Sept. 8, 1964 J. ROTHSTEIN 3,148,276

METHOD OF INCREASING THE RESPONSE OF PHOTOGRAPHIC EMULSIONS TO RADIATION

Filed Oct. 17, 1960

FIG. 1

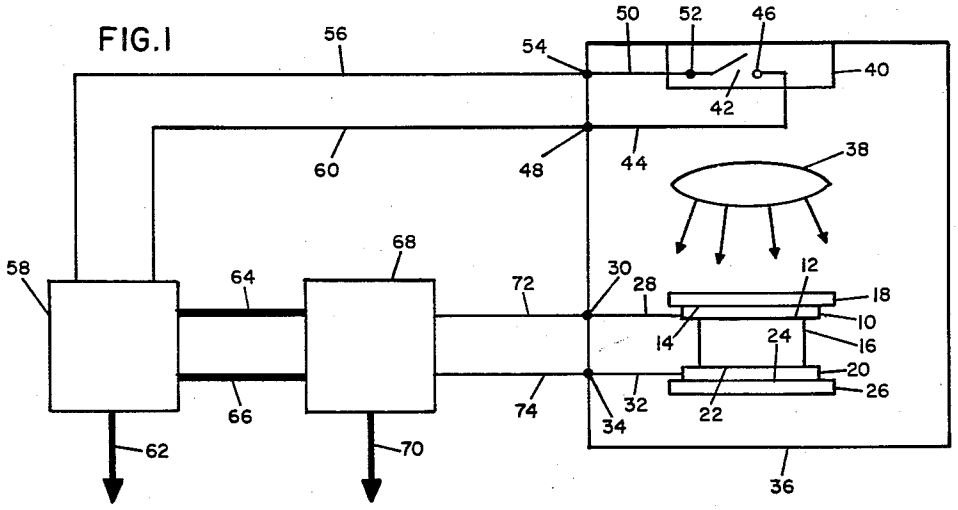


FIG. 3

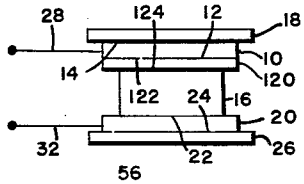


FIG. 2

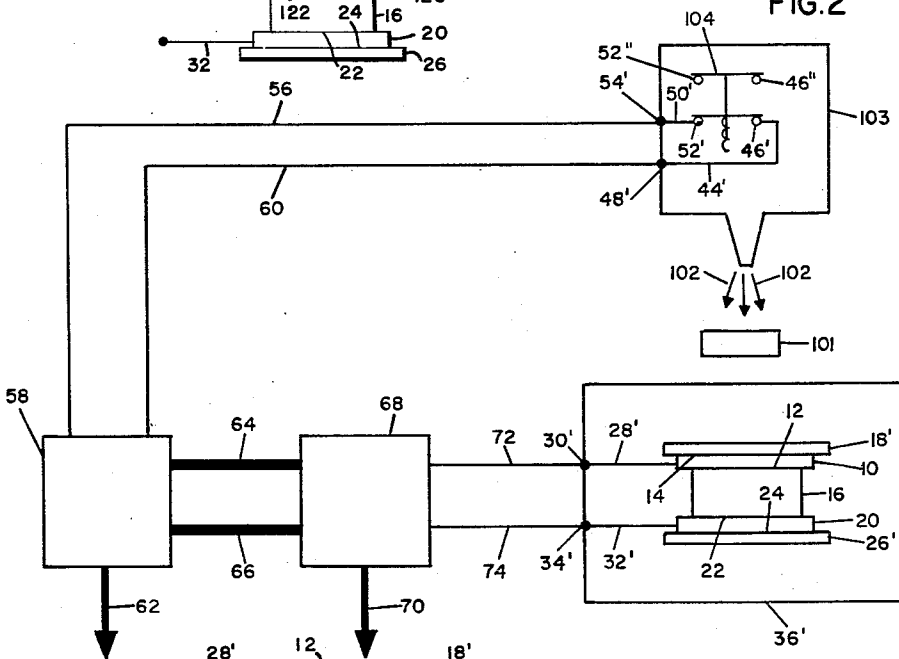
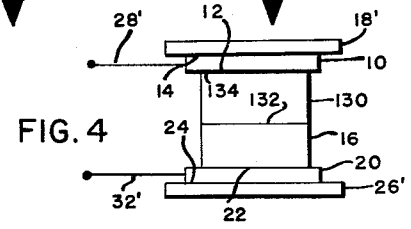


FIG. 4



INVENTOR.

