

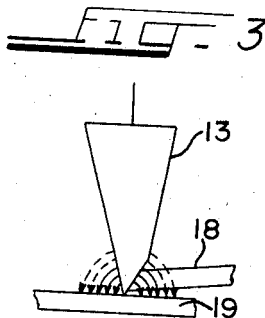
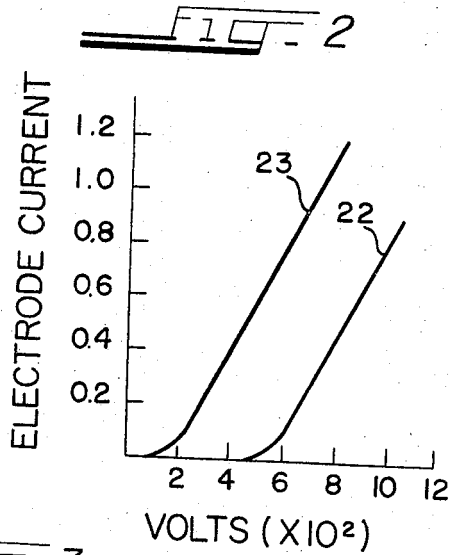
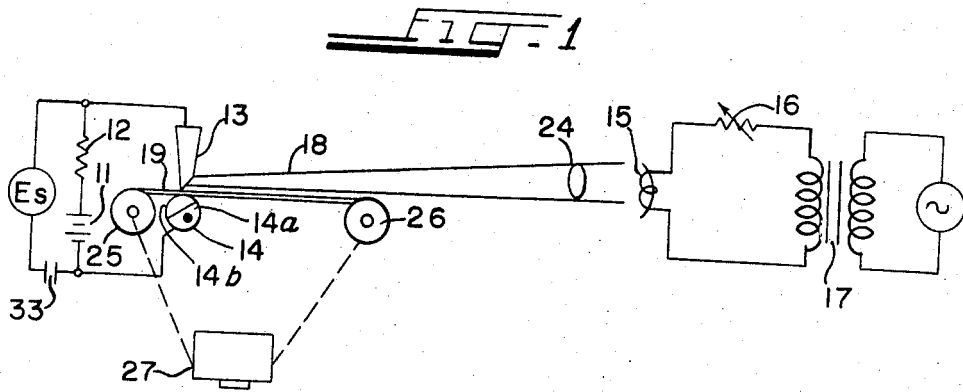
Oct. 10, 1967

J. J. BROPHY
ELECTROSTATIC RECORDING SYSTEM EMPLOYING
PHOTOCONDUCTIVE ELECTRODES

3,346,701

Filed July 5, 1963

2 Sheets-Sheet 1



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JAMES J. BROPHY
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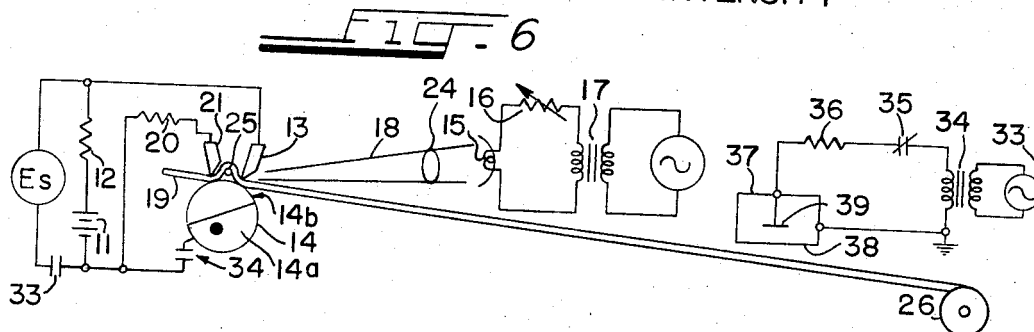
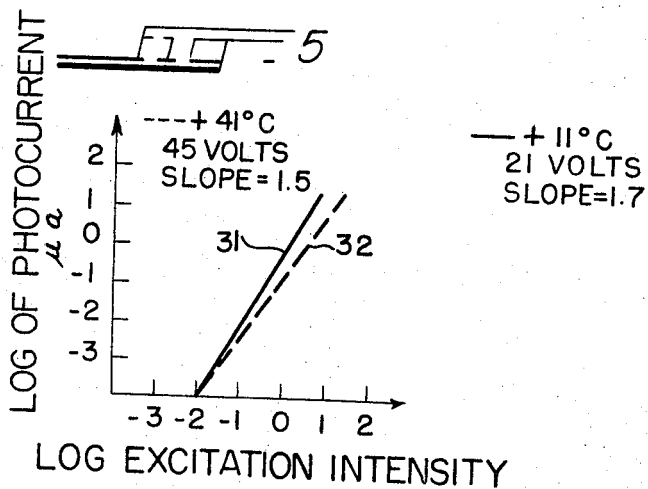
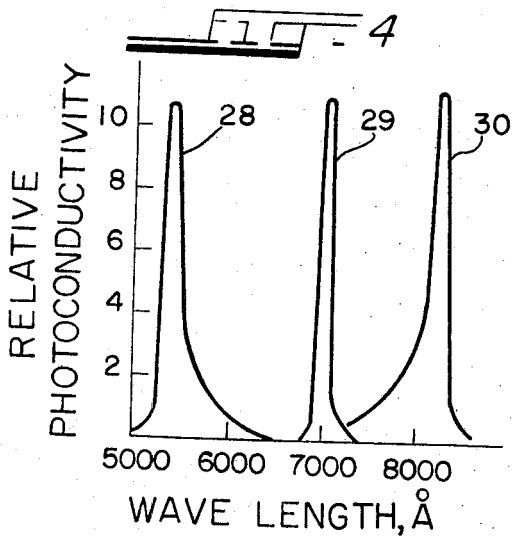
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ELECTROSTATIC RECORDING SYSTEM EMPLOYING PHOTOCONDUCTIVE ELECTRODES

