Surface Voltage Decay Model of Phthalocyanine Binder Type Photorecepter (II)

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Abstract

Recently, demands of high resolution printing by electrophotography are increased. To realize high resolution, high gamma characteristics of surface voltage decay versus irradiation energy are paid attention to. High gamma characteristics can make the electrostatic image formed on the photoreceptor sharp compared with the light image irradiated on the photoreceptor. The mechanism of high gamma characteristics is considered due to structural trap. On the base of the structural trap model, surface voltage decay is calculated by changing the characteristic length of the structural trap. It is obtained, when the characteristic length increase, the gamma value of surface voltage decay increases. The gamma values obtained by experiments are compared with the calculated results and the characteristic length is estimated.

Introduction

Electrophotographic printer is widely used from home to office. Photoreceptor is the key component of electrophotography. Various materials such as organic or inorganic materials are used for photoreceptor. Concerning its structure, there are several types: mono layer, multi-layer, or pigment dispersion type. Aiming at realization of high-resolution printing, digital (or high-γ) photoreceptor is proposed[1)]. The characteristics of the photoreceptor are as follows: till some level of light exposure, surface voltage decay is very little, but more than certain level of light exposure, surface voltage decays abruptly. So, the electrostatic latent image formed on the photoreceptor is very sharp, because of the surface voltage on the photoreceptor becomes digital (nearly "on" or "off"). It is considered that the photoreceptor is fit for digital image printing.

Digital photoreceptor proposed firstly is phthalocyanine dispersion type.[1] Recently, another type of digital photoreceptor is proposed.[2,3] The studies on the carrier transport mechanism have been carried out from the viewpoint of trapping.[4-6] It is pointed out that structural trap plays an important role in digital characteristics[2-4] and that there is reciprocity relation between half decay time and light irradiation energy.[7] The existence of structural trap is reported in other material system.[8] To understand the phenomena more, the surface voltage decay is estimated on the base of structural trap model.

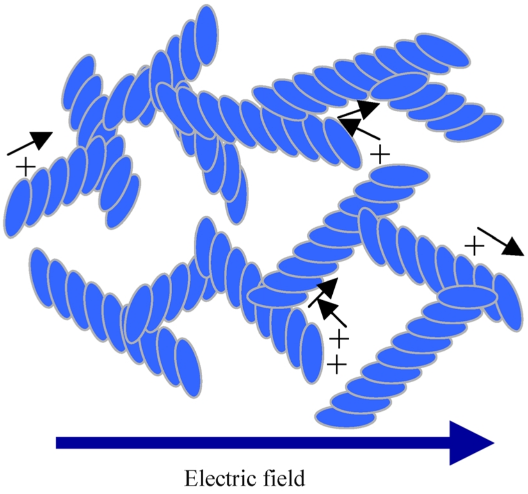

Figure 1. Schematic diagram of carrier transport between phthalocyanine : shaded circles, phthalocyanine.

Carrier Transport Model and Discussion

1) Model and Equation

In usual photoreceptors, the surface voltage decay by light irradiation is mainly controlled by the photo carrier generation, on the other hand, in the phthalocyanine binder type photoreceptor, the decay is suggested to be controlled by the other mechanism from the strange surface voltage decay characteristics. Phthalocyanine is dispersed in insulative binder, so it is considered the existence of structural trap. The carrier transport model is shown in Figure 1.

Phthalocyanine particle is dispersed in binder. Carrier moves through the nearest path between phthalocyanine particles or the contact point between them.

Figure 2 shows the mechanism of structural trap. Thermally activated carrier can move to nearest phthalocyanine particle.