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METHOD OF INCREASING THE RESPONSE OF PHOTOGRAPHIC EMULSIONS TO RADIATION

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6 Claims. (Cl. 250—65)

The present invention relates to radiation responsive systems and more particularly to radiation responsive systems employing electrical circuits in conjunction with photographic emulsions, and methods and means for enhancing the response of same.

Many investigators, since the earliest day of photography, have sought, by use of electrical means, to increase the response of the photographic process. It is believed that they were unsuccessful primarily because they did not appreciate the necessity for combining the application of extremely high electric fields during the time that the photographic emulsion is responding to the impingement of radiation thereupon, with a duration of application of the electric field chosen to avoid dielectric breakdown. The electric fields I have used, successfully exceed those permitted on the basis of published dielectric strengths of materials used as insulators or as the dielectric of condensers. Under pulsed conditions, however, these conventional materials, like the photographic emulsion, would not fail. Nor was it appreciated heretofore how enormous the electric field must be in order to obtain a useful effect. It was also not appreciated that the dielectric breakdown processes could be circumvented by going to times sufficiently short to avoid breakdown at fields high enough to derive useful effects. In essence, prior investigators did not appreciate that the maximum electric field, that may be applied to a dielectric without breakdown, is a function of the total time during which it is applied; that is, that E max.$=f(t)$, in which the mathematical physical relationships are very complicated and not well understood. Hereinafter this relationship will be referred to as the electric field-time characteristic of the dielectric and applies to extremely high electric field strengths, not to published dielectric strengths. I will use the term "E_{bb}" to define the maximum electric field strength that may be applied for a maximum time, t_{bb}, before breakdown of the dielectric occurs and in accordance with the foregoing relationship. Thus, if an electric field of strength, E, greater than E_{bb} is applied for time, t_{bb}, breakdown will occur. Likewise, if an electric field of strength, E_{bb}, is applied for a time, t, that is greater than t_{bb}, breakdown will occur. Moreover, it must be understood that if E_{bb1} is increased to a greater value E_{bb2}, then its corresponding t_{bb1} will change to a correspondingly smaller t_{bb2}. Since earlier investigators did not appreciate and apply the foregoing relationship, their work consisted either of negative results in which the emulsion was completely unaffected, or else breakdown processes occurred in which film blackening was maximal and merely a measure of the disruptive process rather than of the incident light intensity. I am aware that electrical discharges have been used in various photographic manners but in these cases an actual discharge such as a spark, corona, or other breakdown process supplies electrons, ions, and photons. In my process actual breakdown is avoided and an increased response proportional to the incident light or other radiation is obtained within the radiation sensitive medium. Ionization not strictly proportional to incident radiation, such as accompanies breakdown, is undesirable and would interfere with the operation of my invention. It must be emphasized that there is a fundamental difference between the present invention and conventional xerography, electrophotography, or their numerous variations in that the latter separate the light responsive and the recording functions. In the present invention there is no such separation, the electric field reaching in, as it were, to a fundamental step of the photographic, light-responsive, or radiation-responsive process, itself.

An object of the present invention is to improve the response of photographic emulsions.

The term "response" is herein employed to connote characteristics of a photographic emulsion such as sensitivity, contrast, density, speed, range of radiation over which the emulsion is sensitive, and other characteristics related to or derived from the aforesaid characteristics.

The term "radiation" is herein employed to connote all electromagnetic radiations to which photographic emulsions are responsive including but not limited to, infra-red, visible light, ultraviolet, X-rays and gamma rays, corpuscular emissions such as alpha and beta radiations, protons, deuterons, fission fragments, heavy ions and cosmic radiations.

