

July 20, 1965

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3,196,010

ELECTROPHOTOGRAPHIC PROCESS FOR FORMATION OF DEFORMATION
IMAGES IN DEFORMABLE INTERFERENCE FILMS

Filed May 8, 1962

2 Sheets-Sheet 1

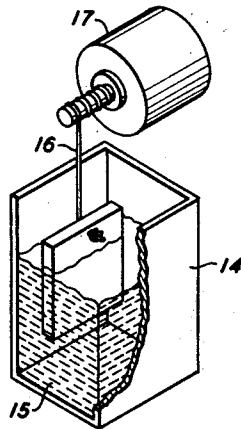


FIG. 1

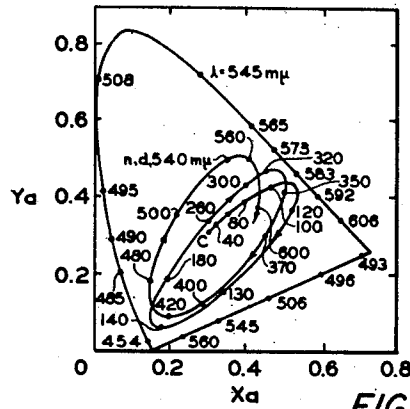


FIG. 2

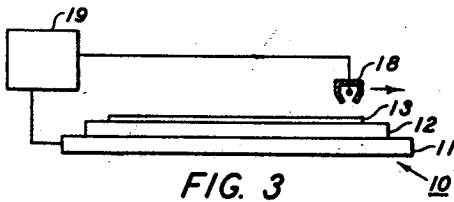


FIG. 3

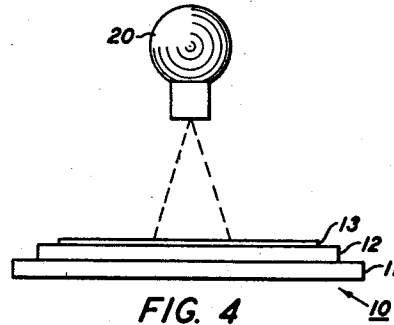


FIG. 4

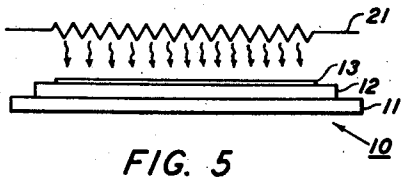


FIG. 5

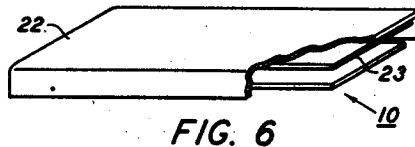


FIG. 6

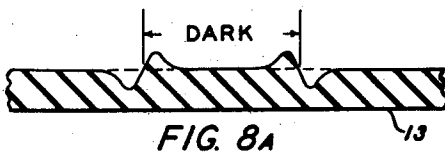


FIG. 8A

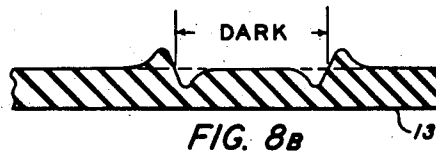


FIG. 8B

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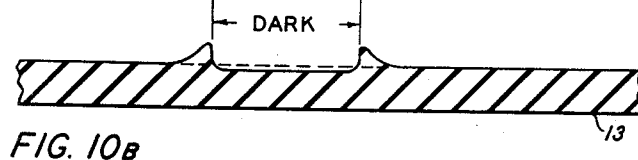
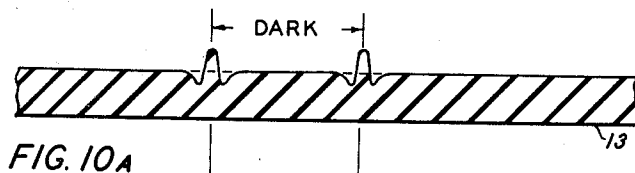
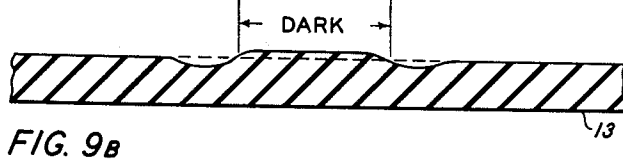
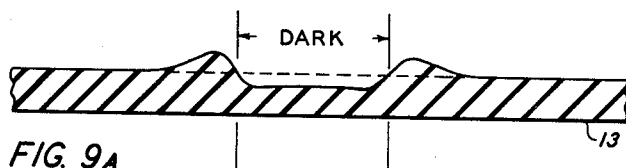
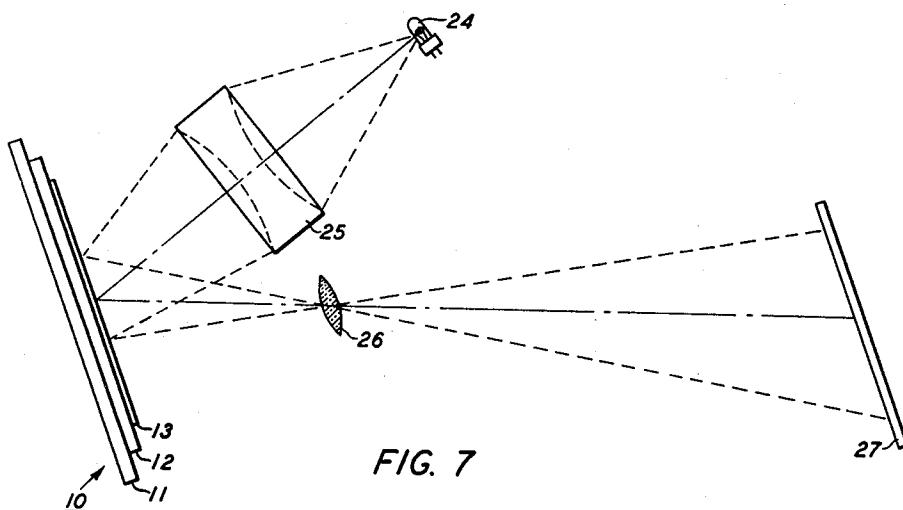
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2 Sheets-Sheet 2



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ELECTROPHOTOGRAPHIC PROCESS FOR FORMATION OF DEFORMATION IMAGES IN DEFORMABLE INTERFERENCE FILMS

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11 Claims. (Cl. 96—1)

This invention relates to xerography and more particularly to novel electrostatic methods of forming visible patterns in response to optical images.

In the usual forms of xerography an electrostatic latent image is formed by the combined action of an electric field and a pattern of light and shadow on a photoconductive insulating layer. The latent image is immediately, subsequently, or in some cases, simultaneously, converted into a visible image by the selective attraction, repulsion, or redistribution in image configuration of finely divided solid or liquid particles.

