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ELECTROSTATIC REPRODUCTION METHOD AND APPARATUS EMPLOYING A
PHOTOEMISSIVE SURFACE
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FIG. 1

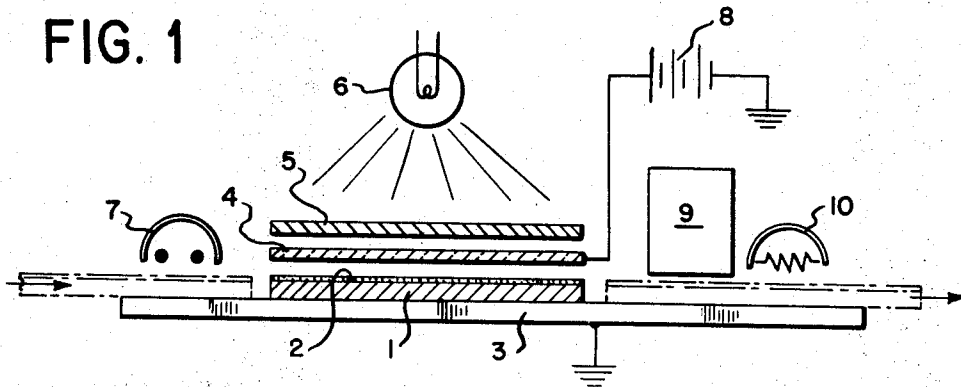
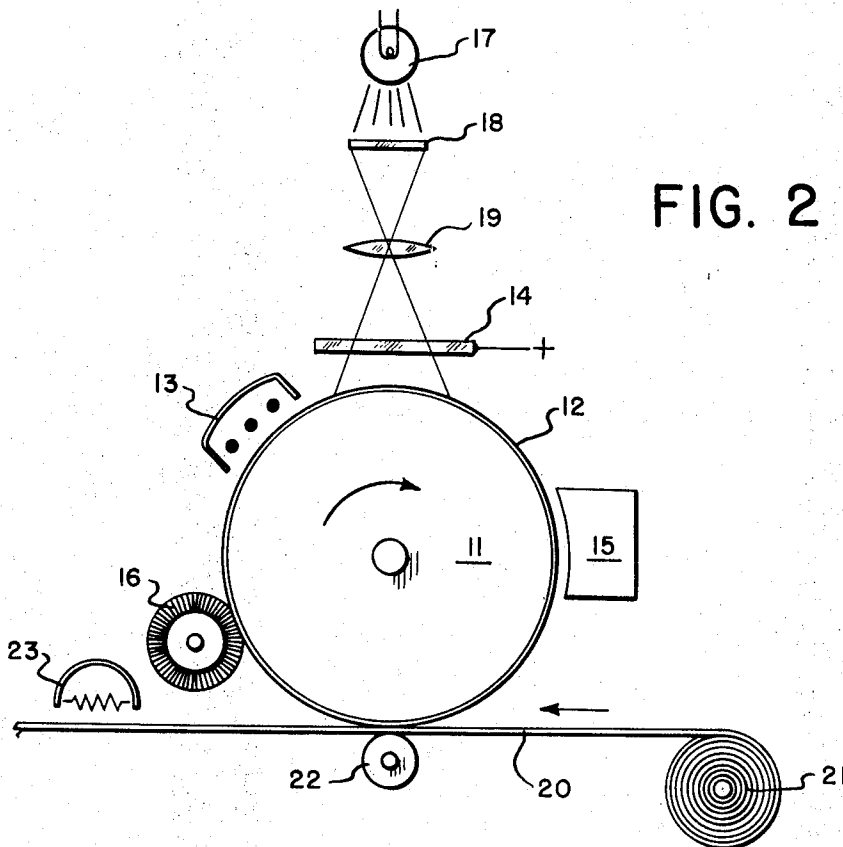


FIG. 2



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ELECTROSTATIC REPRODUCTION METHOD AND APPARATUS EMPLOYING A PHOTOEMISSIVE SURFACE

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10 Claims

ABSTRACT OF THE DISCLOSURE

A layer of material having an insulated photoemissive surface is exposed to a light image of frequency f to cause the external emission of electrons therefrom. The photoemissive surface has substantial adsorption at the frequency f and an external ionization threshold E such that hf is less than E and $2hf$ is greater than E , where h is Planck's constant. The externally emitted electrons are accelerated away from the surface on the side thereof away from the layer to produce an electrostatic latent image which is processed to yield a visible image. Advantageously a negative electrostatic charge is applied to the photoemissive surface before exposure to the light image.

This invention relates to a method and apparatus for producing an electrophotographic image, and more particularly to a method and apparatus for producing such image by means of emission of electrons from a photoemissive surface.

My invention utilizes a recent and important scientific discovery concerning the photoelectric activity of certain materials. The discovery has been published in the scientific literature (see "Double-Quantum External Photoelectric Effect in Organic Crystals" by Pope et al., The Journal of Chemical Physics, vol. 42, No. 7, Apr. 1965), and is summarized here. Briefly, it has been found possible to eject electrons from suitable insulating materials using high intensity light of a wavelength much longer than anyone has previously expected would be effective.

Ordinarily, the ejection of electrons from the surface of an insulator requires the use of light of very short wavelength. Typically the wavelength is less than 2500 A.U. (angstrom units), in the far ultra-violet region. However, I have observed that by illuminating certain organic materials with high intensity, strongly absorbed light of energy several electron volts smaller than the reported external ionization threshold of the materials, an electron emission can be produced at a rate proportional to the square of the light intensity. I believe that the high intensity of the light gives rise to what may be termed a "double-quantum external photoelectric effect" whereby two excitons produced in the organic material by two absorbed light quanta interact close to the surface of the material to eject an electron from the surface.

Electrophotographic processes have been suggested employing photoemission from insulating materials by ultra-violet light of wavelength corresponding to the external ionization threshold thereof. The required short wavelength, e.g. 2500 A.U., has serious disadvantages. At these wavelengths very few of the commercially available materials used for photographic film or transparencies will permit transmission. Thus, a photographic transparency containing an image to be copied would be uniformly opaque at this wavelength and could not be used to project the image onto a photosensitive surface. In addition, at these short wavelengths the reflective power of surfaces such as white paper becomes seriously compromised in the sense that contrast between white and black tends to disappear. Finally, all optical systems must be made of

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quartz, since the transmission of ordinary lens materials at these wavelengths is extremely poor. For these reasons electrophotographic imaging systems using photoemission of electrons from an insulating surface have had little if any, significant practicability.

In accordance with the present invention, a photo emissive insulating surface is exposed to a light image to cause the emission of electrons therefrom, and the emitted electrons are accelerated away from the surface by an electric field to produce an electrostatic latent image on the surface. The material forming said insulating surface and the light frequency f are selected with respect to each other so that the material has a substantial absorption at the frequency f and an external ionization threshold E such that hf (the energy of a photon) is less than E and $2hf$ is greater than E where h is Planck's constant. Advantageously, a negative charge is applied to the insulating surface prior to exposure to the light image. This greatly improves the efficiency. A high light intensity is employed say of the order of 10^{15} quanta/cm.²/sec., so that sufficient photoemission is obtained to yield a useable electrostatic latent image.

In this manner, it becomes possible to use wavelength radiation in the near ultra-violet region (for example, 3930 A.U. close to the visible region) to produce an electrophotographic image by photoemission, previously obtained only with much shorter wavelengths, thereby escaping the above-mentioned limitations inherent in the use of shorter wavelengths.

Materials suitable for use in this invention are those in which mobile excitons are generated by light. Such materials include certain conjugated aromatic hydrocarbons, particularly anthracene, tetracene and perylene.

There are believed to be at least two different types of mobile excitons that can coexist in these materials, one of which is generated at a lower energy than the other. These types of excitons are called Frenkel, or neutral excitons, and Wannier, or ionic (charge-transfer) excitons. In a given material the Frenkel exciton generally requires less energy for its creation than the Wannier exciton. In either case, however, the energy required to produce the exciton is much less than the reported external ionization threshold for the material.

It has been observed that an external photoelectric emission from a material can be produced by what is believed to be the mutual annihilation of two excitons of either type. Thus, in anthracene both an electron emission attributable to the annihilation of two Frenkel excitons and an emission attributable to the annihilation of two Wannier excitons have been observed. In the case of tetracene and perylene electron emission is produced by what is believed to be the mutual annihilation of two Wannier excitons.

