V. M. Fridkin

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Abstract

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V. M. Fridkin

Photoelectrets and the Formation of a Latent Electrophotographic Image

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The phenomenon of permanent internal photopolarization in dielectrics was discovered in 1938 by G. Nadzhakov and was named the photoelectret state by analogy with thermoelectrets (⁀1). In works (2,3) the duration of preservation of polarization in photoelectrets was investigated, as well as the influence of temperature on the process of their depolarization. In a number of our works, the photoelectret state was studied in single crystals of sulfur and anthracene, and also in polycrystalline sulfur, from the point of view of the influence of the polarization conditions on the magnitude of the charge of the photoelectret (4,5).

The photoelectret state in dielectrics is due to the accumulation of a space charge in the process of photoconductivity. When an electron passes from the valence band into the conduction band, it undergoes a displacement in the direction of the field and, falling at the end of the displacement out of the conduction band, becomes fixed at some local level, whose nature may be different. It is possible that, in the case of single crystals, these local levels are due to various structural defects. The higher stability of the polar textures mentioned above in comparison with single-crystal photoelectrets, discovered in works (2,4), indicates a particularly stable fixation of electrons at deep local levels arising at the boundaries of crystalline grains in polycrystalline specimens.

In work (⁀6) a method was described for obtaining electrophotographic images on the surface of polycrystalline photoelectrets and, thereby, a new direction was proposed in the field of research on permanent internal photopolarization.

The present work contains a number of new results obtained in the study of the photoelectret state by means of the electrophotographic method.

The method described in work (⁀6) for obtaining electrophotographic images on photoelectrets consisted of the following. Layers of polycrystalline sulfur about 50 μ thick were deposited in vacuum on aluminum plates. The layers were polarized under an applied voltage and continuous illumination through a semitransparent electrode. The charge on the surface of the photoelectret obtained in this way could be measured with a dynamic electrometer.

A positive image was projected onto the surface of the photoelectret. As a result of the exposure, the illuminated regions of the photoelectret were depolarized,

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

while the darkened regions retained the initial polarization. Since the rate of depolarization of a photoelectret depends on the illumination (ˆ2), the latent image formed as a result of exposure, caused by the nonuniform distribution of polarization, can reproduce the halftones of the original. To develop the latent image, the triboelectric effect was used. Asphalt powder was mixed with finely crushed crystals of table salt. In this case the particles of table salt became negatively charged, and the asphalt particles positively charged. The mixture

two powders was poured onto the surface of the photoelectret preserving the latent image, and, depending on the sign of the charge on the surface of the photoelectret, the latent image was developed by particles of asphalt or table salt, which were retained only on the areas that had preserved polarization. Figure 1 shows a specimen of such an electrophotograph, obtained on a photoelectret made of polycrystalline sulfur with the aid of a halftone original.

Fig. 1. Specimen of an electrophotograph obtained on a photoelectret made of polycrystalline sulfur with the aid of a halftone original

We investigated the dependence between the magnitude of the surface charge of a photoelectret (or the electric-field strength at its surface) and the optical density of the developed image. A layer of polycrystalline sulfur, deposited in vacuum and about 50μ thick, was polarized at different field strengths and at a uniform illumination of about $2 \cdot 10^{-6}$ W/cm^2, produced on the surface of the layer with the aid of a photolamp. The layer was polarized for 10 min, after which the illumination was stopped and the voltage was removed. Glass with a deposited silver layer was used as the semitransparent electrode. With the aid of a dynamic electrometer, the magnitude of the field strength at the surface of the photoelectret was measured; after this the surface of the photoelectret was developed in the manner indicated above, and the optical density of the image developed by asphalt particles was measured with an FT-2 photometer. Figure 2 presents the dependence of the optical density ΔD on the magnitude of the electric-field strength at the surface of the photoelectret.

Fig. 2. Dependence of the optical density ΔD on the magnitude of the electric-field strength at the surface of the photoelectret

The linear dependence between the optical density of the image developed on the surface of the photoelectret and the magnitude of its surface charge was taken by us as the basis of an electrophotographic, or sensitometric, method for studying the photoelectret state in single crystals and in polycrystalline specimens. In

Fig. 3

Figure 3: Fig. 3

Fig. 4

Figure 4: Fig. 4

particular, by measuring the optical density of the electrophotographic image on the surface of a photoelectret we investigated the duration of preservation of photopolarization in a photoelectret made of polycrystalline sulfur. A layer of polycrystalline sulfur about 50μ thick was polarized for 10 min at a polarizing-field strength of 5 kV/cm and an illumination on the surface of the layer of $2 \cdot 10^{-6}$ W/cm^2. The photoelectret prepared in this way was kept for a definite time in the short-circuited state in the dark. At the required moment the surface of the photoelectret was developed and its optical density was measured.

the optical density of the image, and for the subsequent measurement, corresponding to another time interval, the polarization of the layer was produced again. Fig. 3 shows the dependence of the optical density ΔD on the time elapsed from the moment polarization ended. It is seen from Fig. 3 that, after a short-term decrease over the course of a week, the polarization of the photoelectret does not change over 30 days and reaches a stable value amounting to 40% of the initial polarization. It was of particular interest to compare the duration of preservation of the latent image in ordinary electrophotography and in electrophotography on photoelectrets. Electrophotography known up to now was based on the adsorption of ions on the surface of a dielectric possessing photoconductivity. The formation of the latent image occurred in this case as a result of exposure of the dielectric surface charged in this way to some positive image. The subsequent development of the latent image was carried out by the method described by us above. The technique for obtaining electrophotographic images of this kind was set forth by us in work (7).

Fig. 3. Dependence of the optical density of an electrophotographic image on a photoelectret, ΔD, on the time elapsed from the moment polarization ended.

Fig. 4. Regression of the latent electrophotographic image: *a*—in the case of a photoelectret, *b*—in the case of adsorption of ions on the surface of a dielectric possessing photoconductivity.

We investigated the regression of the latent electrophotographic image both in the case of a photoelectret and in the case of adsorption of ions on the surface of a dielectric possessing photoconductivity. In both cases one and the same layer of polycrystalline sulfur, of thickness of the order of $50\,\mu$, deposited in vacuum on an aluminum plate, was used. In one case the layer was polarized for 10 min at a polarizing-field strength of about 5 kV/cm and illumination at the surface of the layer of $2 \cdot 10^{-6}$ W/cm^2. In order in this case to exclude the appearance of a homocharged space charge caused by the transfer of charges from the semitransparent electrode to the photoelectret, a glass plate 1 mm thick was placed between the sulfur layer and the semitransparent electrode. In the other case, the layer of polycrystalline sulfur was placed in the field of a corona discharge and was charged in the dark. A point, located at a distance of 10 mm from the surface of the layer and connected to the negative pole of a high-voltage rectifier (a voltage of about 6 kV was used), served as the corona electrode. During the discharge process, whose duration was 1 min, ions from the air were adsorbed on the surface of the sulfur layer. After charging, the layer was shielded and kept in the dark for a definite time. At the required moment the surface of the charged layer was developed by the method described above and the optical density of the developed electrophotographic image was measured. To carry out each new measurement of the optical density, corresponding to a definite time interval, charging of the layer was performed again under the same conditions.

Fig. 4 shows the time dependence of the percentage ratio of the magnitude of the optical density of the developed electrophotographic image—

of the image to its initial value for a photoelectret (a) and for a layer charged by means of a corona discharge (b). From the curves presented it is evident that in case (b) there is a rapid regression of the latent electrophotographic image, and the charge on the surface of the layer falls practically to zero. For the photoelectret, the regression of the latent electrophotographic image proceeds much more slowly and, as was shown above, the charge reaches a stable value different from zero. It is precisely this circumstance that allowed us to call electrophotography on photoelectrets an electrostatic analogue of magnetic recording (^{6}).

The results obtained confirm the assumption made above that the latent electrophotographic image on a polycrystalline photoelectret is due to the trapping of electrons at deep local levels arising at the boundaries of crystalline grains. The initial short-term decrease in the polarization of the photoelectret and the regression of the latent electrophotographic image associated with it are evidently due to the release of electrons from shallow levels. In the case of ordinary electrophotography, associated with the adsorption of ions on the surface of a dielectric, the formation of a latent electrophotographic image is due to the localization of electrons predominantly at shallow levels, which leads to rapid regression of the latent image and to the fall of the surface charge to zero. It is possible that a detailed study of the law of regression of the latent electrophotographic image will make it possible to determine the activation energies corresponding to the various local levels participating in the formation of the latent electrophotographic image.

The connection studied in the present work between the phenomenon of permanent internal photopolarization and the formation of a latent electrophotographic image is also of interest from another point of view. The individual crystalline grains of the polycrystalline sulfur investigated by us are at the same time grains of the electrophotographic layer. On the other hand, we have shown (^{5}) that for sulfur single crystals there is an exciton mechanism of depolarization of the photoelectret when it is illuminated. It follows from this that the formation of a latent electrophotographic image on polycrystalline sulfur is directly connected with the process of exciton excitation of each grain of the electrophotographic layer. This does not mean that elements of an electrophotographic image cannot be obtained on an individual grain, or that the resolving power of the electrophotographic layer is wholly determined by the grain size. We have obtained electrophotographic images on large single crystals of sulfur and anthracene in which a photoelectret state had first been created. It is possible that in this case the latent electrophotographic image was due to the localization of electrons at levels associated with structural defects.

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Institute of Crystallography
Academy of Sciences of the USSR

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