A variety of xerographic methods are known which generally conform to the above description and which enjoy widespread commercial use as well as being fully described in various patents and other publications.

Now in accordance with the present invention, there is provided a new form of xerography in which an electrostatic pattern is made visible as a pattern of color or interference fringes in image configuration on an extremely thin continuous deformable film or layer. Further in accordance with the present invention, there is provided a xerographic imaging method capable of providing durable images through the use of liquid films. Still further in accordance with the present invention, there is provided a xerographic imaging method in which the appearance of the image may be altered by a reversal of electrical charging polarity. Still further in accordance with the present invention, there is provided a xerographic imaging method providing substantial enhancement of edge effects. There are also provided novel forms of images wherein the images are presented by optical interference effects in thin films. These and other features, advantages and limitations of the invention will become apparent from the following description and drawings in which:

FIG. 1 is a perspective view of a method of preparing a xerographic plate for use in the invention;

FIG. 2 is a diagram relating film thickness to color;

FIG. 3 is a schematic representation of plate charging;

FIG. 4 is a schematic representation of plate exposure;

FIG. 5 is a schematic representation of film softening by heating;

FIG. 6 is a schematic representation of film softening by solvent vapor;

FIG. 7 is a schematic representation of image projection;

FIG. 8 is illustrative of images formed with one material;

FIG. 9 is illustrative of images formed with a different material; and,

FIG. 10 is illustrative of images formed with a mixture of materials.

FIG. 1 illustrates a method for applying a thin overcoating to a xerographic plate 10, as is required in the present invention. The plate 10 is suspended in a tank 14 filled with a coating solution 15 by a string 16 which is wrapped around the shaft of a slow speed motor 17 such as a clock motor. Coating solution 15 comprises a dilute solution of either a solid material or a non-volatile liquid dissolved in a volatile solvent. When motor 17 is energized, plate 10 is slowly withdrawn from tank 14 and a thin coating or film is formed on the sur-

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face of plate 10 as the volatile solvent evaporates. The film can generally be employed in the procedures to be described even before the volatile solvent has completely evaporated. As is known, the thickness of the film after solvent evaporation may be varied by changing the rate of withdrawal, typically in the range of 3" to 24" per minute, or the concentration of coating solution 15. Slower speeds and weaker concentrations give rise to thinner coatings and vice versa. In accordance with the principles of the present invention as will be set forth later, the preferred coating thicknesses lie within the range of approximately 80 to about 125 millimicrons. However, with special types of interferometric detection, thicknesses of 10 to 500 millimicrons are operative. Further information on the nature of the film and of the xerographic plate itself will be given in conjunction with FIG. 3 and subsequent figures. The above coating method is capable of forming coatings of very uniform thickness. Such coatings are desirable but not absolutely necessary. Accordingly, simpler coating methods may be employed, such as swabbing plate 10 with a cotton pad moistened with coating solution 15.

The coating formed by the procedure of FIG. 1 is a thin transparent coating having approximately the minimum thickness necessary to show interference between the light from its two reflecting surfaces since this interference is a means by which images are made visible in the film. Such a thin coating has optical properties resembling those of an oil film on water and exhibits bands of color and the like. Light is reflected from each of the two surfaces of the film and, as is well known in optics, the two reflected beams will re-enforce or subtract from each other depending on the phase difference between them. Interference is first evident at the quarter wavelength at the shortest wavelength of visible light; this is seen in films of about 120 millimicrons. For quarter wavelength films, monochromatic light from the second surface travels a total of half a wavelength farther than that reflected at the first surface. The wave forms are therefore 180° out of phase and destructive interference results. The resultant amplitude is the difference in the amplitudes of light from each surface which are functions of the surface reflectivities. To achieve complete cancellation, it will be seen that the second surface reflectivity will have to be somewhat greater than the first because the light traveling the longer path undergoes losses at each of its two passages through the first surface. Complete cancellation, however, is not required in the present invention.

FIG. 2, which is taken from Kubota, H., Journal Optical Society of America, 40 (1950), 146, plots within a standard color diagram the colors shown by these interference films as a function of film thickness in millimicrons times the index of refraction of the film. By means of such a diagram, thickness of a film may be determined by its color or its color may be predicted from its thickness. It will be seen that the range of thicknesses previously indicated as preferred for this invention generally correspond to a quarter wavelength of visible light. Thicker films are theoretically capable of exhibiting optical interference effects but the color effects become weaker and harder to detect except under monochromatic illumination and the color fringes corresponding to variations in film thickness are virtually undetectable unless the films are extremely flat. As a further point, it is noted that the unique mechanical and electrical properties which have been found by applicants to contribute to their image forming process are only found in very thin films. Accordingly, the preferred range of thickness is, as indicated above, in the general range of 80 to 125 millimicrons.

FIG. 3 illustrates the charging of plate 10 and more clearly depicts plate 10 itself. Xerographic plate 10 com-

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prises an electrically conductive support member 11, which may be dispensed with in some embodiments, upon which is coated a layer 12 of photoconductive insulating material over which lies the thin film 13 formed by the procedure of FIG. 1 or any other procedure for forming thin films. Layer 12 is characterized as being a sufficiently good electrical insulator in the dark to retain an electrostatic charge for an appreciable length of time and a sufficiently good electric conductor when illuminated by light or other activating radiation to dissipate electric charge. Various materials are known for layer 12 and include both vitreous materials such as sulfur, anthracene or selenium as well as dispersions of photoconductive pigments, such as zinc oxide, in film forming electrically insulating binder materials. A particularly suitable form of layer 12 which is in commercial use comprises a smooth shiny layer of vitreous selenium having a thickness which may range from a few microns to a few hundred microns but is typically on the order of 20 microns. Support member 11 may comprise metal plates or metal foils, metallized paper or plastic, paper with a sufficiently high moisture content to render it conductive, glass with an opaque or transparent conductive coating, or the like. A polished aluminum plate is a particularly suitable embodiment of support member 11. Film 13 is, as already indicated, a very thin layer of transparent electrically insulating material and may be either a liquid or a solid. It will be apparent from the foregoing discussion that film 13 is not drawn to scale and layer 13 is, in fact, of insignificant thickness compared to layer 12.