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10 Claims. (Cl. 179-100.1)

This invention is directed to electrostatic recording and more particularly to an improved electrostatic recording system and method wherein photoconductive materials are employed.

It has been shown experimentally that in electrostatic recording it is advantageous to employ a recording electrode made from a material of high resistance. Ferrites have been used extensively. The advantages of high resistivity for the recording electrode are thought to be twofold: first, the electrical resistance of the electrode itself acts as a ballast resistor to smooth fluctuations in recording current to the changes in recording tape characteristics; and secondly, the stored electrical energy in the recording system due to the relatively high potentials employed is not available to puncture the tape in the event of electrical failure of the tape because of the voltage drop across the high resistance electrode which occurs when breakdown currents attempt to flow. It is desirable to improve these characteristics further by varying the resistivity of the electrode with distance such that, for example, the very tip of the electrode might be low resistance while the remainder be high resistance. This variation in resistance of the electrode will reduce the available stored energy even further and will contribute in addition to reducing recorded noise by altering the characteristics of the recording gas discharge.

Accordingly, it is an object of this invention to provide an improved electrostatic recorder and method. Another object of this invention is to provide an improved electrostatic recorder and method by the use of a photoconductive electrode. Yet another object of this invention is to provide an improved electrostatic recorder and method by the use of a photoconductive electrode and controlling the resistance of such electrode by a light pattern. Yet still another object of this invention is to provide an improved electrostatic recorder and method by the use of photoconductive electrodes and varying the resistance of such electrodes by light beamed thereon in accordance with the intelligence to be recorded.

The foregoing and other objects will become more apparent to the reader from the following detailed description along with the accompanying drawings wherein like numerals refer to like parts:

FIGURE 1 is a schematic of a basic electrostatic recording system in accordance with the principles of this invention;

FIGURE 2 is a plot of electrode potential versus electrode current, useful in explaining this invention;

FIGURE 3 is an enlarged view of the electrode configuration of FIGURE 1;

FIGURE 4 is a plot of relative photoconductivity of three materials as a function of wavelength, useful in describing the operation of this invention;

FIGURE 5 is a plot of the photoconductivity of a crystal of cadmium selenide at various temperatures and voltages as a function of excitation intensity; and

FIGURE 6 illustrates the preferred embodiment.

Briefly described, the objects of this invention are accomplished by controlling the resistivity profile of the recording electrode by the use of a sensitive photoconductor as the electrode material, and illuminating such electrode with the desired light pattern to achieve the proper resistivity profile.

The particular technique of electrostatic recording de-

scribed in this application has been referred to as charge injection. More particularly, such recording embraces the technique whereby there results a motional tape current between two electrodes when the electrode potential difference exceeds a specific threshold whereby large quantities of ions of opposite polarity are simultaneously deposited on opposite sides of a moving charge retentive medium passing therebetween. These charges are subsequently embedded in the medium by the intense electric field existing between the recording electrode and a backing electrode associated therewith. For a more detailed description of this process, the reader's attention is directed to copending application Serial No. 844,472 entitled "Transducer System and Method" filed Oct. 5, 1959, now U.S. Patent No. 3,159,318 issued Dec. 1, 1964, and assigned to the present assignee.