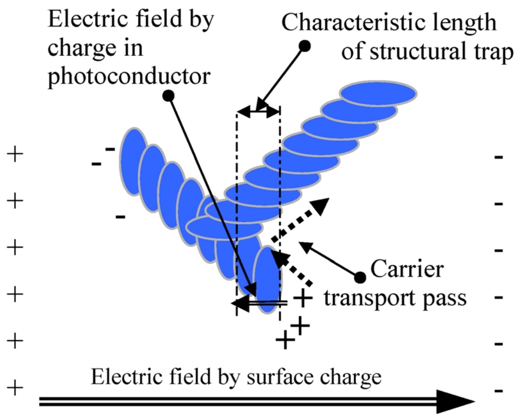

Figure 2. Trapping model of structural trap

2) Numerical Calculation

Model calculation is carried out on the base of conductivity. The model is very approximated one, however, it has characteristics of simplicity and it is useful to understand the tendency of phenomena. Surface voltage **Vs** is expressed as,

$$\varepsilon \frac{dVs}{dt} = -\sigma Vs. \tag{1}$$

where ε is the dielectric constant and σ is the conductivity of photoconductive layer. The conductivity σ is expressed as,

$$\sigma = ne\mu. \tag{2}$$

where **n** is the density of free carrier, **e** is electron charge and μ is carrier mobility. The mobility is divided to product of two terms as,

$$\mu = \mu_0 \exp\left(\frac{e\frac{Vs}{l}d - e\frac{\phi}{\varepsilon}d}{kT} \right). \tag{3}$$

where **d** is the characteristic length of the structural trap, **l** is the thickness of photoconductive layer, **ϕ** is the photo excited free carrier charge amount per unit area, **k** is Boltzmann constant and **T** is absolute temperature. The photo excited free carrier number per unit area **ϕ** is expressed by the following equation,

$$\phi = e\int \eta I dt - \frac{\varepsilon}{l}(V_0 - V_s). \tag{4}$$

where **η** is the carrier quantum efficiency by light, **I** is the light intensity and $\mathbf{V_0}$ is initial surface voltage. The latter term of Eq.(4) means carrier disappearance by the neutralization at the boundary of photoconductive layers. The quantum efficiency usually depends on electric field. The efficiency increases with the electric field and saturates to certain value less than 1.[9] We express approximately as,

$$\eta = \frac{\left(Vs/Vc\right)^{\gamma}}{1+\left(Vs/Vc\right)^{\gamma}}. \tag{5}$$

where **γ** and Vc is fitting parameters. The density of free carrier **n** and the photo excited free carrier charge amount per unit area **ϕ** are related as,

$$n = \frac{\phi}{el}. \tag{6}$$

Eqs. (2)–(3), (6) are substituted to Eq.(1) and numerical calculation is carried out coupled with Eq. (4) to which Eq.(5) is substituted. (**NDSolve** of Mathematica® is used in this calculation.)

Model calculation is carried out by using the following conditions:

l=$2.5\mathrm{x}10^{-5}$ [m] , **I** =$4.6\mathrm{x}10^{15}$ [photons/(m^{2}S)],
$\mathbf{V_0}$=700 [V], **ε**=$2.66\mathrm{x}10^{-11}$ [F/m],
k =$1.38\mathrm{x}10^{-23}$ [J/K], **T**=298 [K],
e=$1.6\mathrm{x}10^{-19}$ [C], **γ**=1.0,
Vc=100 [V].

Light intensity **I** is determined as: initial surface charge is neutralized in one second when the quantum efficiency is 1. The intensity is expressed as,

$$I = \frac{\varepsilon V_0}{el}. \tag{7}$$

Surface voltage decay is calculated on the cases of half and double intensity of light irradiation. The value **γ** and Vc of Eq.(5) is determined from the experimental data.[9]

The mobility of phthalocyanine binder system of TiOPc is reported10) that the mobility is 10-10 – 10-8 m2/Vs at the electric field 6x107V/m on the condition of phthalocyanine wt% 20-50%. Transit time Tr which means the time of photogenerated carrier going though the photoconductive layer is calculated,

$$Tr = \frac{l^2}{\mu_0 \cdot V_0}. \tag{8}$$

Transit time is estimated from 10msec to 0.1msec. So, we calculate surface voltage decay curve on the conditions of transit time; 10msec, 1msec, and 0.1msec.