Xerographic plate 10 is now electrostatically charged by passing over its surface a corona charging device 18 which is connected to a high voltage power supply 19 adapted to apply it with a D.C. voltage of several thousand volts. By this means the surface of plate 10 is brought to an electric potential, either positive or negative, on the order of several hundred volts. Corona charging devices are well known in the xerographic art and suitable ones are described, for example, in U.S. Patents 2,777,957 and 2,836,725. Other methods of applying a uniform potential onto an insulating surface are known and may be employed.

The next step in carrying out the invention is exposure of the charged xerographic plate to a pattern of light and shadow, schematically illustrated in FIG. 4 wherein a photographic enlarger 16 is shown projecting a light pattern upon xerographic plate 10. It will be noted that support member 11 may be in some cases be transparent and in those cases, exposure may be effected through the opposite face of plate 10 from that shown in FIG. 4. Other methods or apparatus for exposure may be employed, such as exposure in a camera or the like.

If film 13 is a liquid, the steps leading to image formation are now complete; otherwise film 13 must be at least temporarily softened or liquefied and two alternative methods are illustrated in FIGS. 5 and 6. FIG. 5 illustrates a heat softening of layer 13 through application of heat from adjacent heating element 21 or the like. An alternative method is shown in FIG. 6 in which xerographic plate 10 is placed under a sheet metal cover 22 on the underside of which is a blotter 23 saturated with a solvent liquid such as trichloroethylene. The space beneath cover 22 becomes saturated with solvent vapors which are absorbed by film 13 and which cause the film to soften. Obviously, the particular solvent and the material comprising film 13 must be so chosen that the solvent will dissolve or soften the coating. The methods of FIGS. 5 and 6 are functionally equivalent to each other and each may be carried out with various forms of apparatus. Where the photoconductive insulating layer 12 of plate 10 comprises vitreous selenium, the method of FIG. 6 is generally preferred because of the tendency of selenium layers to be damaged by excessive heat or excessively prolonged heating.

As a result of the foregoing procedures, there is formed

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through electrostatic forces acting on the surface of film 13 a pattern of very minute variations in the thickness of film 13. These are so thin as to be ordinarily invisible and undetectable. However, because the thickness of film 13 has been chosen to be nearly a quarter wavelength of light, these minute variations are readily visible as a pattern of color fringes. These fringes may be examined simply by looking at the surface of plate 10 by reflected light. The images are also readily adaptable to projection, particularly by reflection techniques. A suitable form of projection apparatus is shown in FIG. 7. It comprises a light source 24 and a condensing lens 25 which direct a converging beam of light onto plate 10. The light specularly reflected by plate 10 is intercepted by a projection lens 26 and focused on a projection screen 27 or the like. While the apparatus shown is well adapted to discriminate between specularly and diffusely reflected light, images prepared in accordance with the present invention are substantially specular in character. Greater contrast in the projected image may be obtained by using a substantially monochromatic light source, such as a mercury lamp or sodium vapor lamp as light source 24. When such a light source is used the image comprises different regions having substantially the same color but having great variations in brilliance or intensity. Since the xerographic plate discharges in relation to the intensity of radiation projected in the exposure step, the present invention may also be used to measure varying exposure intensity. A color photograph may be taken of the pattern of color fringes formed, and by comparing this photograph with a predetermined color scale, intensity at a particular point is determined.

It is a unique feature of images formed according to the present invention that they are quite durable even when they comprise liquids rather than solids. Thus, liquid images or solid images maintained in a liquid condition by solvent vapors may be formed in a second or less but last for a time ranging from 20 minutes to upwards of several hours. It is noted that in other methods for forming images through electrostatic deformation of materials, the images tend to be fugitive even when made of materials which are nominally quite solid. The reason for the durability of images according to the present invention appears to be that the electrostatic forces causing image formation are capable of reducing the thickness of film 13 over areas as wide as 5 mm. This represents a lateral migration by the material comprising film 13 of 50,000 times the thickness of the film. It is not surprising then that the slight lateral components of surface tension pressures do not quickly restore the films to uniform thickness.