Referring now in detail to FIGURES 1 and 2, a dielectric tape 19 is arranged to pass between recording electrode 13 and backing electrode 14 to record the intelligence thereon. It has been discovered, that in order to obtain sufficient amount of charge transfer from the electrodes to tape 19, it is necessary that the voltage across electrodes 13 and 14 exceed a certain minimum threshold. This threshold for a tape 19 composed of quarter mil "Mylar" (a Du Pont trademark for its polyester film) is in excess of about 635 volts. Curve 22 of FIGURE 2 approximates the motional current for tape 19 under these conditions.

Battery 11 applies a bias voltage across tape 19 via electrodes 13 and 14 and ballast resistor 12. Motor 27 is coupled to supply reel 25 and take up reel 26 to draw tape 19 between the electrodes. Battery 11 has a potential of about 1,000 volts and establishes the operating range of the recording system at about the mid-point of the linear portion of curve 22. Under these conditions, as tape 19 passes between electrodes 13 and 14, a constant current will exist and deposit equal amounts of positive and negative charge on opposite sides of tape 19. By making electrode 13 of a photoconductive material such as, for example, cadmium sulfide (CdS) the series resistance of electrode 13 may be made to vary, thus varying electrode current in proportion to changes in resistance of electrode 13. The signal E_s is applied across battery 11 and resistor 12 in parallel with electrodes 13 and 14 to vary the constant current in accordance with the intelligence to be recorded on tape 19. Capacitor 33 serves to block the DC from the signal E_s .

In FIGURE 3, an enlarged view of electrodes 13 is shown. If beam 18 is focused onto the tip of electrode 13, only that illuminated portion of electrode 13 will have increased conductivity. Under these conditions, it is believed that gas discharge occurs only around the conductive region of electrode 13 to tape 19 as indicated by the solid lines. In contradistinction to this, conductive metal electrodes such as those heretofore used will pass the charge stored throughout electrode 13 by gas discharge as indicated by the dotted lines. It will be obvious that the charge paths are of greater intensity and are likely to spread out further than those depicted by the solid lines. Also, the smaller discharges are believed to be less noisy (smaller amplitude) and provide better resolution (closer to electrode edge) as is shown.

The forbidden-energy gaps of cadmium sulfide (CdS), cadmium selenide (CdSe) and cadmium telluride (CdTe), correspond to photon energies in the visible wavelength region as is respectively illustrated by curves 28, 29 and 30 in FIGURE 4. From such curves the proper wavelength of beam 18 can be easily chosen depending on the photoconductive material used. In addition, the log of the photoconductivity (which is a function of the resistivity of the material) varies substantially linearly with the logarithm of the light intensity as is illustrated in FIG-

FIGURE 5. Plots 31 and 32 indicate the photocurrent of a crystal of cadmium sulfide at different temperatures and voltages. Thus it can be seen by selecting the proper frequency to be supplied to transformer 17, the wavelength and intensity of beam 18 may be properly selected to conform with the theory just explained. This signal will be of desired frequency and amplitude. Its amplitude is controlled by the turns ratio of transformer 17 and variable resistor 16. Lens 24 is desirable to focus beam 18 onto electrode 13.

FIGURE 4 was taken from "Electronic Processes in Materials" by James J. Brophy and Leonid V. Azaroff, McGraw-Hill Book Company, Inc., copyright 1963 at page 253. FIGURE 5 was taken from "Photoconductivity of Solids" by Richard H. Bube, John Wiley & Sons, Inc., copyright 1960 at page 343. For a more detailed analysis and description of semi-conductivity and photo-conductivity of solids, reference is made to the aforementioned texts.

The signal to be recorded may be applied in parallel across the input terminals of transformer 17. This signal (E_s) is coupled to the secondary of transformer 17 in series with resistor 16 and lamp 15. Lamp 15 is of the variable intensity type which intensity varies linearly with voltage. The beam from lamp 15 is focused onto electrode 13. As the intensity and wavelength of beam 18 varies, the resistance of electrode 13 will accordingly change. These resistance changes will cause the motional tape current to vary in accordance with the beam intensity and wavelength. By this expedient, smaller signal levels may be used. In addition, the high resistivity of electrode 13 is maintained because the actual resistivity of most photo-conductive materials is on the order of megohms.