A further object of the invention is to provide a new and improved photographic recording system.

Another object of the invention is to provide a new and novel method for increasing the sensitivity of a photographic emulsion.

An additional object of the invention is to provide a novel method of increasing the range of radiations to which a photographic emulsion is responsive.

A further object of the invention is to provide a new and novel method for increasing the contrast of a photographic emulsion.

Still another object of the invention is to provide a novel method whereby reciprocity failure in a photographic emulsion may be reduced.

Other and further objects will be explained hereinafter and will be more fully pointed out in the appended claims.

In summary, I have discovered that all of these objects are attained by impressing an intense electric field on a photographic emulsion during the time that the emulsion is responding to the impingement of radiation thereupon. This electric field must be of sufficiently short time duration to preclude catastrophic dielectric breakdown of the emulsion. And, it must be of sufficient amplitude to provide the desired increase in response. Thus, a very large E_{bb} must be used, but cannot be applied for a time longer than its corresponding t_{bb}.

The invention will now be described in connection with the accompanying drawings, FIGURE 1 of which is a sectional diagram of the invention shown connected to apparatus, schematically illustrated, for operating the same where the incident radiation in infra-red, visible light or ultra-violet;

FIGURE 2 is similar to FIGURE 1 but in which the incident radiation comprises X-rays; and

FIGURES 3 and 4 illustrate different embodiments of the radiation responsive materials of FIGURES 1 and 2 respectively.

The embodiments described refer to specific applications, but it will be apparent to all those skilled in the art of radiation detection and recording what modifications are required for applications involving radiations other than those specifically described herein.

Referring to FIGURE 1, electrode **10** is a transparent conducting film, such as tin oxide or titanium oxide. It is arranged with one of its surfaces **12** in intimate contact with photographic emulsion **16**. The other surface **14** of electrode **10** is bonded by film tension to a transparent support **18**. Support **18** is made of a transparent material such as glass. Similarly, electrode **20** is a transparent conducting film, such as tin oxide or titanium oxide. It is placed with one surface **22** in intimate contact with photographic emulsion **16**. The other surface **24** of electrode **20** is bonded to support **26**. In this embodiment,

support 26 may or may not be transparent depending upon whether emulsion 16 is or is not to be exposed to light through support 26. If emulsion 16 is not to be exposed to light through support 26, both electrode 20 and support 26 can be replaced by a conducting member [not shown] such as a chemically inert metal like platinum or a platinum-clad base metal. Conductor 28 connects electrode 10 to terminal 30 which is mounted on a light tight container, here illustrated schematically as 36. Conductor 32 connects electrode 20 to terminal 34, also mounted on light tight container 36. Hardware for mounting emulsion 16, electrodes 10 and 20, and supports 18 and 26, is not illustrated in order to simplify the explanation of the present invention and because such mounting means are well known in the photographic art.

Also mounted in light tight container 36 are a lens system schematically illustrated at 38 and a shutter assembly schematically illustrated at 40. Again mounting hardware is not illustrated. Light tight container 36 has an opening (not illustrated) to permit the entry of light when shutter assembly 40 is operated. Shutter assembly 40 has a synchronization switch 42 that closes when shutter assembly 40 is completely open. Conductor 44 connects terminal 46 of switch 42 to terminal 48 mounted on light tight container 36. Likewise, conductor 50 connects terminal 52 of switch 42 to terminal 54 mounted on light tight container 36.

Conductors 56 and 60 connect terminals 54 and 48 respectively to dual pulser 58. Dual pulser 58 is connected to a 115 volt, 60 cycle, alternating current power source (not shown) by power cable 62.

Dual pulser 58 contains a pulse generating circuit (not shown) that is triggered to produce a pulse by a switch closure, such as the closure of switch 42. Such pulse generating circuits are well known in the electronics art and are, therefore, not described here in detail. Two pulse outputs are provided in dual pulser 58, each having a resistive-capacitance variable delay circuit. Again, such outputs and delay circuits are well known in the electronics art and are, therefore, not described in detail.

The variable delay circuits in dual pulser 58 are adjusted so that the first pulse is produced and transmitted along cable 64 when synchronization switch 42 closes. The second pulse is produced and transmitted along cable 66 at a later time. The time difference is made equal to the time duration desired for the application of the electric field to the emulsion 16. Thus, in my tests, I used times ranging from 10 to 100 microseconds. Note that the time, t, during which a particular electric field, E_{bb} is applied must be equal to or less than its corresponding t_{bb} to avoid breakdown.

Pulse cables 64 and 66 connect dual pulser 58 to high voltage power supply 68. In my tests, I used a variable high voltage power supply in which I was able to vary the voltage output from 500 volts to 4 kv. However, it is to be understood that for commercial applications, a fixed voltage depending upon the strength of electric field desired, may be used. Power supply 68 has a thyratron switching circuit (not illustrated) for turning on the high voltage output by completing the circuit between the output terminals and a charged high voltage capacitor (not illustrated). Power supply 68 has another thyratron switching circuit (not illustrated) for shorting the charged high voltage capacitor to ground thereby removing the high voltage on the output terminals and causing both thyratrons eventually to extinguish. These circuits are not illustrated because they are well known in the electronics art. The thyratron switching circuits are triggered by the pulses produced by dual pulser 58. Cable 70 connects power supply 68 to a 115 volt, 60 cycle, alternating current power supply (not shown). The high voltage output of power supply 68 is connected by conductors 72 and 74 to terminals 30 and 34 respectively on light tight container 36.

The system operation will now be explained. Dual pulser 58 and high voltage power supply 68 are energized, allowed to warm up and the high voltage capacitor in power supply 68 is charged. Shutter assembly 40 is operated to cause light to impinge upon emulsion 16 through lens system 38. When the shutter is completely open, synchronization switch 42 closes, dual pulser 58 operates, delivering a first pulse to high voltage power supply 68 through cable 64. This first pulse triggers the thyratron switching circuit that turns on the high voltage output of power supply 68. This high voltage output appears across electrodes 10 and 20 by way of conductor 72, terminal 30 and conductor 28 to electrode 10, and by way of conductor 74, terminal 34 and conductor 32 to electrode 20. The high voltage appearing across electrodes 10 and 20 creates a large electric field within emulsion 16.

At the desired later time, which, as above discussed, is equal to or less than the t_{bb} corresponding to the E_{bb} to be applied, dual pulser 58 delivers a second pulse through cable 66 to high voltage power supply 68. This second pulse triggers the other thyratron switching circuit which shorts the high voltage capacitor to ground thereby removing the high voltage from the output terminals. Eventually the thyratrons extinguish and the capacitor is then recharged. The high voltage across electrodes 10 and 20 and the electric field within emulsion 16 are thereby removed.

In FIGURE 2 the invention is illustrated as utilized in X-ray apparatus. Electrode 10 is a thin conducting film such as tin oxide, titanium oxide, a semiconductor, or a layer of metal, since optical transparency is not required. It is arranged with one of its surfaces 12 in intimate contact with photographic emulsion 16. The other surface 14 is bonded by film tension to a support 18'. Support 18' is made of a material that is sufficiently transparent to X-rays. Electrode 20 is similar to electrode 10. It is placed with one surface 22 in intimate contact with photographic emulsion 16. The other surface 24 of electrode 20 is bonded to support 26'. In this embodiment support 26' may or may not be transparent to X-rays depending upon whether emulsion 16 is or is not to be exposed to X-rays through support 26'. Again, if emulsion 16 is not to be exposed to X-rays through support 26', both electrode 20 and support 26' can be replaced by a conducting member (not shown) such as a chemically inert metal like platinum or a platinum-clad base metal. Conductor 28' connects electrode 10 to terminal 30' which is mounted on a light-tight and X-ray transparent container 36', here schematically illustrated. Conductor 32' connects electrode 20 to terminal 34' on container 36'. Hardware for mounting emulsion 16, electrodes 10 and 20, and supports 18' and 26' to container 36', and for removing and replacing same, is not shown because such hardware is well known in the art. Moreover, understanding of this application of the invention is thereby facilitated.

Terminals 30' and 34' are connected to high voltage power supply 68 by means of conductors 72 and 74.

Illustrated schematically at 101 is the object being subjected to X-rays schematically illustrated at 102, produced by X-ray machine 103, also schematically illustrated.

In X-ray machine 103 switch 104 is illustrated, in the operated position, as a spring loaded double-pole push button switch that is normally disconnected. Contacts 52'' and 46'' when shorted as illustrated close a circuit (not illustrated) that causes a pulse of X-rays 102 to be generated. As illustrated X-rays 102 are directed through object 101 toward emulsion 16.

Concurrently contacts 52' and 46' are shorted completing the circuit by way of conductors 60, 44', 50' and 56 and terminals 48' and 54' to dual pulser 58.

Since the remainder of the apparatus is the same as heretofore described, the operation of the X-ray system will now be described.

Dual pulser 58, high voltage power supply 68 and X-ray machine 103 are turned on and allowed to warm up. The object 101 to be X-rayed may then, or earlier,

be placed in position. Push button switch 104 is operated causing X-rays 102 to be generated which pass through object 101, container 36', support 18', electrode 10 and impinge upon emulsion 16.

Concurrently, contacts 52' and 46' are shorted completing the circuit to dual pulser 58 that triggers the pulse generating circuit to produce an electrical pulse.

The variable delay circuits in dual pulser 58 are adjusted so that the first pulse is produced and transmitted along cable 64 to high voltage power supply 68 to trigger the thyratron switching circuit that turns on the high voltage output at some time after X-rays start impinging upon emulsion 16 and producing free electrons therein. As before described the high voltage output appears across electrodes 10 and 20 creating an enormous electric field within emulsion 16, until the second pulse is delivered by dual pulser 58. And, as before described, the second pulse triggers a second thyratron switching circuit that shorts the charged high voltage capacitor in power supply 68 to ground, thereby removing the high voltage from electrodes 10 and 20 and causing both thyratrons eventually to extinguish. The time difference between the first and second pulse is made equal to or less than the f_{bb} corresponding to the E_{bb} to be applied. This, again, must be short enough to preclude catastrophic dielectric breakdown of emulsion 16.

It is emphasized that the electric system illustrated, in part, for producing the short time duration electric field, is merely one of many that could be used. Thus, theoretically, switching transistor circuits could be substituted for the thyratron circuits in high voltage power supply 68.

The assembly of emulsion 16, electrodes 10 and 20, and supports 18 and 26 illustrated in FIGURE 1 may be replaced, if desired, by the assembly illustrated in FIGURE 3, in which an optically transparent film 120 of a photo-conductive material such as cadmium sulfide is inserted between electrode 10 and emulsion 16. All of surface 12 of electrode 10 makes electrical contact with all of surface 122 of photo-conductive film 120. Likewise, all of surface 124 of photo-conductive film 120 makes electrical contact with emulsion 16. Obviously, if it is desired that emulsion 16 be exposed through electrode 20, a similar film of photo-conductive material may be inserted between electrode 20 and emulsion 16.

When radiation such as light impinges upon emulsion 16 through support 18, electrode 10 and photo-conductive film 120, electrons are freed in the photo-conductive film 120 according to intensity variations of the incident radiation. If this radiation contains photons of sufficiently high energy, photoelectrons will be produced which will aid the photographic response of emulsion 16, particularly in an applied field. When the high voltage pulse is properly applied to electrodes 10 and 20, the electric field created across emulsion 16 and photo-conductive film 120 varies as to emulsion 16 according to the intensity of the incident radiation. As seen from emulsion 16, the field originates at electrode 20 and at a virtual electrode within photo-conductive film 120 having a variable distance from emulsion 16; that is, closer where the intensity of the incident radiation is strong and further away where the intensity is weak. It is as if the electric field impressed upon emulsion 16 were modulated according to the intensity of the incident radiation. The result is that the response of emulsion 16 is thereby greatly enchanced by the "modulated" field as compared to the "unmodulated" field used when photo-conductive film 120 is omitted.

Referring to FIGURE 2, electrode 10, if desired, may be made of a metal having a high atomic number, or a conducting or semi-conducting compound of elements of high atomic numbers. Such materials emit photo-electrons when subjected to X-rays. These photoelectrons further enhance the response of emulsion 16.

The assembly of emulsion 16, ele ctrodes 10 and 20, and supports 18' and 26' illustrated in FIGURE 2 may be replaced, if desired, by the assembly illustrated in FIGURE 4, in which a phosphor 130 is inserted between electrode 10 and emulsion 16. All of surface 12 of electrode 10 makes electrical contact with all of surface 134 of phosphor 130. Likewise all of surface 132 of phosphor 130 makes electrical contact with emulsion 16.

When X-rays impinge upon emulsion 16 through support 18', electrode 10 and phosphor 130, several phenomena occur. First, the phosphor converts some of the X-radiation, according to its intensity, to visible or ultraviolet light to which the emulsion is more sensitive. The response of the emulsion is thereby enhanced. Phosphor screens serving this purpose are in general use in the X-ray field and are known as "intensifying screens." Second, when irradiated, the phosphor conducts according to the intensity of the incident radiation. Thus, a virtual electrode is created within the phosphor. The distance of this virtual electrode from emulsion 16 varies according to the intensity of the incident radiation. Thus, it is closer to emulsion 16 where the incident radiation is stronger and further away where the intensity is weak. As above described, the electric field when applied, appears to be modulated according to the intensity of the incident radiation.

Last, if the phosphor contains elements of high atomic number (calcium tungstate is one of many such phosphors), photoelectrons will be supplied, as above described, to the emulsion, which will further enhance the response of emulsion 16.

Obviously, the response of emulsion 16 can be further enhanced as above described by inserting in addition a phosphor [not shown] between electrode 20 and emulsion 16. In such event, emulsion 16 will be further responsive to those X-rays that pass through emulsion 16 and impinge upon said additional phosphor.

A theory of the process will now be described, which is believed to be sound on the basis of present knowledge and appears to be verified by experiments. It is to be understood, however, that a modified or even an entirely different theory of the actions taking place might be correct, without affecting this invention.

According to our present understanding of the photographic process it appears that electrons are freed in the emulsion when light or other radiation impinges thereon and migrate to sites where they facilitate the reduction of silver from the silver halide. A complex art called dye sensitization has arisen which has produced substantial improvements in the sensitivity, speed, and spectral response of photographic emulsions. Experiments have shown that the photo-conductive response of the dyes used for sensitization corresponds very closely to the spectral response characteristics conferred on the emulsion when sensitized by those dyes. This has been interpreted as meaning that the sensitizer produces electrons under the influence of light by a process essentially similar to that in photoconductivity, and these electrons can then migrate to the photographically sensitive sites, in the emulsion. As is well known, the use of different dyes can confer different spectral responses on what is essentially the same emulsion. Many schemes for sensitizing slow emulsions have been proposed. While many of them work for slow emulsions, the improvements they engender in fast emulsions (i.e. dye sensitized) are negligible. The reason for this is that these methods do not increase the number of primary electrons available for migration to the sensitive spots beyond what can be provided by dye sensitization. The present invention represents a fundamentally different approach in that a true amplification of the number of electrons produced by the light is achieved before the development process takes place. The increase in sensitivity and speed is therefore independent of the sensitivity of the base material to which the teaching of this invention is applied.

It is known that photographically sensitive materials are sensitive to electrons. By the application of suitable electric fields the present invention increases the number of

electrons produced in light sensitive material by incident light. The invention makes this increase in the number of photographically active electrons proportional to the intensity of the exciting light. While in my experiments I have used short electrical pulses as the preferred wave-form, it is possible, in principle, to use direct current, alternating current, radio frequency, a series of pulses, or more complex wave-forms. The reason for limitation to short pulses at the present time is the danger of dielectric failure of the emulsion. It is believed that improved emulsions can be made, which would remove or ameliorate this restriction. This will be clear as the theory of operation, which is believed to be correct, is further discussed.

When a photographic image or other light pattern is formed on emulsion **16** by the shutter assembly **40** and lens system **38**, electrons are freed in the emulsion. During the time that these electrons are free, a very high electric field is impressed on emulsion **16** as heretofore described. In principle, the field could be impressed a number of times while the electrons are free. Under the influence of the field the electrons acquire energy and make ionizing collisions within emulsion **16**. A large number of electrons is thereby produced which can enter into subsequent photographic or other image or record-forming processes in the usual way. In my experiments I have used fields calculated to be as high as 4 million volts per centimeter for times equal to or less than the t_{bb} corresponding to such electric field without dielectric breakdown of the emulsion.

If the time duration of the electric field was lengthened beyond some 25 to 100 microseconds, depending upon the applied voltage and the electric field-time characteristic of the emulsion, dielectric breakdown, puncture, and local blackening of the film were observed. The electron avalanching process is qualitatively similar to that observed in photoconductors, semiconductors, and electrical discharges in gas, and can culminate in breakdown of the medium. In the case of dielectrics, and here the photographic emulsion is to be considered a dielectric, it is believed that dielectric breakdown is caused by local ohmic heating. This heating accompanies ionic conduction. The use of short voltage pulses enables one to apply electric fields to such dielectrics that are much higher than can normally be applied with relatively long voltage pulses. The reason for this is that ionic mobilities are not high enough initially and do not increase enough for the ions to move significantly during the time the short voltage pulse is applied. The ions therefore cannot acquire a significant amount of energy from the electric field and thus cannot transfer energy to the emulsion and heat it. Were the ions able to do this, the heating of the emulsion would increase the ionic mobility, whereby a progressive heating and ionic conduction would occur which would culminate in dielectric breakdown of the emulsion.

It is therefore clear that the restriction to short voltage pulses is a reflection of the present state of the art of manufacturing photographic emulsions. When photographic emulsions are manufactured with reduced ionic conductivity and increased dielectric strength, stronger electron avalanches may be produced with long pulses without danger of dielectric puncture of the film. As ionic conductivity in the emulsion, as distinguished from that in the silver halide crystallites, is not important in the present-day photographic process, this parameter is not controlled particularly well, giving rise to considerable variation in the length of time emulsions can support a given electric field without breaking down.

In some of my experiments, I applied high voltage pulses to films kept in the dark and then developed them. The results of these experiments showed that the application of these high fields, for intervals of time less than that during which dielectric failure occurs, would not cause the emulsion to act as if it were exposed to light. It looked like unexposed film.

Under the same conditions, but with light impinging on the emulsion, the use of a pattern of conducting and non-conducting portions on electrode **10**, on which was superimposed a gray scale (not illustrated), has shown for one and the same emulsion, and for a number of intensity steps, that in the regions where no field was applied the sensitivity was normal; whereas in the regions where the electric field was applied, blackening and contrast were notably enhanced. Furthermore, this additional blackening varied with light intensity in a proportional manner, for the steps on the gray scale were proportionally and better marked in the field sensitized regions than they were in the field-free regions. The improvement in contrast was very notable. The results were compatible with the view that an increase in speed of approximately 2 orders of magnitude had been obtained. The use of very short pulses in tests with films showing a significant reciprocity failure at short times, indicated that there was no reciprocity failure for this electronic sensitization process.

Similar results will be produced with X-rays impinging upon emulsion **16** as heretofore described.

The present invention can be viewed as a non-chemical method of improving the photographic process which amplifies the electronic steps of the process and thus adds improvements which are superimposed on whatever improvements are obtained by chemical means either before or after the exposure. An attractive feature of the present invention resides in the fact that the electrical pulse itself can be used as a shutter if this is desired. This could be of great advantage for photography in very dim light where the duration of time exposures could be reduced considerably. This is particularly desirable in astronomical photography and night-time aerial photography, for example. It is also advantageous for pulsed illumination as when flash tubes are used for photographic ballistic studies, stroboscopic photography, and other fast photographic applications. Another attractive feature of this invention is that loss of speed engendered by decreased grain size (needed for higher resolving power) can be restored without sacrificing other advantages of decreased grain size.

While the foregoing has stressed the photographic application using visible light and X-rays, it is clear that the same principle applies more generally for any physical agent, be it infrared, visible, ultraviolet, or gamma ray radiations, or electrons, positrons, protons, deuterons, alpha particles, mesons, or any other of the particles of physics capable of acting on an emulsion or other sensitive material.

Although the invention has been described in terms of one embodiment, it is understood that the invention has broader applications and is in no way limited to this embodiment.

Further modifications will occur to those skilled in the art and all such are considered to fall within the spirit and scope of the invention as defined in the appended claims.

I claim:

1. The method of increasing the response of a material sensitive to incident radiation, said material having an electric field-time characteristic defining the relationship between very intense electric field strengths, E_{bb}, and the corresponding maximum times, t_{bb}, during which they may be applied to said material without dielectric breakdown thereof occurring, comprising:

exposing said material to said radiation;

impressing upon said material a very intense electric field E_{bb} while said material is responding to said radiation; and

limiting the time duration of electric field E_{bb} to a time not greater than its corresponding t_{bb}.

2. The method of increasing the response of a material sensitive to incident X-ray radiation, said material having an electric field-time characteristic defining the relationship between very intense electric field strengths, E_{bb}, and the corresponding maximum times, t_{bb}, during which they may be applied to said material without dielectric breakdown thereof occurring, comprising:

converting a portion of said X-ray radiation to light;

exposing said material to said light and said X-ray radiation;

impressing upon said material a very intense electric field E_{bb} while said material is responding to said light and said radiation; and

limiting the time duration of the electric field E_{bb} to a time not greater than its corresponding t_{bb}.

3. The method of increasing the response of a material sensitive to light, said material having an electric field-time characteristic defining the relationship between very intense electric field strengths, E_{bb}, and the corresponding maximum times, t_{bb}, during which they may be applied to said material without dielectric breakdown thereof occurring, comprising:

exposing said material to said light;

impressing upon said material a very intense electric field E_{bb} while said material is responding to said light; and

limiting the time duration of electric field E_{bb} to a time not greater than its corresponding t_{bb}.

4. The method of increasing the response of a photographic emulsion sensitive to incident radiation, said emulsion having an electric field-time characteristic defining the relationship between very intense electric field strengths, E_{bb}, and the corresponding maximum times, t_{bb}, during which they may be applied to said emulsion without dielectric breakdown thereof occurring, comprising:

exposing said emulsion to said radiation;

impressing upon said emulsion a very intense electric field E_{bb} while said emulsion is responding to said radiation; and

limiting the time duration of electric field E_{bb} to a time not greater than its corresponding t_{bb}.

5. The method of increasing the response of a photographic emulsion sensitive to incident X-ray radiation, said emulsion having an electric field-time characteristic defining the relationship between very intense electric field strengths E_{bb}, and the corresponding maximum times, t_{bb}, during which they may be applied to said emulsion without dielectric breakdown thereof occurring, comprising:

converting a portion of said X-ray radiation to light;

exposing said emulsion to said light and said X-ray radiation;

impressing upon said emulsion a very intense electric field E_{bb} while said emulsion is responding to said light and said radiation; and

limiting the time duration of the electric field E_{bb} to a time not greater than its corresponding t_{bb}.

6. The method of increasing the response of a photographic emulsion sensitive to light, said emulsion having an electric field-time characteristic defining the relationship between very intense electric field strengths, E_{bb}, and the corresponding maximum times, t_{bb}, during which they may be applied to said emulsion without dielectric breakdown thereof occurring, comprising:

exposing said emulsion to said light;

impressing upon said emulsion a very intense electric field E_{bb} while said emulsion is responding to said light; and

limiting the time duration of electric field E_{bb} to a time not greater than its corresponding t_{bb}.

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