Continuous tone rendition and large area reproduction by means of the present invention may be enhanced by appropriately increasing and distributing the discrete areas of charge gradient. For instance, the xerographic plate may be exposed to a screen pattern before, after, or simultaneously with, the described exposure step. A detailed description of this manipulation may be found in U.S. Patent 2,598,732. Similar results may be attained in other ways known to the art, for instance, by using a xerographic plate with a photoconductive component made up of finely-divided uniformly-distributed particles rather than a continuous layer. This creates a halftone effect allowing one to simulate continuous tones, for example, by creating patterns conforming to the intensity of exposure throughout the entire area as distinct from limited to edge effects.

Images can also be made in accordance with the present invention by bringing a thin liquid or liquefied film of the type already described into close, but non-contacting proximity, with a xerographic plate or other surface bearing an electrostatic latent image or on which such a latent image may be formed. The electrostatic forces associated with the electrostatic image have been found to be effective in acting across the small gap separating

the thin film from the latent image and act to produce a visible color fringe image on the film. In this embodiment of the invention, the thin film may be supported on any smooth surface including, but not limited to, a xerographic plate.

The nature of the electrostatic forces forming images in accordance with the present invention is not fully understood and is clearly not the same as that associated with other methods relying upon surface deformation through electrostatic effects. Thus, for example, when film 13 comprises silicone resin SR-840 (General Electric Company) the application of a positive charge in the step of FIG. 3 yields a positive image while the application of a negative charge produces a negative image. These effects are illustrated in FIGS. 8A and 8B which are enlarged cross sections of a film 13 which has been exposed to a pattern of light comprising a dark area surrounded by illuminated areas. FIG. 8A shows the results for positive charging and shows that under these conditions the silicone resin is attracted into the non-illuminated or electrostatic charge areas and flows away from the illuminated or non-charged areas. Under these conditions, the resin can be described as electrophilic in the sense that it is attracted to charged areas. FIG. 8B shows the results for negative charging which are substantially opposite to that of FIG. 8A. Under these conditions, the resin can be described as electrophobic in the sense of being repelled from charged areas. Where vapor softening is to be used with this material, trichloroethylene is a suitable solvent. While the cause of the effects illustrated in FIGS. 8A and 8B are not understood, it may be postulated that they are related to the effect of electric charge or field on the surface tension of film 13.

Sucrose acetate isobutyrate is another material suitable for forming film 13. It may be softened by exposure to trichloroethylene vapors for about 1/2 second or to perchloroethylene for 1-2 seconds or to isopropyl alcohol for about 20 seconds. Heat softening may also be effected by heating to 140° F. for about 10-20 seconds. Again positive and negative initial plate charging potentials yield opposite effects but in the reverse order of SR-840, i.e., a negative image results from positive charge and a positive image from negative charge. This material can be described as electrophobic for a positive charge and electrophilic for a negative charge. Thus, the results of negative charging correspond approximately to FIG. 8A, while the results of positive correspond approximately to FIG. 8B. Another suitable material is Piccolastic A-75 resin (Pennsylvania Industrial Chemicals Company). This behaves in a manner similar to sucrose acetate isobutyrate except that image formation takes about 1-2 seconds with trichloroethylene vapor instead of about 1/2 second.

As previously indicated, film 13 may comprise an electrically insulating liquid as well as a solid. Since the films are exceedingly thin, it is necessary that the liquid have a very low vapor pressure in order that it not evaporate too rapidly. Certain petroleum oils are satisfactory but a particularly useful class of materials comprises the ester liquids recommended for use as plasticizers or for use in diffusion type high vacuum pumps. One particularly suitable material of this type is Flexol (di-2-ethylhexyl phthalate, Carbide and Carbon Chemicals Company). The performance of this material is somewhat similar to Piccolastic A-75 or sucrose acetate isobutyrate and is illustrated for positive and negative charging respectively in FIGS. 9A and 9B, respectively. Another suitable material of this type is Narcoil, a diffusion pump fluid made by National Research Corp. Any of various volatile liquids such as heptane may be used to dilute these liquids for coating purposes.