FIGURE 6 depicts the preferred embodiment. The dynamic range and other properties of a charge injection electrostatic recording are measurably increased by subjecting tape 19 to a reverse polarity pre-bias treatment with a prior electrode 21 and backing electrode 14 combination. The subsequent motional tape current at the second electrode pair—electrode 13 and common backing electrode 14—is identified by curve 23 in FIGURE 2. In the absence of signal, the net result of a pre-bias treatment is an essentially neutral tape 19, for properly chosen values of electrode potentials. Actually, the circuit of FIGURE 6 provides that the pre-bias and bias currents are equal because the DC path is a series circuit. That is, the bias and pre-bias current flows from battery 11, through ground, resistor 20, pre-bias electrode 21, tape 19, backing electrode 14, tape 19, bias electrode 13, resistor 12 and back to battery 11.

Tape 19 is drawn between electrodes 21 and 13 having the common flexible backing electrode 14. Battery 11 represents a 1,500 volt DC bias source and is applied to the two tape surfaces while tape 19 is drawn between the electrodes. Under these conditions, the total bias voltage divides automatically in the approximate ratio of 1.5 to 1 between the first electrode combination (electrodes 21 and 14) and the second electrode combination (electrodes 13 and 14). With this voltage division, the voltage of the tape in transit between the two front electrodes approximately equals one-half of the tape threshold voltage. Threshold voltage being the voltage that must be applied across moving virgin tape before an appreciable motional current results through it.

Common backing electrode 14 engages the underside of tape 19 opposite to that of electrodes 21 and 13 and except for such engagement is electrically insulated from the bias circuit. This is to say, the two frontal electrodes are in DC series through two series thicknesses of tape 19 and the motional DC bias current of tape 19 is identically the same under each frontal electrode but oppositely directed therethrough. By this arrangement, the tape emerges from the electrodes in a substantially uncharged neutral condition.

In all embodiments described herein it should be under-

stood that tape 19 is subjected to a uniform biasing electric field of a magnitude exceeding the previously described threshold value for the surface of the record medium but less than the breakdown electric field strength. Under these biasing conditions, there results an injection of electric charges of opposite sign into opposite sides of the record medium substantially simultaneously. These charges being bound interiorly of tape 19 and being uniformly distributed.

Similarly, as in the previous embodiment, electrode 13 is photoconductive and responsive to light beam 18 from lamp 15. Likewise, lens 24 is employed to focus beam 18 onto electrode 13. In the same manner as previously described, the intelligence may be recorded on tape 19 by varying the resistance of electrode 13 by applying the signal to transformer 17. Blocking capacitor 34 is in the circuit to provide an AC path for the signal but also to block the DC so that the bias and pre-bias currents are equal. Guide pin 25 is interposed between electrodes 13 and 21 so tape 19 has line contact with both frontal electrodes.

In FIGURE 6 an ion generator is illustrated which is used to dust the tape 19 with ions after it has passed the electrodes. Ion dusting may or may not be used but is preferable to enhance record life. It is believed, that one reason for enhanced record life is that the ions neutralize undesired surface charges without affecting the internally stored charges. Also such ions are believed to impede charge transfer between the adjacent coils of the tape as stored on reel 26. One such system for applying ions to tape 19 is by means of the corona generator shown in FIGURE 6. The generator includes a conductive case 37 which is open at one side 38 and which may be provided with an electrostatic shield thereacross. Such shield may consist of a multiplicity of wires extending transversely of case 37 or alternatively, it may be a mesh screen covering the opening 38 facing tape 19. Preferably, case 37 is grounded. Transformer 34 has its output connected between case 37 and a pointed tungsten electrode 39 disposed within case 37. Electrode 39 is insulated from case 37.

Transformer 34 may be of any conventional type, and preferably is powered by commercial voltage source 33 at a commercial frequency. Transformer 34 should have a primary-to-secondary ratio such that the output voltage is in the neighborhood of about 4,000 volts. In the embodiment illustrated, one side of the secondary of transformer 32 is grounded while the other side is connected in series with a current limiting resistor 36, variable capacitor 35 and then through a high voltage conductor to electrode 39. Application of voltages described will produce a slight corona at each of the tips of electrodes 39 and air diffuses through the open side 38 to become ionized and when ionized, diffuses back again against tape 19. With this arrangement, sufficient positive and negative ions are produced and made available outside case 37 to neutralize the beforementioned unwanted charges. Variable capacitor 35 is included to provide adjustment of the quantity of positive and negative ions. Ordinarily the circuit should be adjusted for equal quantities of both.

