased sensitivity, (due to strong X-ray absorption in the gas) and of gaseous electron multiplication (due to high numbers of intervening molecules) could be achieved by increasing the gap width, i.e., the interelectrode spacing. The requirement of high resolution (through short electron energy loss range) cannot be met by increasing the gap width. Hence, the use of a dense high Z superatompspheric gas is an essential feature, since spreading of the electron image grows approximately linearly with gap width for the energetic primary electrons and approximately as the square root of gap for the slow "diffusing" secondary electrons.

It has been shown that the use of a high Z gas and of sufficiently high pressure (ten atmospheres or more) in the gas gap can achieve high quantum efficiency and attendant high sensitivity at least equal to that of films with intensifying screens, without resulting in loss of resolution and will then result in tremendously improved sensitivity and resolution over atmospheric pressure gaps filled with relatively low Z gases. Some of the improved resolution can be traded away for increased abosption by increasing the gas gap, e.g., for very high energy X-rays, because at high pressure all electrons become moderated to low energy in a very short distance and thereafter spread only diffusively, i.e., as the square root of the gas gap. (Gaps as large as 1 cm have been used to produce images with adequate resolution, of a few line pairs per millimeter.)

In the embodiment described above, at least the anode must be quite thin so as to have minimum X-ray absorption. Also, the electrodes should be relatively large in area to provide a usable final image and typically may be up to 40 cm. or more in width and length. The gap between the electrodes is quite small and should be maintained resonably constant. This raises a problem with operation at superatmospheric pressures and the electrode unit as shown in FIG. **1** provides a solution whereby the gas pressure in the gap and the gas pressure above the anode are the same. With this construction, the base **20** and cover **21** of the container carry the pressure and there is no pressure loading on the electrodes.

Since the X rays must penetrate the cover, the cover should be a thin walled structure and the curved shell as illustrated in FIG. **1** is the preferred arrangement for resisting pressure without warping or buckling. The entire cover **21** may be a thin sheet of a light metal, or a window **40** may be provided in a thicker cover and covered with a thin sheet **41.** As an example, a 40 × 40 cm pair of electrodes can be accommodated in a container with a thin walled beryllium cover of thickness 0.4 cm and radius of curvature 300 cm, with an absorption for typical X rays of 30 kev energy of less than 4 percent. The overall thickness of the container would be in the order of 2.5 cm.

As previously stated, an elecrostatic charge image can be formed on the receptor by positive ions as well as by electrons. The embodiment illustrated in FIG. **3** may be the same as that of FIGS. **1** and **2,** except that the receptor sheet **32** is positioned on the cathode **24.** The operation of the system of FIG. **3** may be the same as for the system of FIGS. **1** and **2.**

An alternative electrode arrangement which may be utilized but which is not presently preferred is shown in FIG. **4** where the elements corresponding to those of FIG. **2** are identified by the same reference numerals. With this constuction, the incoming X rays pass through the cathode and generate electrons in the gap between the electrodes, with the electrons being attracted to the anode. The cathode **24** may be similar to the anode **26** of FIG. **2,** i.e., a thin sheet of a light metal or carbon having low X-ray absoprtion, while the anode of FIG. **4** may be a sheet or block of any electrical conductor, such as steel or aluminum. Positive ions may be used in the electrode arrangement of FIG. **4,** with the receptor **32** on the cathode **24,** as shown in FIG. **4***a*.

In operation, the high voltage may be supplied to the electrodes continuously and a picture produced when the X-ray source **10** is energized from the high voltage supply **11.** A relatively high interelectrode potential is used during the X-ray exposure. However, when the electrode unit has the voltage applied thereto for a period of time, breakdown does occur from time to time producing undesirable spots on the finished picture. Accordingly, the control switch **14** is utilized to turn on the high voltage supply to the electrodes at the same time the high voltage supply is turned on to the X-ray source so that the electrodes are energized only for a short period of time. In an alternative arrangement, the electrodes may be maintained at a potential below the desired operating potential, typically 10 percent below, with the operating voltage being raised to the desired value by actuation of the control switch. By way of example, the electrode gap and the gas in the gap and the gas pressure may be selected such that the desired electrode potential is 5,000 volts which produces the de-

sired operation and also has a tendency to produce the undesired breakdown in the gap. The voltage supply 13 is set to provide an electrode voltage of 4,500 volts under stand-by conditions and, when the switch 14 is actuated, the output of the supply 13 is increased to 5,000 volts during the time the X-ray source is energized.