Surface voltage decay is calculated on the condition of transit time 1m sec and 10 m sec excluding the structural trap effect. The calculation is carried out on three cases of the characteristic length of structural trap: 40nm, 80nm, and 120nm. The calculated results of surface voltage decay are shown in Fig. 3 and Fig. 4, respectively. Surface voltage decay is also calculated on the condition of transit time 0.1m sec excluding the structural trap effect. The calculation is carried out on three cases of the characteristic length of structural trap: 40nm, 100nm, and 160nm. The calculated results of surface voltage decay are shown in Fig. 5.

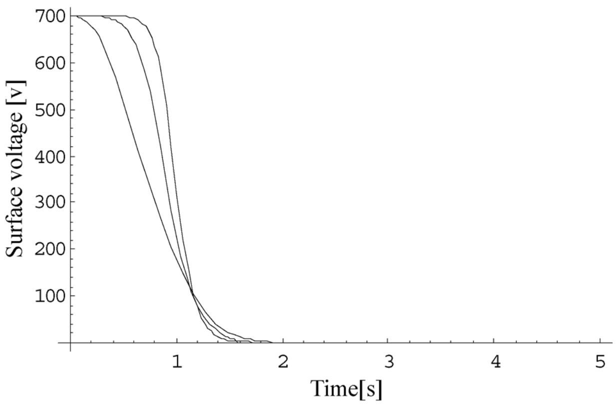

Fig.3 Surface voltage decay curve of transit time : 10msec,and the characteristic length : 40,80,120nm.

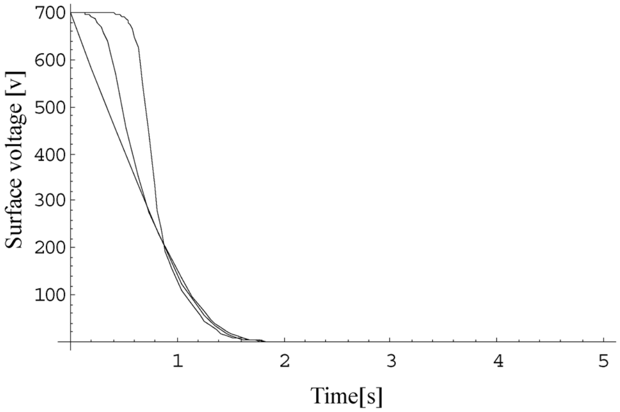

Fig.5 Surface voltage decay curve of transit time : 0.1msec,and the characteristic length : 40,100,160nm.

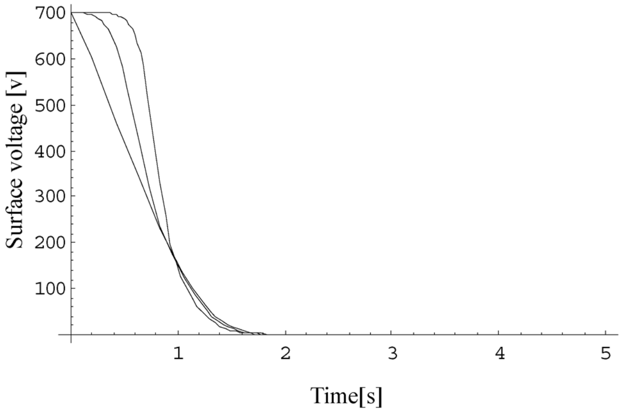

Figure 4. Surface voltage decay curve of transit time: 1 msec, and the characteristic length: 40, 80, 120 nm.

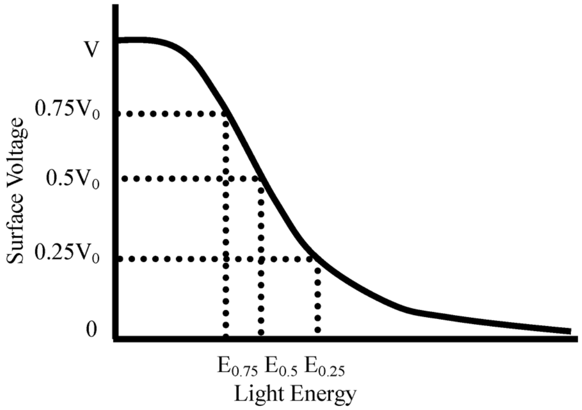

Figure 6. Definition of $E_{0.75}$, $E_{0.5}$, $E_{0.25}$.