It should be noted that the AC field is applied between electrode 39 and case 37, and therefore the field does not extend outwardly of the ion source to provide a source of interference or of permanent signals to tape 19. While only one particular source of ions has been described, it should be noted that many other suitable arrangements may be used as will occur to those skilled in this particular art.

While I have shown means for applying ions after tape 19 has passed between the electrodes, it should be noted that similar ion generator may be disposed before tape 19 passes between the electrodes. In both cases, the ions have a tendency to neutralize external electric fields and also to neutralize tribo-electric or other surface charges on tape 19.

In the illustrated embodiments, electrodes 13 and 21 are substantially identical to each other in geometry and each preferably comprises an integral knife edge engaging one side of tape 19. Preferably, each of the knife edges represents the intersection of a pair of lapped surfaces at the point of engagement with tape 19. The knife edges may have a radius of 0.25 inch and be operative, however, if the radius is reduced to .0005 inch, frequency response improves. Accordingly, a further decrease in radius of the knife edge such as that obtained by the intersection of two lapped surfaces, produces a further improvement in frequency response and improved signal to noise ratio.

By way of example, edge angles between the inclined surfaces of electrodes 13 and 21 away from tape 19 of 30°, 34° and 60° have been found satisfactory, but an angle of 90° between the edges of electrodes 13 and 21 and tape 19 gave a definitely muffled quality to the playback of signals.

Backing electrode 14 comprises a semi-cylindrical conductive block 14a having a multiplicity of steel wires 14b extending arcuately from block 14a into engagement with the undersurface of tape 19. The lower electrode may be adjustable into and out of engagement with tape 19. It has been found that the lower wire electrode 14 as illustrated in FIGURES 1 and 6 is highly advantageous and greatly improves the quality of reproduction. It is found that when the wire electrode is used, pressure contact is obtained at a large number of points on the tape because each individual wire of electrode 14 presses a corresponding point of tape 19 against the knife edge of the opposed confronting electrode. Each end of the wires 14b is secured in good conductive relation to conductive block 14a yet the individual wires are free to deflect inwardly slightly as they press the tape against the knife edges.

All of the electrodes may be photoconductive and regulated by illumination. Along these lines, however, it is difficult to obtain the advantages of a resilient backing electrode such as that described in this application if it is made of photoconductive material. Furthermore, while the resilient multiple wire backing electrode is preferred, backing electrode 14 may consist of a felt or soft springy material impregnated with a conductive particulate such as for example, graphite.

All electrodes should be narrower than the width of tape 19. This requirement is necessary to prevent spurious arcing between electrodes. The transverse extent of the electrodes will vary, of course, depending on the drive system. For example, if tape travel guides are employed there is less likelihood of misalignment and therefore the electrodes need not be as narrow as would be the case without guides.

Obviously, modifications will occur to those skilled in this art without departing from the novel concepts disclosed herein.

I claim as my invention:

1. An electrostatic recorder comprising a pair of spaced apart, confronting electrodes, means for moving a charge retentive dielectric record medium along a record medium path between said pair of electrodes, means connected to said electrodes for applying a voltage therebetween greater than a threshold voltage for said record medium corresponding to an electric field intensity causing an abrupt rise in electrode current flow as said record medium passes therebetween but of magnitude less than that to cause breakdown of the medium, at least one of the electrodes extending from a first boundary adjacent the record medium path to a second boundary relatively remote from said record medium path with the applied voltage tending to produce current flow along a current flow path extending between said first and second boundaries, wherein the improvement comprises

said current flow path between said first and second boundaries being formed of a material of variable resistivity, and

means acting on a limited segment of said material forming a portion only of the length of said current flow path to modify the configuration of the electric field between the one of said electrodes and the record medium.

2. An electrostatic recorder comprising a pair of spaced apart, confronting electrodes, means for moving a charge retentive dielectric record medium along a record medium path between said pair of electrodes,

means connected to said electrodes for applying a voltage therebetween greater than a threshold voltage for said record medium corresponding to an electric field intensity causing an abrupt rise in electrode current flow as said record medium passes therebetween but of magnitude less than that to cause breakdown of the medium,

at least one of the electrodes extending from a first boundary adjacent the record medium path to a second boundary relatively remote from said record medium path with the applied voltage tending to produce current flow along a current flow path extending between said first and second boundaries,

wherein the improvement comprises

said current flow path between said first and second boundaries being formed of a photoconductive material whose resistivity along said current flow path determines the total resistance between said first and second boundaries, and

means providing for the illumination of a limited segment of said photoconductive material adjacent said first boundary for tending to concentrate charge flow between the one of the electrodes and the record medium at said limited segment, other portions of said current flow path between said limited segment and said second boundary having a relatively high resistivity in comparison to the resistivity of said illuminated segment.