An alternative configuration for the container of the electrode unit is illustrated in FIGS. 5 and 6, with the electrodes being curved and with the upper electrode serving as the cover or pressure shell. A base 20' has a cover 21' mounted thereon at a hinge 22', with the cover clamped in a closed position by screws 45. Gas under pressure is provided from the source 30 through line 31' with a control valve 46. An outlet line 47 may be provided if desired. In FIG. 5, the curved electrode is shown with a positive or outward curvature. Alternatively, a negatively or inwardly curved pressure shell can be used, and will exhibit equal strength.

In either case, a central opening 48 is provided in the cover 21', with a thin sheet of a light metal clamped at the opening and serving as the anode 26'. The anode 26 may be held in place by brackets 49 fixed to the cover by screws, with a seal gasekt 50 under the anode. Another seal gasket 51 may be provided between the cover and base. The plastic sheet receptor 32' may be held in place by spring claips 55.

A cathode 24' is carried on the base 20' with an insulator 25' therebetween. The electrical power supply 13 may be attached at an electrical connector 56 with the outer or ground shell of the connector connected to the base, cover and anode, and with the insulated center pin connected to the cathode. The construction and operation of the electrode unit of FIGS. 5 and 6 is otherwise identical to that of FIG. 1.

Although exemplary embodiments of the invention have been disclosed and discussed, it will be understood that other applications of the invention are possible and that the embodiments disclosed may be subjected to various changes, modifications and substitutions without necessarily departing from the spirit of the invention.

We claim:

1. In a radiographic system for operation with a source of X rays, the combination of:

a pair of electrodes comprising an anode and a cathode;

first means for supporting said electrodes in spaced relation with a small gap therebetween and for maintaining a superatmospheric pressure in said gap;

a dielectric sheet in said gap at one of said electrodes;

an X-ray absorber and electron and positive ion emitter in said gap between said anode and cathode for producing a charge image on said dielectric sheet, said absorber and emitter comprising an X ray opaque gas at superatomspheric pressure and having an atomic number of at least 36; and

second means for connecting a high voltage electric power supply across said electrodes for attracting electrons toward said anode and positive ions toward said cathode for deposit of one of said types of charged particles on said dielectric sheet;

With the gas in the gap moderating the energy of and reducing the means free path of said electrons to increase the quantity of and reduce the dispersion of electrons moving toward said anode and positive ions toward said cathode normal to said dielectric sheet.

2. A system as defined in claim 1 in which said first means includes means for maintaining said gas in said gap at a pressure of at least about 150 psig.

3. A system as defined in claim 1 wherein the product of the gap width at the zone of X ray incidence times the gas pressure in the gap is at least about 10 mm atmospheres.

4. A system as defined in claim 1 wherein the product of the gap width at the zone of X ray incidence times the gas pressure in the gap is in the range of about 10 mm atmosphres to about 200 mm atmospheres.

5. A system as defined in claim 4 wherein the electric potential across said electrodes at the zone of X ray incidence is selected to provide operation in the plateau of the Townsend curve of voltage vs. current so that substantially no electron avalanching occurs in the gap.

6. A system as defined in claim 1 wherein the electric potential across said electrodes at the zone of X ray incidence is selected to provide operation in the plateua of the Townsend curve of voltage vs. current so that substantially no electron avalanching occurs in the gap.

7. A system as defined in claim 1 wherein said dielectric sheet is positioned at said anode and electrons are deposited thereon.

8. A system as defined in claim 1 wherein said dielectric sheet is positioned at said cathode and positive ions are deposited thereon.

9. A system as defined in claim 1 wherein said anode is a light metal or carbon readily penetrated by the X rays and is disposed on the X-ray source side of said gap.

10. A system as defined in claim 1 wherein said cathode is a light metal or carbon readily penetrated by the X rays and is disposed on the X-ray source side of said gap.

11. A system as defined in claim 1 including a control for the system high voltage electric power supply and for the X-ray source for simultaneously energizing the source to emit X-rays and energizing the system high voltage electric power supply to apply a voltage across said electrodes.

12. A system as defined in claim 11 wherein said system high voltage electric power supply provides a first lower voltage and a second higher voltage, with said control switching said system high voltage electric power supply from said first voltage to said second voltage on energizing the X-ray source.