It has been observed that certain materials are electrophilic for a given charging polarity whereas other materials are electrophobic for that same polarity. Unique effects can be achieved by forming film 13 of a mix-

ture of materials exhibiting electrophilic and electrophobic response under a given polarity. With such a mixture it is possible to make the two types of response neutralize each other so that film thickness is substantially independent of illumination, or of charge, in uniformly illuminated areas but varies sharply in or at regions corresponding to transitions between black and white. Such an effect can be achieved, for example, by forming film 13 of a mixture of a minor amount, approximately 1%, by weight of Piccolastic A-75 in silicone resin SR-840. FIG. 10A shows the results obtained with such a film under conditions of positive charging. It is seen that the average film thickness is the same in both light and dark areas but that there is a very sharp discontinuity in film thickness, and hence a prominent color fringe, at the transition between light and dark areas. FIG. 10B shows the results obtained with the same film 13 for negative charging. It is seen that under these particular conditions, electrophilic and electrophobic responses do not completely balance each other and the electrophobic response predominates somewhat. This method of image formation is capable of giving greatly enhanced edge effects. Additionally since deformation is limited to narrow ranges and the thickness of film 13 is uniform in most areas, it is considerably easier to erase images of this type through softening as compared to the previously described type where substantial lateral flow is required to restore layer 13 to a uniform thickness.

While the invention has been described in terms of specific embodiments and specific materials and certain theories of operation, it is to be understood that other embodiments and materials will occur to those skilled in the art and that the functioning of the invention is in no way dependent upon the correctness of any theory and accordingly, the invention is intended to be limited only by the scope of the appended claims.

What is claimed is:

1. The method of forming a photoexact interference effect reproduction of a light pattern comprising applying to the photoconductive insulating surface of a xerographic plate an interference film of mechanically deformable insulating material, said film having a thickness in the range of about 80 to about 125 millimicrons, electrostatically charging the xerographic plate, and exposing the plate to a light pattern.

2. The method according to claim 1 wherein said interference film comprises a liquid.

3. A method of forming a photoexact interference effect reproduction of a light pattern comprising applying to the photoconductive insulating surface of a xerographic plate an interference film of solid plastic insulating material capable of being made deformable and having a thickness in the range of about 80 to about 125 millimicrons, electrostatically charging the xerographic plate, exposing the plate to a light pattern, and rendering the insulating material deformable.

4. The method according to claim 3 wherein the insulating material is rendered deformable by exposure to heat.

5. The method according to claim 3 wherein the insulating material is rendered deformable by exposure to a solvent therefor.

6. The method of forming a photoexact interference effect reproduction of a light pattern comprising bringing an interference film of liquid insulating material having a thickness in the range of about 80 to about 125 millimicrons into close non-contacting proximity with a surface bearing an electrostatic latent image.

7. The method of forming a photoexact interference effect reproduction of a light pattern comprising bringing an interference film of insulating plastic material capable of being made deformable and having a thickness range of about 80 to about 125 millimicrons into close non-

contacting proximity with a surface bearing an electrostatic latent image and rendering the insulating material deformable.

8. The method according to claim 7 wherein the insulating material is rendered deformable by exposure to heat.

9. The method according to claim 7 wherein the insulating material is rendered deformable by exposure to a solvent therefor.

10. A method of forming a photoexact interference film reproduction of a light pattern in which the thickness of the interference film is modulated in thickness substantially only in regions corresponding to discontinuities of the light pattern, comprising applying to the photoconductive insulating surface of a xerographic plate a liquid interference film having a thickness in the range of about 80 to about 125 millimicrons of a mixture of electrophilic and electrophobic insulating material, electrostatically charging the xerographic plate, and exposing the plate to a light pattern.

11. The method of forming a photoexact interference film reproduction of a light pattern in which the thickness of the interference film is modulated in thickness substantially only in regions corresponding to discontinuities of the light pattern comprising applying to the photoconductive insulating surface of a xerographic plate an

interference film having a thickness in the range of about 80 to about 125 millimicrons of a mixture of electrophilic and electrophobic solid insulating plastics, electrostatically charging the xerographic plate, exposing the plate to a light pattern, and rendering the solid insulating plastics deformable.

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