Materials suitable for use in this invention have, in general, been found to fluoresce. Fluorescence is usually a good indication that Frenkel excitons have been created and that they have a reasonably long lifetime. Single component systems, rather than mixtures or complexes are usually preferable. Moreover, it is desirable to choose materials that have a high absorption coefficient in the energy region suitable for the generation of Frenkel excitons. It is also important that the energy required to generate excitons in a material be more than half the energy required to produce an external photoelectric effect.

Different materials will have different external ionization thresholds and different absorption curves. It is desirable to select a material having a strong absorption peak near the visible light range, and select the light frequency to be at or near this peak. Thus anthracene has a strong absorption at 3930 A.U., producing a Frenkel exciton with an energy of 3.15 electron volts. This exciton energy is more than one-half of the energy of 5.65 electron

volts at 2180 A.U. required to produce external photoelectric emission from the material, and satisfies the above conditions.

Describing a preferred embodiment of the invention in more detail, a uniform negative charge is applied to a surface comprised of the above-described photoemissive insulating material. The surface is then exposed to a high intensity light image of the subject to be copied or reproduced. Although of high intensity, the quantum energy of the light image radiation may be substantially less than the normal work function energy of the material, that is, longer wavelength light may be used to form this light image. As already described, the double-quantum process is thus induced in the illuminated surface and electrons are emitted from the surface in the areas illuminated by the light image. An electric field is provided to accelerate the emitted electrons away from the surface, and a latent electrostatic image in the form of the light image remains on the surface.

This latent electrostatic image may then be processed in the same way as in conventional electrophotographic processes. The latent image may be developed into a visible image directly on the surface by the application of an electroscopic developer material which is attracted to the positively charged areas of the latent image and repulsed by the negatively charged areas. Or, a different electroscopic developer may be applied which is selectively attracted to the negatively charged image areas, instead. The resulting visible image may be fixed permanently on the surface by heat or other means, or it may be transferred to a second surface, such as a paper sheet, by pressing it in contact with the second surface. The visible image may then be fixed on the second surface. In this latter case the photoemissive surface may be cleaned, if necessary, and used again to produce other images.

An important feature of my invention is the initial application of a uniform negative charge to the photoemissive surface. Without the negative charge, the exposure of the surface to the light image would still produce the emission of electrons from the surface. However, the emitting areas would become increasingly positive as electrons were emitted, thereby producing a retarding field effect on electron emission. The emission from the surface would therefore be dependent on the degree of charge residing on the surface, as well as on the intensity of the incident light. Since it is the usual purpose of photography to render an image that is faithful to the gradations in intensity of light falling upon a photosensitive surface, this charge dependency is generally undesirable. It is avoided in the present invention by charging the photoemissive insulating surface with electrons prior to exposure to light, preferably to a negative potential equal or greater in magnitude than the change in potential produced by the photoemission. In this way there is no retarding field effect and the photoelectric response is dependent only on the intensity of the incident light.

The invention will be further explained in connection with the accompanying drawings in which:

FIG. 1 is a schematic drawing of a first embodiment of the electrophotographic apparatus of the invention; and

FIG. 2 is a schematic drawing of a second embodiment thereof.

Referring to FIG. 1, a sheet of paper 1 is coated with a layer 2 of anthracene, a material previously noted to be suitable for use in this application. The coated sheet may be moved over an electrically grounded metal plate 3 in the direction indicated by the arrows. A transparent, electrically-conductive sheet 4, such as NESA coated glass is mounted over the plate 3 and above that is mounted a photographic negative 5 bearing an image of the material desired to be copied. A light source 6 capable of producing a high intensity burst of light of 3950 A.U. is provided and mounted above the negative 5.

An electrostatic charger 7, such as a negative corona charger, electroscopic developing means 9 and fixing

means 10 are also mounted over the base plate 3. The conductive sheet 4 is connected to the positive terminal of a DC voltage source, shown diagrammatically as a battery 8, to produce a field between the conductor 4 and plate 3 of about 1000 volt/cm.

In operation the coated sheet of paper is moved on the plate 3 under the energized charger 7 which applies a uniform negative electrostatic charge to the exterior surface of layer 2. The sheet is then moved under the conductor 4 and the light source 6 is energized to expose the layer 2 to high intensity 3950 A.U. radiation which is transmitted through the image areas of the negative 5. As explained above, the illumination causes the emission of electrons from the exterior surface of the layer 2, and these emitted electrons are accelerated toward, and collected by, the positive transparent conductor 4. A latent electrostatic image of the subject to be copied remains behind on the surface of layer 2.

When the light source 6 is turned off, the sheet is moved under the developing means 9 where a positively charged dark powder is applied to the latent image to generate a visible image, since the powder will selectively adhere to those portions of the surface of layer 2 which were not exposed to radiation through the negative 5. The sheet may then be passed under the fixing means 10, such as a heat source, and the visible image is made permanent on the sheet.

In the embodiment shown in FIG. 2, a grounded metal drum 11 is arranged to rotate in the direction of the arrow. The surface of the drum is coated with a layer 12 of the photoemissive insulating material specified above. About the periphery of the drum 11 are mounted an electrostatic negative charging means 13, a transparent conductive sheet 14 conducted to a positive voltage source, electroscopic developer means 15 and a drum surface cleaning means 16, such as a rotary brush. A high intensity light source 17 is mounted over the drum so that its illumination passes through light portions of a photographic transparency 18 of a subject to be copied, and is focused by a lens 19 onto the surface 12 of the drum. A web 20 of paper from a reel 21 is brought in to contact with the drum surface 12 by a roller 22, and fixing means 23 are mounted over the travel path of the web 20.

In the operation of this embodiment, the drum 11 is rotated in the direction shown and the charger 13 is energized to coat the surface 12 with a layer of negative charge. The drum rotation is then stopped and the light source 17 is energized to produce, as in the first embodiment, a latent electrostatic image on the surface 12. When the light source 17 is turned off the drum is rotated further to bring the latent image under the developer means 15, where it is made visible, and then brought into contact with and transferred to web 20 by the action of pressure roller 22. As the drum rotates further, the paper web with the visible image thereon moves under the fixing means 23 and the image is made permanent. As the drum continues to rotate, the surface 12 is cleaned by cleaning means 16 to be ready for reproducing another image upon further rotation.

It will be understood that various changes in the details, materials, steps and arrangement of parts which have been herein described and illustrated in order to explain the nature of the invention may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

I claim:

1. A method of forming an electrophotographic image which comprises exposing a layer of material having an insulated photoemissive surface to a light image of frequency f for causing the external emission of electrons from said surface at the portions thereof exposed to the light of said light image, said light image impinging on said surface and said external emission of electrons being from the side thereof away from said layer, and applying an external electric field to accelerate the externally

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emitted electrons away from said surface on the side thereof away from said layer to produce an electrostatic latent image on said surface, said photoemissive surface having an absorption peak in the region including said frequency f and an external ionization threshold E such that hf is less than E and $2hf$ is greater than E , where h is Planck's constant.

2. The method according to claim 1 including applying a negative electrostatic charge to said insulated photoemissive surface prior to exposure thereof to said light image.

3. The method according to claim 2 including developing said electrostatic latent image by applying an electroscopic substance to the surface to form a visible image upon said surface.

4. The method according to claim 3 including fixing the visible image upon said photoemissive surface.

5. The method according to claim 3 including transferring said visible image to a support surface and fixing the visible image thereupon.

6. Electrophotographic apparatus which comprises a layer of material having an insulated photoemissive surface which has an absorption peak in a region including a frequency f and an external ionization threshold E such that hf is less than E and $2hf$ is greater than E , where h is Planck's constant, electrode means spaced from said photoemissive surface on the side thereof away from the layer, means for applying a positive potential to said electrode means to accelerate externally emitted electrons away from said surface, and means for exposing said surface to a light image of said frequency f to cause

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the external emission of electrons from said surface in the portions thereof exposed to the light of said light image and produce an electrostatic latent image on said surface, said light image impinging on said surface and said external emission of electrons being from the side thereof away from said layer.

7. Apparatus according to claim 6 including means for applying a negative electrostatic charge to said insulated photoemissive surface prior to exposure thereof to said light image.

8. Apparatus according to claim 7 including means for applying an electroscopic material to said latent image to form a visible image.

9. Apparatus according to claim 8 including means for fixing said visible image on said surface.

10. Apparatus according to claim 8 including means for transferring said visible image to a support surface and means for fixing the visible image upon the support surface.

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