13. A system as defined in claim 1 wherein said first means includes a pressure vessel with said electrodes disposed therein,

said pressure vessel including means for installation and removal of said dielectric sheet to and from said one electrode,

said pressure vessel including a curved thin wall readily penetrated by X rays and positionable on the X-ray source side of said electrodes.

14. A system as defined in claim 1 in which said second means includes means for maintaining the voltage across said electrodes at least about 1,000 volts.

15. A system as defined in claim 14 in which said first means includes means for maintaining said gas in said gap at a pressure of at least about 150 psig.

16. A method of producing an electrostatic image on a dielectric sheet, including the steps of:

positioning the dielectric sheet at an electrode in a gap between anode and cathode electrodes positioned adjacent an object to be imaged;

passing x-rays through said object and one of said electrodes;

absorbing incoming X rays in the gap by maintaining in the gap an X-ray opaque gas of atomic number at least 36 at superatomosperhic pressure and generating electrons and positive ions in the gas, and the gas in the gap moderating the energy of and reducing the mean free path of said electrons to increase the quantity of and reduce the dispersion of electrons moving toward said anode and positive ions toward said cathode normal to said dielectric sheet

attracting electrons toward the anode and positive ions toward the cathode by applying a high potential across the electrodes depositing one of the types of charged particles on the dielectric sheet.

17. A method as defined in claim **16** including maintaining the product of gap width at the zone of X-ray incidence times the gas pressure in the gap at at least about 10 mm atmospheres.

18. A method as defined in claim **16** including maintaining the product of gap width at the zone of X-ray incidence times the gas pressure in the gap in the range of about 10 mm atmospheres to about 200 mm atmospheres.

19. A method as defined in claim **18** including selecting the electrode potential to operate the system in the plateau of the Townsend curve of voltage vs. current so that substanitally no electron avalanching occurs in the gap.

20. A method as defined in claim **16** including selecting the electrode potential to operate the system in the plateau of the Townsend curve of voltage vs. current so that substantially no electron avalanching occurs in the gap.

21. A method as defined in claim **16** including positioning the dielectric sheet at the anode and depositing electrons thereon.

22. A method as defined in claim **16** including positioning the dielectric sheet at the cathode and depositing positive ions thereon.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,774,029 Dated November 20, 1973

Inventor(s) Muntz et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 45-46 "trav-erss" should be --trav-erses--

Column 3, line 29 "means" should be --mean--
line 62 "setp" should be --step--

Column 4, line 4 "grain" should be --gain in--
line 6-7 "deielec-tric" should be --dielec-tric--
line 17 "limiatation" should be --limiatation--
line 33 "quantium" should be --quantum--
line 35 "saml1" should be --small--
line 48 "diagnoistic" should be --diagnostic--

Column 5, line 2 "quantium" should be --quantum--
line 13 "elections" should be --electrons--
line 21 "means" should be --mean--
line 57 "intial" should be --initial--
line 62 "palteau regin" should be --plateau region--
line 63 "contrat" should be --contrast--

Column 6, line 21 "determinse" should be --determines--
line 34 "means" should be --mean--
line 39 "Krytpon" should be --Krypton--
line 50 "absoprtion" should be --absorption--
line 64 "possibily" should be --possibly--

Column 7, line 62 "suistituting" should be "substituting--

Column 8, line 29 after "is", insert --a--
line 33 "presures" should be --pressures--
line 67 "low" should be --lower--

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,774,029 Dated November 20, 1973

Inventor(s) Muntz et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Page 2

Column 9, line 6 "crecptor" should be --receptor--
line 19 "atmos" should be --atoms--
line 20 "photolectrons should be --photoelectrons--
line 60 "abosption" should be --absorption--

Column 10, line 43 "absoprtion" should be --absorption--

Column 11, line 24 "gasekt" should be --gasket--
line 27 "claips" should be --clips--
Claim 1, line 58, "superatomspheric" should be --superatmospheric--
Claim 1, line 65, "With" should be --with--
Claim 1, line 66, "means" should be --mean--

Column 12, line 14, Claim 4, "atmosphres" should be --atmospheres--

line 22, Claim 6, "plateua" should be --plateau--

Column 13, line 8, Claim 16, "superatomospheric" should be --superatmospheric--
line 9, Claim 16, after "gas", delete "and"

line 15, Claim 16, after "sheet" insert --; and--

Signed and sealed this 9th day of July 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents