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(54) **Title:** SEMI-INSULATING MATERIAL TESTING AND OPTIMIZATION

(57) **Abstract:** Testing of material for use in electrophotographic printing for characteristics determined to be important for efficient high quality printing. These show a more complete profiling of the dielectric relaxation process in the material whether it is in use as a photoconductive drum or belt, charging rolls, developing rolls or output media such as paper or intermediate transfer belts. These characteristics which give a more complete understanding of the dielectric relaxation include intrinsic charge density, charge mobility, dielectric constant, and surface charge injection.

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TITLE OF THE INVENTION

SEMI-INSULATING MATERIAL TESTING AND OPTIMIZATION

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority of U.S. Provisional Patent Application No. 60/159,857 Entitled: SEMI-INSULATING MATERIAL TESTING AND OPTIMIZATION incorporated herein by reference filed October 15, 1999; U.S. Provisional Patent Application No. 60/192,203 Entitled: DIELECTRIC RELAXATION ANALYSIS SYSTEM incorporated herein by reference filed March 27, 2000; and U.S. PCT International Application No. PCT/US00/12728 incorporated herein by reference filed May 10, 2000.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

N/A

BACKGROUND OF THE INVENTION

In electrophotographic printing of images such as in the xerographic process, toner is attracted to a surface of a photoconductive drum or belt selectively charged and then transferred by electrostatic processes to print output media such as paper. The photoconductive drums or belts must function to hold a selectively applied charge corresponding to a document or image original. The output media must be able to dielectrically relax appropriately in order for fast, efficient printing of high quality images to be produced.

The properties of these materials that are so critical in the production of electrophotographic images have been poorly understood for the intended use. Traditional characterization of these materials typically involved resistance measurements and simple RC modeling, which was found to be of limited use if at all in selecting or designing materials advantageous for such uses.

Special reproduction environments present additional problems the causes of which are not well understood. These include the presence of toner scatter or print dropouts accompanying electrostatic discharge in the air gap over the paper, the potential for image deletion or image print through in duplex printing due to the presence of an image on the reverse side in the second pass through, the tendency of transparency material to not support good images printed on it and the problem of color shift due to residual charge effects in multi-pass color printing. Therefore, a novel technique for characterization of these materials for the purposes of understanding the mechanism, predicting the performance, and specification for material design, is needed.

SUMMARY OF THE INVENTION

The present invention tests materials for use in electrophotograpic printing with a whole set of characteristics determined to be important for efficiency and high quality images. The materials include, but not limited to, photoconductive drums or belts, charging rolls, developer rolls, intermediate transfer belts and output media such as paper, transparencies or textiles. It is well known that the performance of these materials in this application depends critically on the process of dielectric relaxation when the material is under electrical stress. The traditional method for electrical characterization of these materials typically involves measurements of resistance in closed-circuit experiments and analyses based on the equivalent circuit model, which have been found to be of limited success in correlating the results with the imaging performance.

In the present invention, a test system and data analysis procedure are provided to characterize dielectric relaxation process in these materials in terms of charge transport parameters that include, but not limited to, intrinsic charge density, charge mobility, and charge injection from the contact surfaces.

The apparatus of this invention consists of a charging source, a voltage detector and a current detector in an open-circuit mode of measurement. The configuration closely simulates the actual application of the materials in electrophotography and thus, can yield information more relevant for the applications (than the conventional resistance measurement in a closed circuit). Furthermore, the non-contact feature of the test system enables non-destructive, high speed scanning evaluation over a large two-dimensional area of the material. The apparatus is in part similar to the one described in commonly owned US patent 5,929,640, incorporated herein by reference.

The data are processed based on a model developed from first principle charge transport theory. The model provides the procedure for deducing the above-mentioned charge transport parameters from the measured voltage and/or current. Furthermore, a single figure of merit, namely, an effective resistance or an apparent resistance, that consolidates the roles of a large number of charge transport parameters mentioned above, can also be deduced from the measured voltage and/or current for routine characterization such as in production quality control.

The data acquisition and processing described above are carried out automatically by the control software.

A good correlation has been obtained between the charge transport parameters and printing performance. Common print quality deficiencies, for example, toner scatter, image deletion, image print through in duplex printing, and color shifts in full color prints, can be attributed to inadequate dielectric relaxation in the materials involved, in this case, the transfer media. Thus, a dielectric relaxation profile of a material obtained by the technique and analysis of this invention serves the purpose of performance prediction and design guideline for new materials.

BRIEF DESCRIPTION OF THE DRAWING

These and other features of the present invention are more fully described below and in the accompanying drawing of which:

Fig. 1 is a diagram of an application of the invention:

Fig. 2 is a circuit diagram of an equivalent circuit view characterizing the environment of the invention;

Fig. 3 is a graph illustrating the deficiency inherent in the traditional analytical model;

Fig. 4 is a further diagram of an application of the invention illustrating applicable theory used with the invention;

Fig. 5 illustrates the electric fields present in the environment of the application along with applicable theory;

Fig. 6 is a chart and associated formulas illustrative of the effect of a parameter measured according to the invention;

Fig. 7 is a chart and associated formulas illustrative of the effect of a further parameter measured according to the invention;

Fig. 8 is a diagram of apparatus useful in performing measurements according to the invention;

Fig. 9 illustrates a further form of apparatus for performing measurements according to the invention;

Fig. 10 illustrates an alternative form of scanning apparatus for performing measurements according to the invention;

Fig. 11 illustrates an equivalent circuit formulation for expressing parameters according to the invention;

Fig. 12. This figure is intentionally left blank

Fig. 13 is a graph illustrating the effect of a material parameter on charging voltage over time;

Figs. 14a and 14b are graphs illustrating the effects on charging and discharging situations of a parameter measured according to the invention;

Fig. 15 is a graph illustrating the effects on charging and discharging situations of a parameter measured according to the invention;

Fig. 16 is a graph illustrating the effect on relaxation current of two parameters measured according to the invention;

Figs. 17 - 19 are graphs and associated formulas illustrating techniques for determining a further parameter according to the invention;

Fig. 20 is a diagram of a measurement set up useful in the invention;

Fig. 21 is a graph and associated formulas useful in determining a parameter of dielectric relaxation according to the invention;

Fig. 22 is a graph and associated formulas illustrating the relationship between a parameter measured according to the invention and other electrical properties;

Fig. 23 is a diagram of portions of measurement apparatus and associated formulas useful in describing a measurement technique and associated calculation of a parameter according to the invention:

Fig. 24 is a graph illustrating the interdependence of the dimensions in the apparatus of Fig. 23 and measured parameters;

Figs. 25 and 26 are graphs illustrating the considerations in selecting materials according to the invention for use in applications involving air breakdown.

Figs. 27 - 30 are graphs illustrating the effect on transfer efficiency of the parameters according to the invention;

Figs. 31a and 31b are system diagrams illustrating the creation of two dimensional output displays from data taken over an area of a material according to the invention;

Fig. 32 is a graph illustrating the effect of parameters on duplex printing according to the invention;

Fig. 33 is a diagram illustrating the use of the present invention with the issues involved with printing on transparency media;

Figs. 33a-33c are diagrams illustrating the process of multi-pass printing on output media;

Figs. 34-35 illustrates the transfer efficiency differences between passes in multi-pass reproduction.

DETAILED DESCRIPTION OF THE PREFERED EMBODIMENT

The present invention provides for a complete understanding of electrophotographic printing processes by which semi-insulating material such as media, which includes paper and the like to be printed on, or printing equipment elements like rollers, belts, and drums used in the steps of printing. In the present invention the material is characterized according to a plurality of properties affecting the efficiency of charge transport by testing in a fixed or scanning procedure. The properties include such characteristics as charge mobility, μ, intrinsic charge density, q, dielectric constant, ε, and charge injection, s. The defect detection operates in a scanning mode to identify the nature and location of a defect in the material and to characterize its resistance by apparent resistance, Ra, or effective resistance, Re.

Fig. 1 shows the application of these materials in electrophotography schematically. Exemplary of a toner transfer system includes a biased circuit 20 across the entire set of elements comprising of electrodes 18, a charged photoreceptor 16, a patterned toner layer 14, an air gap 22 and the receiver or media 10. The voltage or current applied by the biased circuit is distributed among all the elements in the circuit and generates an electric field in each element. To maximize the toner transfer efficiency, the electric field in the toner layer must be maximized. This can be accomplished effectively by relaxing (decreasing) the voltage across the media, thereby shifting the bias voltage in the media to the other elements in the circuit, including the toner layer.

High efficiency which translates into fast operation and high quality printed output requires the dielectric relaxation across the media be fast and uniform. Testing of materials for this function is important to identify formulations that fit these stringent demands closely. Traditional approaches have modeled the material as a RC circuit as shown in Fig. 2. There the relaxation properties are modeled as a resistance 24, capacitance 26 and conventional source of voltage 28 with the predicted relaxation 30 shown as a plot of logarithm of voltage against time in Fig. 3. Actual response of typical materials is shown in curve 32 showing how poorly the prior models have predicted material relaxation properties.

The present invention provides testing techniques that accurately determines the dielectric relaxation behavior of semi-insulating materials leading to a superior understanding of the suitability of materials and a definition of optimum properties for electrophotographic printing. Fig. 4 identifies the theoretical basis for the use of the parameters, including charge mobility, intrinsic charge density, dielectric constant and charge injection, in describing such dielectric relaxation.

Exemplary of an application of the present invention is electrostatic toner transfer. Traditionally, conductivity of the receiving media is used as a figure of merit for transfer efficiency. The conductivity is the product of charge density and mobility. But the two factors must be treated independently, because a material of a given conductivity with a high charge density and a low mobility may not work equally as a material of the same conductivity with a low charge density and a high mobility. The mobility in materials of present interest is generally field dependent, and the dependence has important effects on the dielectric relaxation. Also, the physical condition at the interfaces between the sample and electrode can strongly influence the extent of charge injection, which in turn affects the dielectric relaxation. The extent of charge injection can be determined by steady state current measurements as described later.

The intrinsic charge density, q, affects the efficiency of toner transfer to a receiving material as shown in Figs. 5 and 6. Fig. 5 shows the electric field variation across the toner layer 14 at one instant of time in the transfer process. Fig. 6 shows how the efficiency increases as a function of time, where time is given in units defined in terms of transit time, tT, which is inversely proportional to mobility. The longer the time allowed for toner transfer, the larger the electric field across the air gap 22 and the toner layer 14 rather than the receiver or media 10, and hence, the greater is the efficiency or amount of toner to be transferred. The nested curves show that the efficiency increases dramatically with increasing intrinsic charge density of the material. For smaller q, the efficiency is further dependent on charge injection, s. As shown in Fig.7, the time for full transfer, tf, increases as charge injection decreases. In practice, because the process time in a given printer has to be longer than the time to full transfer, a lower limit on mobility in the receiver can be derived from the time to full transfer, process time, the receiver layer thickness, and the bias voltage.

Apparatus for the measurement of these and other parameters that predict the dielectric relaxation and resulting efficiency of materials and media for the creation of images by electrophotography is shown in Figs. 8 - 11. Fig. 8 shows a rotating drum 40 having a material 42 such as a coating or paper sheet, to be tested for dielectric relaxation firmly placed around it. A corona charge applicator 44, energized by a source 46, charges the material 42. The drum 40 conducts, through current sensor 48, to facilitate the relaxation of the material 42. The voltage on the material is sensed by a non-contact detector 50 placed at a distance from the corona charger 44. The voltage output is measured as a function of time since the application of the charge. This signal, along with outputs from other units descried below, is used in a processor 52. The current output during corona charging is sensed by a current sensor 48 connected to the rotating drum 40. The apparatus of Fig. 8 is more fully described in part in commonly owned US patent, 5,929,640, incorporated herein by reference.

Fig. 9 shows further apparatus used for determining responses of a material to the application of a current and that is used in determining the dielectric relaxation parameters such as charge injection. A body of material 60 is instrumented to receive current on either or both the top and bottom surfaces 62 and 64 from current sources 66 and 68 which can include a corona source. A voltage sensor 70 detects the surface voltage over time resulting from the application of a current to either or both of the surfaces 62, 64. Insulating (or, blocking) layers 72 and/or 74 are added selectively to isolate one or both surfaces to enable detection of injection properties for each surface.

Fig. 10 shows a test set-up similar to that of Fig. 8 except that a combination 83 of a corona source 82 and a voltage sensor 86 moves along the axial direction of a cylindrically shaped sample or helically around the sample. Corona source 82 applies a charge and the resulting voltage is sensed by a non-contact sensor 86 and processed by voltage processor 88. Such a processor may be used with all the other tests described for calculation and other purposes. A current sensing circuit 90 is provided for detecting the current from the material in response to the application of a voltage or current.

Fig. 11 shows an equivalent circuit for the replacement of the resistance R of a conventional model for the dielectric relaxation of a material with a parameter, Re 100, that is determined from the testing with the apparatus shown above and described below.

Using apparatus above, such as that in Figs. 8 or 10, a charge is applied to a test material and the buildup of the charge measured as voltage or current as a function of time at a controlled scanning speed. Fig. 12 shows the theoretical relations between the above parameters in material 110 and the measured voltage or current. Typical results are shown in Figs. 13-16. In Fig. 13, the curves show the effect of intrinsic charge density on the build up of the voltage. The larger the charge density, the slower is the build up.

Figures 14 a and 14b show the effects of charge injection, specified by the parameter "s", on the build-up and the decay of the voltage respectively. It is shown that the build-up is less sensitive than the decay to variation in charge injection. The same effect is seen in Fig. 15, in which the material has an order of magnitude higher charge density than that in Fig. 14. Additionally, it can be seen that the higher charge density reduces the charging voltage than that in Fig.14.

The above and related experimental results lead to a set of criteria for designing receiver materials such as intermediate transfer belt, transfer rollers or paper for efficient transfer. High charge density is essential for good transfer efficiency. In the case of transfer belt or rollers, however, the stability of charge injection becomes equally critical since the surface conditions of the receiver material may degrade over time in use.

Using the apparatus of Fig. 9, the injection parameter, s, can be found for both the top and bottom surfaces of the material. This is done by applying a current to the material with no blocking layer and with one blocking layer on each side. The steady state current with no blocking layers is a combination of the surface charge injection of both surfaces. These are separated using a blocking layer for each surface separately and a corona application of voltage. The current will fall off as a function of time to some steady state level as the material collects charge. These will differ, or not, as a function of the surface being not blocked.

Fig. 16 shows the effect of charge injection on the steady state current, and suggests the use of steady state current for the determination of charge injection level. These are in normalized values which can be resolved to real numbers by those skilled in the art.

Charge mobility is determined from experimental results of steady current measurements utilizing the physics that relates the charging current into a material, its dimensions and the voltage across the material. This relationship can be expressed as:

$$Jss < Jo = \varepsilon\mu Vmax^2/L^3 .$$

This relationship places a lower bound on the mobility. The Jss or steady state current, measured from the techniques above should be less than the space-charge-limited current, Jo, and less than Jmax as shown in Fig. 17. The maximum charging or cut-off voltage (Vmax) of the corona and thickness, L, of the material are design parameters known in advance. The dielectric constant is determined by conventional methods for the material. Using an iterative procedure as shown in Figs. 18 and 19 involving normalized values of Jmax/Jo and Jss/Jo, it is possible to obtain the lower bound value of the mobility. Mobility is typically a function of the polarity of the charging current and must be done with both positive and negative corona sources to get the values for both.

Charge density is determined using a set up of the type shown in Fig. 9 using a corona for source 66 and with both blocking layers 72 and 74 in place, schematically shown in Fig. 20. The intrinsic charge density is determined by the integral of the charging current, per unit of material, from its initial high value at the time of activation of the corona to zero when the corona cut off occurs.

The apparatus will, in its data, include the effect of the blocking layers and this must be factored out in the final figures for intrinsic charge density using the equations associated with Fig. 21. The subscripts 1, 2 and s represent the first and second insulator dimensions of length, L, and k dielectric constant, with Vmx being the corona cut-off voltage.

The totality of these parameters present a level of complexity necessary to fully understand the characteristics of a material either as a transport material or print media. They are not as convenient in all cases as a single R and so there is a value to return to the simple model of an RC circuit shown in Fig. 11 to come up with an effective resistance, Re, to describe the material's bulk resistance and its surface charge injection properties. Such an effective resistance, which can be used as a figure of merit for quality control, comparison or advertising purposes, can be arrived at using the information provided below.

Fig. 22 illustrates the variation of effective conductivity, and its mathematically related resistivity, in actual experimental measurements and calculations. Here, R_{ch} is the ratio of V_{max}/J_{max} as defined above and $R_b = R_e R_{ch}/(R_e + R_{ch})$.

The effective resistance can be shown to be equal to the ratio of the voltage to the current values at steady state in the measurements using Fig. 9 apparatus with full or partial blocking. This effective resistance is solely determined by charge injection and is independent of intrinsic charge density.

In cases where scanning apparatus of the sort illustrated in Figs 8 or 10 are used, the time delay between charge application at the corona source and the point of detection, illustrated schematically in Fig. 23 has an effect on the measurement of the resistance. To account for this effect, an apparent resistance, defined as $Ra=V_{av}/J_{av}$ in Fig. 24, is obtained from experiments. Based on the theory described in Fig. 23, the effective resistance Re can be deduced from the value of Ra.

The teaching of this invention allows for the solving of various problems that affect electrophotographic printing. Figs.25 and 26 show the air-gap voltage as a function of air gap thickness, for process times differing by two orders of magnitude, as compared to the Paschen breakdown threshold. These are given in two sets of curves for different charge density and charge injection values. This allows a design of system and media parameters to avoid breakdown possibilities by lying outside of the Paschen threshold area. Given the fact that some safety reserve is desired and that the more irregular the paper the greater the reserve, this allows specifying those parameters more precisely.

The problem of image deletion and print through in duplex printing is addressed using the media characteristics of charge density and injection, q and s respectively, in Figs. 27 - 32 as a function of time, t.

The presence of image on a first side interferes with the local injection of charge and thus reduces the transfer efficiency. The figures show that with increasing q and/or s this can be reduced, in particular with q above 2 or s above 1 and t above 10, all in normalized units.

In the use of transparencies for print output media, there is typically, as shown in Fig. 33, a body 120 with insulating properties preventing effective dielectric relaxation for electrophotographic printing. The substrate side and the toner receiving side are provided with more conductive anti-static coatings, SSC(124) and RSC(122), respectively. Typically a path 126 to ground exists and for more conductive layers 122 shields the effects of a positive bias 128 reducing transfer efficiency and creating poor print quality. This test procedure identifies materials with the potential to cause this residual charge and resulting poor image quality in printing.

In color printing the failure to neutralize charge in toner from a first pass in a multi-pass color printing process will affect the transfer efficiency of the subsequent pass. As Shown in Figs. 33a, b, c the residual charge in toner 140 applied from a photo receptor 142 to receiving media 144 impacts the application of a second toner layer 146 applied subsequently. Additional layers of toner may be placed down subsequently. Neutralization of the charge in an off duty or wait state as shown in Fig. 33b will allow the second color to faithfully be transferred depending on the amount of neutralization. This as a function of the time, tn, allowed for it to occur. The efficiency of this is shown in Fig. 34 and 35 for first and second passes showing a marked efficiency reduction in later passes. This test allows selection of material for color printing to optimize quality and speed.

The test procedures noted above produce output values in the form of one or more parameters of dielectric relaxation of the materials under test. These materials typically are formed with a two dimensional surface and may be in thin sheets, on rollers, belts, drums or otherwise.

The invention is also useful in the generation of two dimensional maps of the parameters of dielectric relaxation described above for material under test. This can be of value as documentary records for quality control, production analysis, aging information, and the like, applicable to output media, rollers, drums and belts among others. Fig. 31a illustrates an example of mapping of the dielectric relaxation data obtained by any of the scanning procedures and apparatus above described. An exemplary scanning system 180 provides output signals representative of one or more parameters of dielectric relaxation generated in these testing apparatus and provides it to a processor 182. Processor 182 performs the calculations described necessary to convert the raw data into actual parameters and format them for display on monitor 184 and also for output as a map 186 by printer 188. Such a map typically shows by color change, gray scale or otherwise the parameter as a function of position in the two dimensional material being tested. A map can be generated for each or either surface where surface properties are involved. The above identified US patent 5,929,640 shows further details of such mapping techniques.

Mapping or charting can also be applied to current flow of a non scanning test as shown in Fig. 31b. As shown there, a material 190 to be tested has charge applied to it through a source 192. Current flows out of the material through a matrix of conductors 194. The matrix includes an array of individual current sensors 196 for electronic scanning. Alternatively, the source is moved in two directions over the material sample for mechanically scanning. Both approaches provide current sensing over a two dimensional area of the material 190. The sensed current levels are applied through a demultiplexer 198 as appropriate to a processor 200 which performs required calculations to obtain the dielectric relaxation or response parameters desired from the set described above and formats them for display in a monitor 202. The processor 200 also formats the data for printing as a map or chart 206 by a printer 204. The Map 206 provides a two dimensional presentation of the parameter(s) using techniques and for purposes described above.

While the description above focuses upon the application of the invention to electrophotographic printing, it may be used in any application where dielectric relaxation properties of materials affects their performance when exposed to electric fields or potentials.

CLAIMS

1. A method for determining the intrinsic charge density property of a semi-insulating material comprising the steps of:

insulating said material from electrical conduction;

injecting charge into said insulated material over a time period from an initial application of maximum charge transfer to a substantially lesser transfer rate;

detecting the current represented by the transfer of said charge injected into said material;

determining the integral of the current over said time period.

2. The method of claim 1 further including the step of applying blocking layers over first and second surfaces of said material to provide said insulation.

3. The method of claim 2 wherein said step of injecting charge includes the step of injecting charge by application of a corona through said blocking layers.

4. The method of claim 1 wherein said time period extends until said current is substantially constant in time.

5. The method of claim 1 wherein said material is selected from the group consisting of print media and charge transport material.

6. A method for determining surface charge injection of a semi-insulating material comprising the steps of;

injecting current into said material in two cases where a blocking layer is applied to first one and then the other of each of two surfaces;

detecting the current at steady state conditions for said two cases; and

determining the surface charge injection for each of said two surfaces from the detected currents.

7. The method of claim 6 wherein said material is selected from the group consisting of print media and charge transport material.

8. The method of claim 6 wherein said step of injecting charge includes the step of injecting charge by application of a corona through said blocking layers

9. A method for determining surface charge injection of a semi-insulating material comprising the steps of;

measuring a steady state current in said material in response to the application of a current;

injecting charge into said material in two cases where a blocking layer is applied to first one and then the other of each of two surfaces;

detecting the current at steady state conditions for said two cases; and

determining the surface charge injection for each of said two surfaces from the measured and detected currents.

10. The method of claim 9 wherein said material is selected from the group consisting of print media and charge transport material.

11. A method for determining the charge mobility of a semi-insulating material comprising the steps of:

injecting current into a material with insulators on either surface, in each of two polarities;

measuring the maximum and steady state current flowing into the material as a function of time;

determining mobility from the measured currents.