3. An electrostatic recorder comprising a pair of spaced apart, confronting electrodes, means for moving a charge retentive dielectric record medium along a record medium path between said pair of electrodes,

means comprising an electric signal source connected to said electrodes for applying a voltage to said electrodes which voltage varies in accordance with a signal to be recorded and is greater than a threshold voltage that produces an electric field between the electrodes corresponding to an abrupt rise in electrode current flow as said record medium passes therebetween but of magnitude less than that to cause breakdown of the record medium,

at least one of the electrodes having a first boundary adjacent the record medium path and a second boundary relatively remote from the record medium path, and having a current flow path extending between said boundaries for said electrode current flow,

wherein the improvement comprises

said current flow path being of photoconductive material between said first and second boundaries and the resistivity of the photoconductive material over the extent of said current flow path between said boundaries determining the total resistance presented to said electrode current flow between said boundaries, illuminating means directed onto said photoconductive material for supplying a substantially constant illumination to said photoconductive material and tending to produce a substantially restricted region of gaseous discharge between the one of said electrodes and the record medium in comparison to the region of gaseous discharge in the absence of said illuminating means, and

means for maintaining said illumination of said photoconductive material continuously at a substantially constant level throughout a recording operation.

4. The recorder of claim 3 with said first boundary of said one of the electrodes being in contact with the record medium, and the region of said current flow path directly adjacent said first boundary being illuminated by said illuminating means to provide a substantially reduced resistivity thereof in comparison with other portions of said photoconductive material between said first and second boundaries.

5. The recorder of claim 3 with said maintaining means maintaining said illumination at a level corresponding to substantially improved resolution in the recording of said signal as compared to the resolution provided by said electrodes in the absence of said illumination.

6. The recorder of claim 3 with said maintaining means maintaining said illumination at a level for substantially reduced recorded noise in the recording of said signal on said record medium in comparison to the recorded noise in the absence of said illumination.

7. An electrostatic transducer comprising means for moving a charge retentive dielectric record medium along a record medium path, first and second frontal electrodes disposed in proximity to the record medium path at one side thereof and successively spaced along the path,

a backing electrode disposed at the opposite side of the record medium path in confronting relation to said frontal electrodes,

a source of electric bias potential connected between said first and second frontal electrodes to produce a voltage between the first frontal electrode and the backing electrode exceeding a threshold voltage that produces an electric field between the first frontal electrode and the backing electrode of intensity corresponding to an abrupt rise in current flow in the first frontal electrode as said record medium passes along said record medium path but of magnitude less than that to cause breakdown of the record medium, means comprising an electric signal source connected between said second frontal electrode and the backing electrode for applying charges of opposite polarity to the opposite sides of the record medium in accordance with a signal to be recorded,

at least one of the electrodes having a first boundary in proximity to the record medium and a second boundary relatively remote from said record me-

dium path and having a current flow path between said first and second boundaries along which electrode current flows during a recording operation,

wherein the improvement comprises said one of said electrodes being formed of a photoconductive material between said first and second boundaries with the resistivity of the photoconductive material along the extent of said current flow path determining the total resistance presented to said electrode current flow between said first and second boundaries,

illumination means for supplying a substantially constant illumination to said photoconductive material and tending to produce a substantially restricted region of gaseous discharge between the one of said electrodes and the record medium in comparison to the extent of the region of gaseous discharge in the absence of said illumination, and

means for maintaining the illumination of said photoconductive material continuously at a substantially constant level throughout a recording operation.

8. The transducer of claim 7 with said first boundary of said electrode being in contact with the record medium and said illuminating means illuminating a segment of said photoconductive material directly adjacent said first boundary while leaving another part of said photoconductive material between said first and second boundaries at a substantially higher resistivity than the resistivity of said segment.

9. The transducer of claim 7 with the characteristics of said illumination being adjusted for substantially improved resolution in recording said signal on the record medium in comparison to the resolution in the absence of said illumination.

10. The transducer of claim 7 with the characteristics of said illumination being adjusted for substantially reduced recorded noise in comparison to the recorded noise in the absence of said illumination.

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