From Figs. 3-5, it is found that the delay of the surface voltage decay becomes remarkable according to the increase of the characteristic length of trap. Concerning the transit time, it is found that the delay increases when the transit time increases. The above phenomena are considered as, when the characteristic length increases, trap depth increases, and for the liberation from the trap more accommodation of carrier is needed. Concerning the transit time dependence, according to the increase of transit time, it needs time for carrier reach the base electrode of the photoreceptor, so the surface voltage decay is delayed.

We characterize the delay phenomena of the surface voltage as follows. Three values of surface voltage are defined at the three points in Fig. 6.

As the surface voltage decay delay become remarkable, the ratio $E_{0.5}/(E_{0.25} - E_{0.75})$ increases. Using these values, the degree of the surface voltage decay delay ***Dsvdd*** is defined,

$$Dsvdd = \frac{E_{0.5}}{E_{0.25} - E_{0.75}}. \qquad (9)$$

The degree Dsvdd is less than 1 when the surface voltage is controlled by charge generation limited model (charge carrier generation rate by photon increases with electric field within photoconductive layer). Therefore, if the degree Dsvdd exceeds 1, it is considered that other phenomena such as mobility controlled by the carrier accumulation arise in the surface voltage decay mechanism.

The dependence of ***Dsvdd*** on the characteristic length of trap is shown in Fig. 7 on the three cases of the transit time. ***Dsvdd*** increases with the increase of the characteristics length of trap. When the transit time increases, ***Dsvdd*** begins to increase in the shorter characteristic trap length.

From the experiment of the condition: temperature 298k, wavelength of the light irradiation 780nm, sample thickness 25 µm, and charging polarity positive, ***Dsvdd*** is obtained 2.6. The line ***Dsvdd***=2.6 is drawn in Fig. 7, and the characteristic length of trap is estimated 70-130nm.

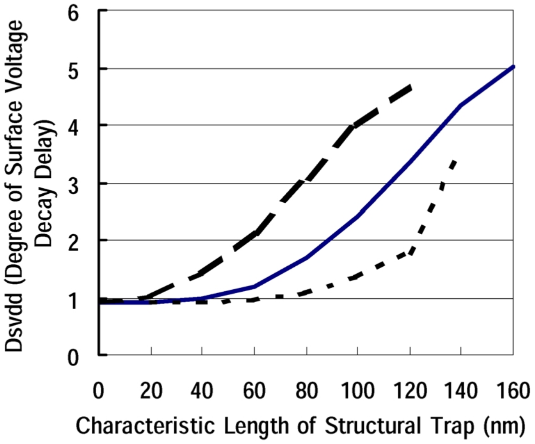

Figure 7. Dsvdd dependence on Characteristic length of trap, - - : transit time 10msec, —— :transit time 1msec, •••••• : transit time 0.1 msec.

Conclusion

The model of surface voltage decay in phthalocyanine binder type photoreceptor is studied on the base of the structural trap model. Macroscopic mobility of carrier depends on the number of excited free carrier and the mobility increased abruptly as the number increases more than certain value when the length structural trap increases. The model calculation of surface decay is carried out and the decay curve explains qualitatively the experimental results. If the transit time is assumed 0.1msec – 10msec form the other phthalocyanine binder system, the characteristic length of structural trap is estimated 70 – 130nm.

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Biography

Hoshino Yasushi is Professor of Nippon Institute of Technology. He gained Bs., Ms. and Dr. degrees from University of Tokyo, 1970, 1972, and 1984 respectively.

After he gained Ms. degree, he joined Electrical Communication Laboratories of NTT and developed first LED printer, high speed laser printer (process speed 89 cm/s), color laser printer by using ultra elliptical laser beam scanning, photo-induced toning technology and ion flow printing. He moved to Nippon Institute of Technology on 1994. He published more than 20 papers and several papers also in IS&T's Journal. He attended almost NIP congresses. E-mail: hoshino@nit.ac.jp