12. The method of claim 11 further including the step of: determining a lower limit for said mobility.

13. The method of claim 11 further including the step of:

plotting a curve of calculated steady state current for said injection step against mobility;

interpolating between the measured steady state current value and said curve a mobility value.

14. The method of claim 11 wherein said material is selected from the group consisting of print media and charge transport material.

15. A method for characterizing semi-insulators selected from the group consisting of print media and transport materials comprising the steps of:

applying charge to the material;

detecting the current in said material as a result of the applied charge;

calculating the mobility of the material as a function of an electric field associated with applying said charge.

16. A method for characterizing semi-insulating material for the effects of two or more parameters including surface charge injection, charge mobility, and intrinsic charge density comprising the steps of:

applying charge to the material;

measuring the long term current and voltage;

determining effective resistance from the long term current and voltage.

17. The method of claim 16 wherein said applying step includes the step of applying through at least one blocking layer.

18. The method of claim 16 wherein said material is selected from the group consisting of print output media and a latent image transfer layer.

19. A method for measuring apparent resistance of a semi-insulating material in a test system comprising the steps of:

applying charge to said material over a plurality of sites at different times;

detecting surface voltage on said material at a site a predetermined time after application of said charge at said site;

sensing current in said material as a function of applied charge;

determining an apparent resistance for said material as a function of said detected voltage and sensed current adjusted for the predetermined time.

20. Media for receiving electrophotographically generated images comprising;

image receiving material in the form of a two dimensional layer;

said material being selected for use in electrophotographic reproduction based on dielectric relaxation characteristics of said material;

said characteristics selected from the group including intrinsic charge density, charge mobility, surface charge injection, and dielectric constant.

21. The media of claim 20 wherein said intrinsic charge density is at least approximately 1.0 normalized unit, given by □V_{mx}/L^2.

22. The media of claim 20 wherein said surface charge injection, in combination with an electrode placed in proximity to said layer, is at least approximately 0.1 normalized units, given by □□V_{mx}/L^2.

23. In an electrophotographic reproduction system a combination of media and system operating parameters that reduces the potential for air gap breakdown adjacent said media by operating outside of the Paschen threshold.

24. Media and systems for use in double sided electrophotographic reproduction having parameters for system process time, and media charge density and injection which avoid significant image print through incidents.

25. The media and system parameters of Claim 24 in which one or more of the criteria of $q > 2$ or $s > 1$ and $t > 10$ are met, all in normalized units.

26. A method for characterizing the dielectric relaxation properties of a material comprising the steps of:

applying charge to said material;

sensing a response of said material to the applied charge;

determining at least one dielectric relaxation property of said material from said sensed response.

27. The method of claim 26 wherein said dielectric relaxation property includes one or more of the properties selected from the group of intrinsic charge density, surface charge injection, charge mobility, effective resistance, and apparent resistance.

28. The method of claim 27 further including the step of applying said charge from a plasma source.

29. The method of claim 28 wherein said material is a semi-insulating material.

30. The method of claim 29 wherein said semi-insulating material is selected from the group of materials for use as electrophotographic output media, photoconductive drums or belts, charging rollers, intermediate transfer belts, and development rolls.

31. A method for providing a two dimensional output representation of dielectric relaxation properties of a material comprising the steps of:

applying charge to said material;

providing output representations of at least one dielectric relaxation property over an area of said material in response to the charge applied to said material.

32. The method of claim 31 wherein said charge applying step includes the step of scanning said material with a plasma source.

33. The method of claim 32 further including the step of sensing the response of said material over said area to the applied charge as it is scanned;

said providing step responding to said signal.

34. The method of claim 31 including the step of

sensing the response of said material to the applied charge with an array of sensors to provide a plurality of output signals;

said providing step responding to said plurality of output signals.

35. Apparatus for determining the intrinsic charge density property of a semi-insulating material comprising:

insulating layers on said material insulating it from electrical conduction;

a charge injector for injecting charge into said insulated material over a time period from an initial application of maximum charge transfer to a substantially lesser transfer rate;

a current detector for detecting the current represented by the transfer of said charge injected into said material;

a processor for taking the integral of the current over said time period as a representation of said intrinsic charge density.

36. The apparatus of claim 35 wherein said layers are blocking layers over first and second surfaces of said material to provide said insulation.

37. The apparatus of claim 36 wherein charge injector injects charge by application of a corona through said blocking layers.

38. The apparatus of claim 35 wherein said time period extends until said current is substantially unchanged.

39. The apparatus of claim 5 wherein said material is selected from the group consisting of print media and charge transport material.

40. Apparatus for determining surface charge injection of a semi-insulating material comprising;

a current injector for injecting current into said material in two cases where a blocking layer is applied to first one and then the other of each of two surfaces;

a detector for detecting the current at steady state conditions for said two cases; and

a processor for determining the surface charge injection for each of said two surfaces from the detected currents.

41. The apparatus of claim 40 wherein said material is selected from the group consisting of print media and charge transport material.

42. The apparatus of claim 40 further including a corona source for injecting current through said blocking layers.

43. Apparatus for determining surface charge injection of a semi-insulating material comprising the steps of;

measuring a steady state current in said material in response to the application of a current;

injecting charge into said material in two cases where a blocking layer is applied to first one and then the other of each of two surfaces;

detecting the current at steady state conditions for said two cases; and

determining the surface charge injection for each of said two surfaces from the measured and detected currents.

44. The apparatus of claim 43 wherein said material is selected from the group consisting of print media and charge transport material.

45. Apparatus for determining the charge mobility of a semi-insulating material comprising:

a current injector for injecting current into a material through insulators on either surface, in each of two polarities;

a sensor measuring the maximum and steady state current flowing into the material as a function of time;

a processor determining mobility from the measured currents.

46. The apparatus of claim 45 wherein said processor further determines a lower limit for said mobility.

47. The apparatus of claim 45 wherein said processor is further operative to provide a calculated steady state current as a function of mobility and operative in response to said measured steady state current and calculated current to provide mobility as an interpolation therebetween.

48. The apparatus of claim 45 wherein said material is selected from the group consisting of print media and charge transport material.

49. Apparatus for characterizing semi-insulators selected from the group consisting of print media and transport materials comprising:

means for applying charge to the material;

means for detecting the current in said material as a result of the applied charge;

means for calculating the mobility of the material as a function of an electric field associated with applying said charge.

50. Apparatus for characterizing semi-insulating material for the effects of two or more parameters including surface charge injection, charge mobility, and intrinsic charge density comprising the steps of:

means for applying charge to the material;

means for measuring the long term current and voltage;

means for determining effective resistance from the long term current and voltage.

51. The apparatus of claim 50 wherein said material is selected from the group consisting of print output media and a latent image transfer layer.

52. Apparatus for measuring apparent resistance of a semi-insulating material in a test system comprising:

means for applying charge to said material over a plurality of sites at different times;

means for detecting surface voltage on said material at a site a predetermined time after application of said charge at said site;

means for sensing current in said material as a function of applied charge;

means for determining an apparent resistance for said material as a function of said detected voltage and sensed current adjusted for the predetermined time.

53. Apparatus for characterizing the dielectric relaxation properties of a material comprising:

means for applying charge to said material;

means for sensing a response of said material to the applied charge;

means determining at least one dielectric relaxation property of said material from said sensed response.

54. The apparatus of claim 53 wherein said dielectric relaxation property includes one or more of the properties selected from the group of intrinsic charge density, surface charge injection, charge mobility, effective resistance, and apparent resistance.

55. The apparatus of claim 54 further including a plasma source for applying said charge.

56. The apparatus of claim 55 wherein said material is a semi-insulating material.

57. The apparatus of claim 56 wherein said semi-insulating material is selected from the group of materials for use as electrophotographic output media, photoconductive drums or belts, charging rollers, intermediate transfer belts, and development rolls.

58. Apparatus for providing a two dimensional output representation of dielectric relaxation properties of a material comprising:

means for applying charge to said material;

means for providing output representations of at least one dielectric relaxation property over an area of said material in response to the charge applied to said material.

59. The apparatus of claim 58 further including means for scanning said material with a plasma source to apply said charge to said material.

60. The apparatus of claim 59 further including means for sensing the response of said material over said area to the applied charge as it is scanned;

said providing means responding to said signal.

61. The apparatus of claim 58 including:

means for sensing the response of said material to the applied charge with an array of sensors to provide a plurality of output signals;

said providing means responding to said plurality of output signals.

62. The apparatus of claim 50 wherein said applying step includes the step of applying through at least one blocking layer.

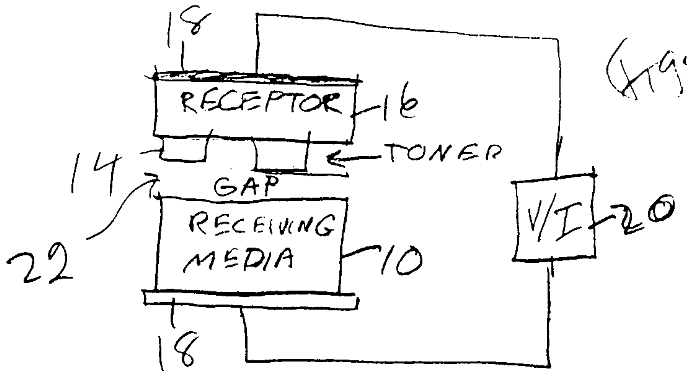


Fig. 1

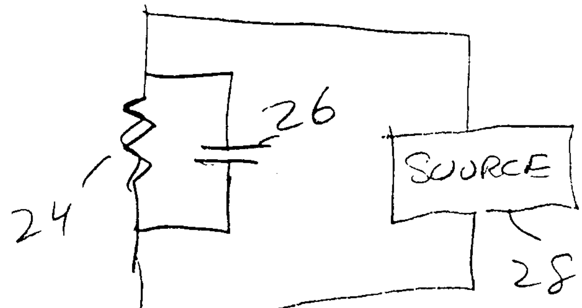


FIG. 2

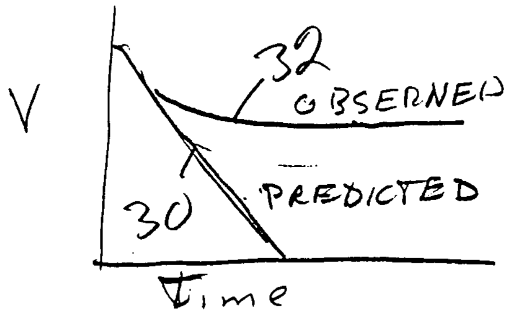


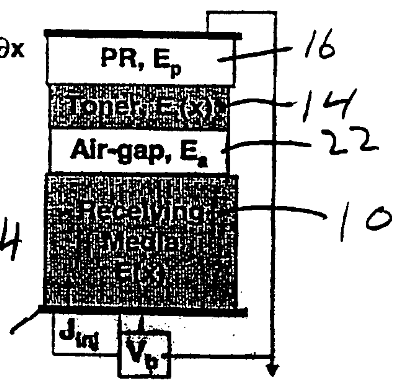
FIG. 3

- **Total Current:** $J_T = [\int_o^L (\mu_p q_p + \mu_n q_n)E dx - \varepsilon(dV/dt)]/L$
- **Poisson's eq.:** $\partial E/\partial x = (q_p + q_n)/\varepsilon$
- **Charge continuity:** $\partial q/\partial t = - \partial(\mu q E)/\partial x$
- **Field-dep. Mobility:** $\mu(E) = \mu_o(E/E_o)^p$
- **Injection currents:**

  $J_{inj}(0) = s\ E(0)$

✔ **Roles of μ and q treated separately, not as a product $\mu q = \sigma = 1/\rho$**

FIG. 4



- **Fields in toner layer:**
  $E_t(x) = E_{to} + q_t x/\varepsilon_t$
- **Transfer efficiency:**
  from $E_t(x_t) = 0$

  $\eta = x_t/L_t = -\varepsilon_t E_{to}/q_t L_t$

  - function of time, charge density q_i, and injection s

    $q_i = \sigma/(\mu_p + \mu_n)$

    unit: $q_o = (\varepsilon_r V_b/L_r^2)$
    $\approx 3\times10^{-6}$ C/cm^3

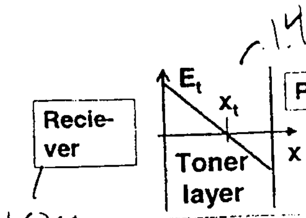


FIG 5

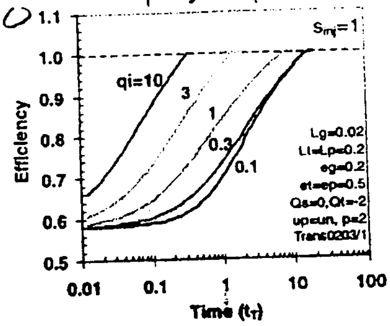


FIG 6

$t_F = m\, t_T = m\,(L_r^2/\mu_o V_b)$; $q_i = n q_o = n\,(\varepsilon_r V_b/L_r^2)$

- **Sensitive to injection (s) at low q_i**
- **Process time :**
  $t_{proc} > t_F = m\,(L_r^2/\mu_o V_b)$
- **Mobility required:**
  $\mu_o > m\,(L_r^2/t_{proc} V_b)$
  $\approx m\,(10^{-6}$ cm^2/ Vsec)
  for $t_{proc} = 0.1$ sec

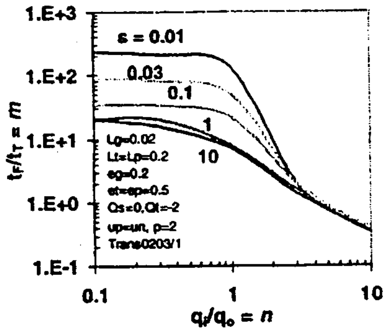


FIG 7

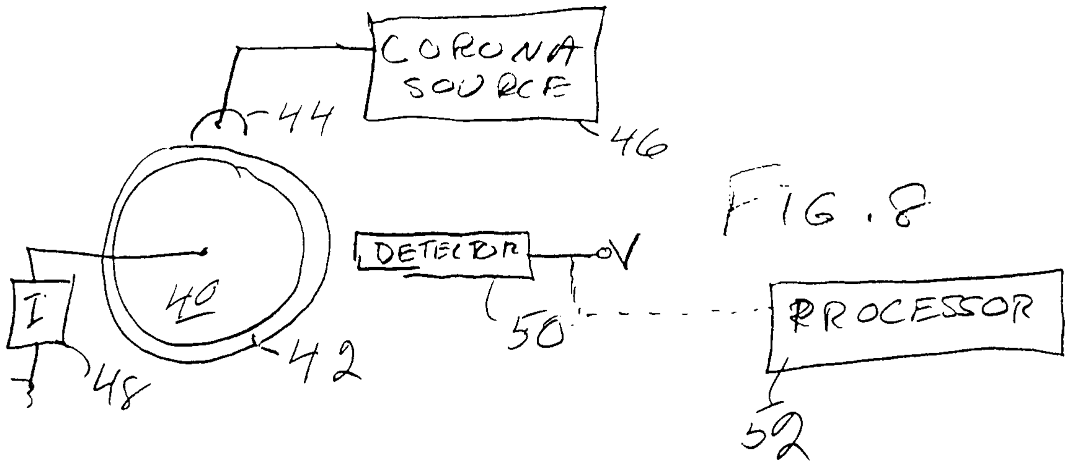


FIG. 8

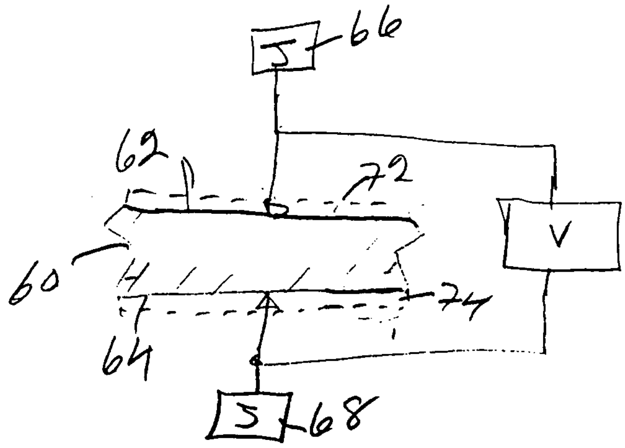


Fig. 9

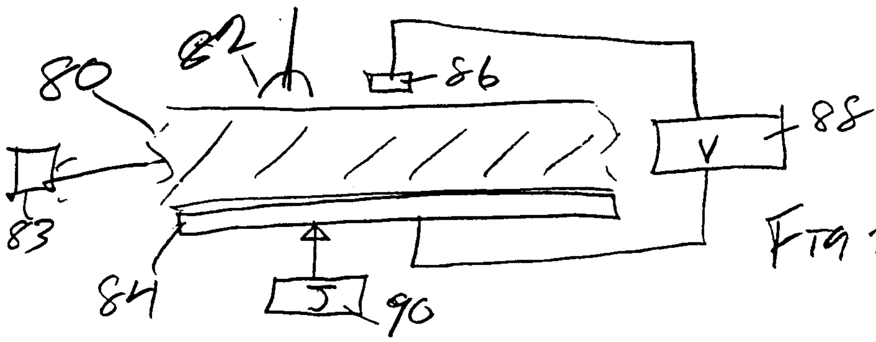


Fig. 10

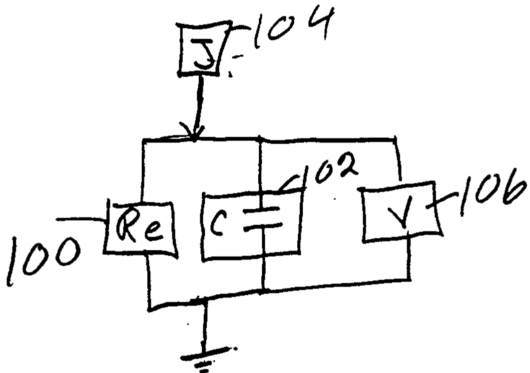


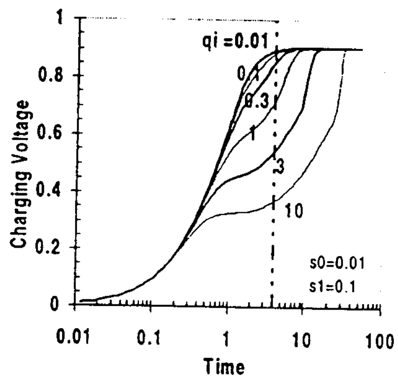
Fig. 11

- Total Current: $J_T = [\int_o^L (\mu_p q_p + \mu_n q_n)E dx - \varepsilon(dV/dt)]/L$
- Poisson's eq.: $\partial E/\partial x = (q_p + q_n)/\varepsilon$
- Charge continuity: $\partial q/\partial t = - \partial(\mu q E)/\partial x$
- Field-dep. Mobility: $\mu(E) = \mu_o(E/E_o)^p$

✓ Injection currents:
$J_{inj}(0) = s_0 E(0)$; $J_{inj}(L) = s_1 E(L)$

✓ Separate independent roles of q and μ, not as $\sigma = \mu q$

- Increased by corona
- Decreased by:
  - * Depletion of intrinsic charge q_i
  - * Transit of injected charge
- Intrinsic q_i varied
- Long $t_{chg} >> 10t_o$
  V_s indep. of q_i
- Short $t_{chg} < 10t_o$
  low V_s for high q_i



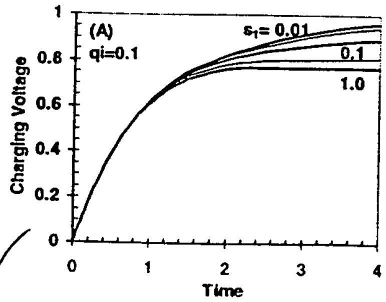
V in corona cut-off V_{mx}
time in $t_o = L^2/\mu V_{mx}$
q_i in $q_o = \varepsilon V_{mx}/L^2$

FIG 13

- **Dependence on Injection (s_1) for $0.01 < s < 0.1$**

Charge: $\Delta V \approx 0.07$

Discharge: $\Delta V \approx 0.4$



14a

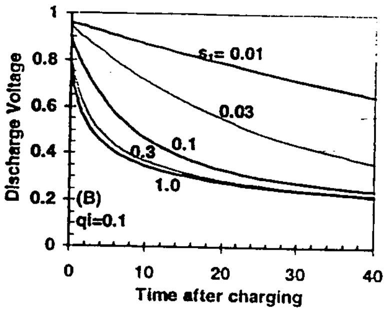


FIG 14b

with small $q_i = 0.1q_o$

- Intrinsic charge density (larger) $q_i = q_o$
- Lower V_{chg}, weaker depend. on s_1 ($0.01 < s_1 < 1$)
- V_{dischg} : Strong dependence on s_1

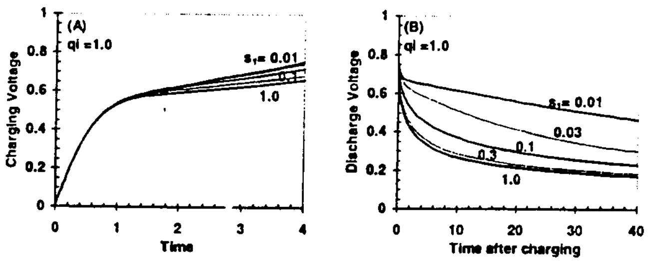


FIG. 15

- Steady state current J_{ss} determined by charge injection s, independent of intrinsic charge density q_i
- Time to reach steady state increases with q_i → estimates of q_i

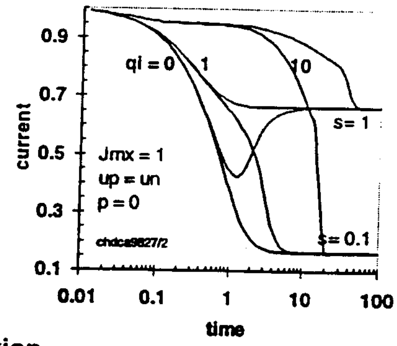


FIG. 16

- For high charge injection,
  $J_{ss} < J_o = \varepsilon\mu V_{mx}^2/L^3 \approx J_{SCL}$
  or $< J_{mx}$
  whichever is less
- Mobility $\mu \geq J_{ss}L^3/\varepsilon V_{mx}^2$

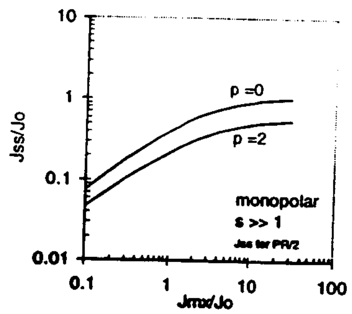


FIG 17

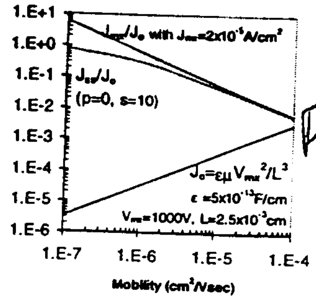


FIG. 18

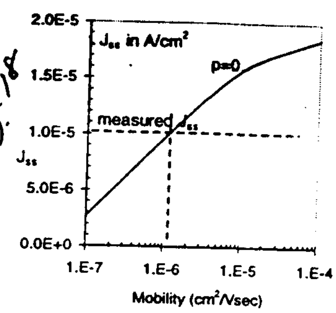


FIG 19

Procedure:

1. For a range of possible μ, calculate $J_o = \varepsilon\mu V^2/L^3$ (blue curve)
2. Divide measured J_{mx} by J_o (magenta curve)
3. Interpolate from J_{ss}/J_o vs J_{mx}/J_o curve in previous slide (green curve)
4. Multiply by J_o. Plot J_{ss} vs μ. Use measured J_{ss} to interpolate for

- Time Integral of Charging Current with injection-blocked sample
- $Q_C = [V_{mx} + Q_i L_s/\varepsilon_s]/(L_1/\varepsilon_1 + L_2/\varepsilon_2 + L_s/\varepsilon_s)$

  for $Q_i = q_i L_s \leq V_{mx}/(L_1/\varepsilon_1 + L_2/\varepsilon_2)$

  $Q_{Cmx} = V_{mx}/(L_1/\varepsilon_1 + L_2/\varepsilon_2)$

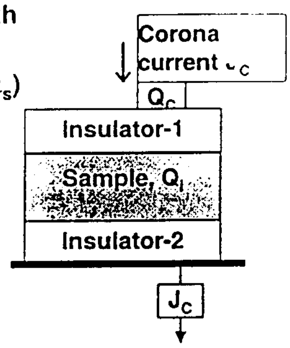
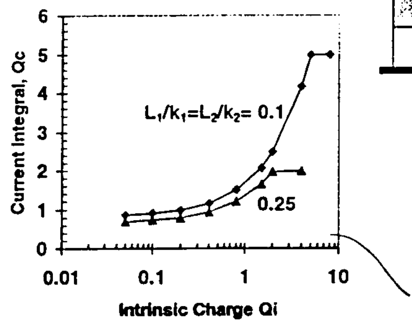


FIG 20



Media/9-00

FIG 21

- Effective R and σ: $R_e = L/\sigma_e A$
- $J_{ss} = J_{mx}(R_b/R_e) = J_{mx}/(1 + R_e/R_{ch})$

  $= J_{mx}/(1 + L/\sigma_e A R_{ch})$ (red curve)

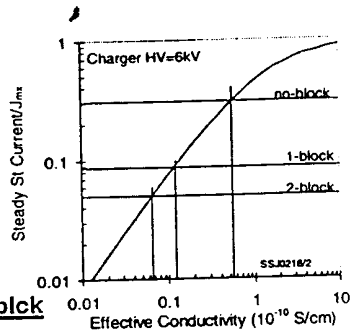
  $\rightarrow \sigma_e = J_{ss} L/AR_{ch}(J_{mx} - J_{ss})$
- Expt'l data (HV= 6kV):

  J_{mx}=11.5 μA; $L = 10^{-2}$ cm

  $R_{ch} = 0.805 \times 10^8 \Omega$; A =1 cm^2

	2-blck	1-blck	No-blck
obs. J_{ss}/J_{mx}	0.05	0.086	0.31
calc. σ_e	0.065	0.12	0.55 (10^{-10}S/cm)
calc. R_e	15.4	8.3	1.82 ($10^8\Omega$)

(agree with results from V_{ss}/J_{ss})



σ_e of the same sample varies due to different injection

FIG 22

- **Scanning Charger and Probe**
  Speed= s; Sizes = W_c and W_p
  Separation (tail-to-head)= d_{cp}
  – Charging time: $t_c = W_c/s$
- Voltage decay after charging:
  $V(t') = V(t_c)\exp(-t'/R_eC)$, $(t' = t - t_c)$
- **Measured Voltage: V_{av}** (average over W_p)
  $x = x_o$ to $x_o - W_p$; or $t' = t_s$ to t_s+t_p where $t_s = d_{cp}/s$, $t_p = W_p/s$
  $V_{av} = V(t_C)(R_eC/t_P)\exp(-t_s/R_eC)[1 - \exp(-t_P/R_eC)]$
- **Measured Current: J_{av}** (average over W_c)
  $x = x_o$ to x_o+W_C, or $t = t_c$ to 0
  $J_{av} = J_{mx}(R_b/R_e)\{1 + (CR_eR_b/t_cR_{ch})[1 - \exp(-t_c/CR_b)]\}$
- **Apparent resistance defined as,**
  $R_a = V_{av}/J_{av}$

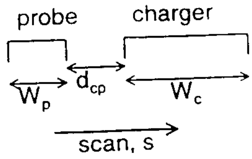
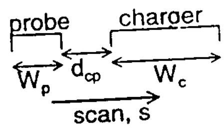


FIG 23

- **Scanning Charger and Probe**
- **Measured Voltage: V_{av}**, average over W_p
  $x = x_o$ to $x_o - W_p$; or $t = t_s$ to t_s+t_p
- **Measured Current: J_{av}**, average over W_c
  $x = x_o$ to $x_o+ W_C$, or $t = t_c$ to 0
- Apparent Resistance
  $R_a = V_{av}/J_{av}$
  varies with
  scan speed s,
  equivalent R_e,
  probe/charger size, t_p/t_c
  probe-charger separation
  charger J-V characteristics



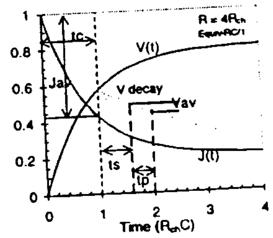
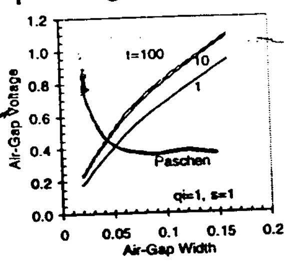


FIG 24

- **Air gap Voltage vs. Paschen curves**

FIG 25



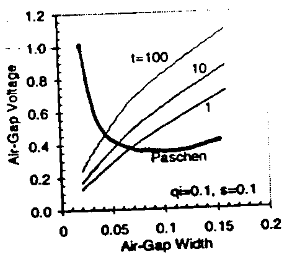
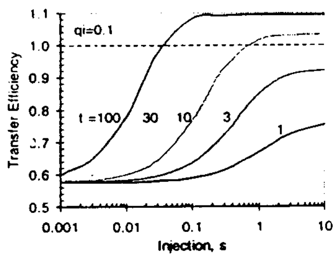


FIG 26

- **Conclusions: Gap voltage fluctuations**
  - **insensitive to DR parameters (q_i, s)**
  - **likely triggered by increased gap due to non-uniformity in media/toner contact geometry**

- Cause: Images on back side block charge injection
- Sensi:ivity of Transfer Efficiency to injection (s) at various process times

FIG. 27



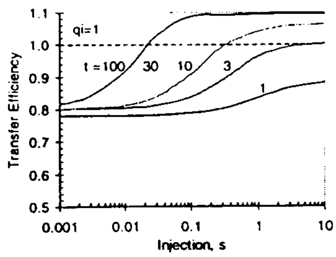
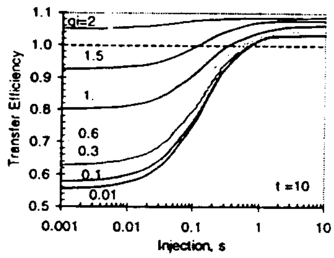


FIG. 28

- Slope represents sensitivity
- Smaller for larger intrinsic charge density q_i
  $\rightarrow$ less print-through

- Transfer Efficiency vs. Injection (s) for various q_i

FIG. 29



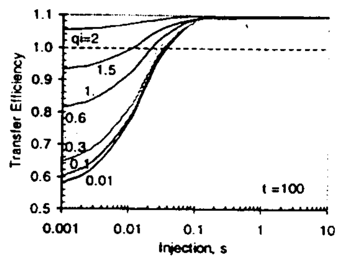


FIG. 30

- Long process time: t >≈ 10
  - full transfer at any q_i for s > ≈ 0.1
  - as q_i decreases, required s and sensitivity to s increases $\rightarrow$ mores print-through

- Transfer Efficiency vs. Injection (s) for various q_i

- at short process time: t ≈1
  - weak sensitivity (slope)
  - efficiency < 1 for small q_i

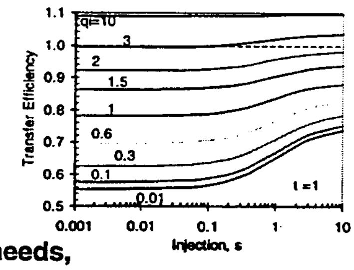


FIG. 32

- Conclusions:
  to minimize print-through needs,
  large q_i >≈ 2, or large s >≈ 1 and t >≈ 10
  - Units $q_o = \varepsilon V_b/L^2$ for q_i and $\sigma_o = \mu q_o$ for s
  - Decreasing V_b increases normalized values of q_i, s

- Good transfer (B01) - Slow ECD decay
  Poor transfer (B02) - Fast ECD decay
- RSC of B02 more conductive than B01 (from ECD)
- ES transfer with positive bias V_b
- Negative charge induced in RSC through leakage path shields bias voltage
- Poor transfer for more conductive RSC (B02)

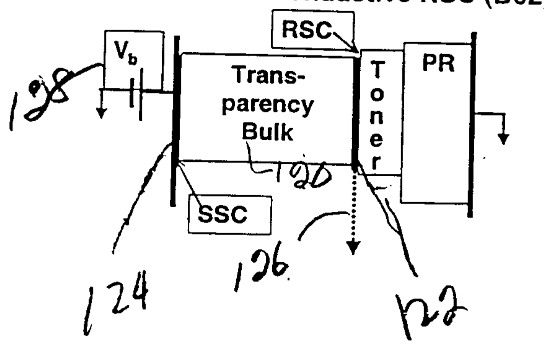


FIG 33

- Transfer of second color limited by charges in toners and receiver from first color transfer
- Neutralization of toner charge and receiver charge
- Current: $J_n = -dQ_{rt}/dt = Q_{rt}/t_n$

  Q_{rt} = interface charge density; t_n = time const

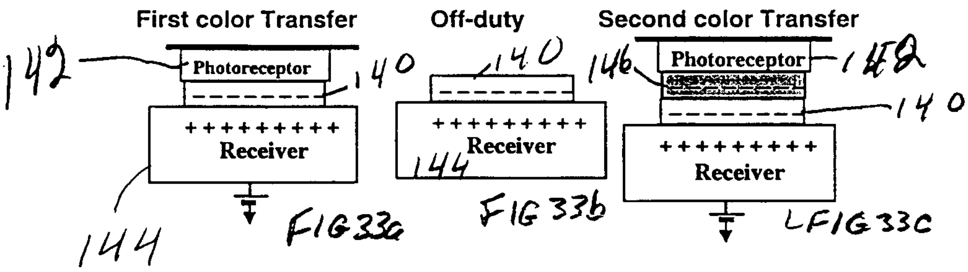


FIG 33a FIG 33b FIG 33c

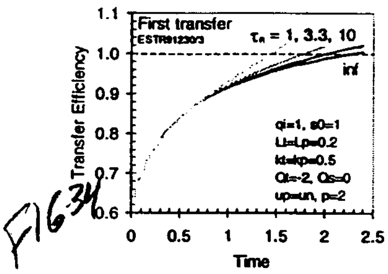


FIG 34

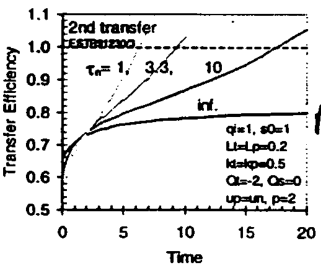


FIG 35

- **Time between transfers (off-duty) =10t_o**
- **Time to full transfer t_F increases as neutralization time constant τ_n increases, especially for the second transfer**
- **Color-shift due to insufficient transfer of 2nd color**

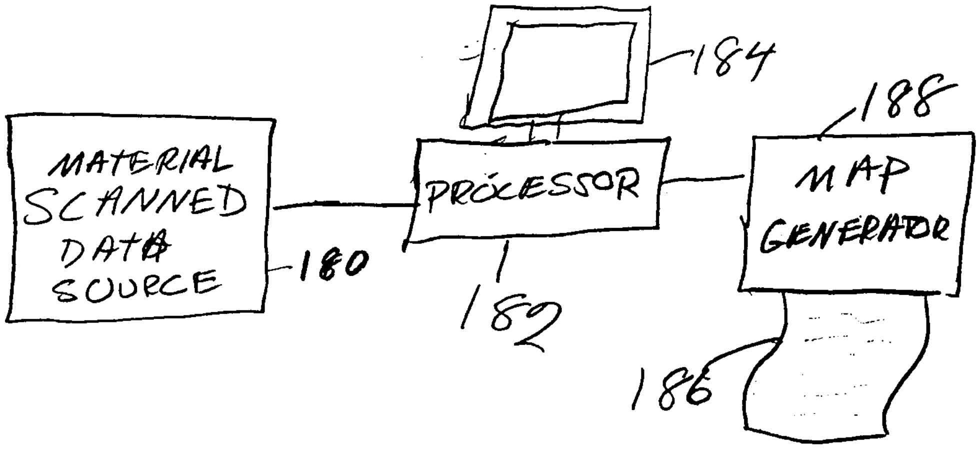

MATERIAL SCANNED DATA SOURCE
180
PROCESSOR
182
184
188
MAP GENERATOR
186

FIG 3/a

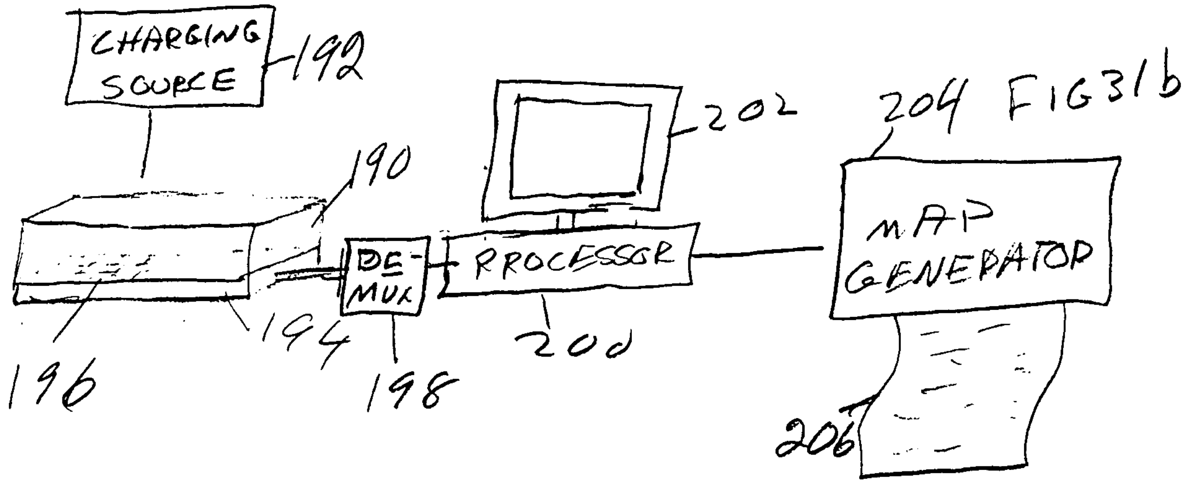

CHARGING SOURCE
192
190
196
194
DE-MUX
198
PROCESSOR
200
202
204
MAP GENERATOR
206

FIG 3/b