Surface Voltage Decay Model of Phthalocyanine Binder Type Photoreceptor

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Abstract

Delay in surface voltage decay is known in phthalocyanine binder type photoreceptor. Because of the delay, sharp electrostatic image can be formed on photoreceptor. So, the photoreceptor is called “digital photoreceptor”. The surface voltage decay mechanism is analyzed on the base of structural trap model. The model explains that the carrier macroscopic mobility increases very abruptly by the increase of free carrier. The model calculation of surface decay curve is carried out and it is found that the decay curve agrees with the experimental tendency.

Introduction

Electrophotographic printer is widely used from home to office. Photoreceptor is the key component of electro-photography. 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)]. To understand the phenomena more, we calculate the surface voltage decay on the base of structural trap model.

Characteristics of binder type photoreceptor

Phthalocyanine used in this experiment is x-type metal free phthalocyanine and its average diameter is 0.5 μm before mixing with binder. Phthalocyanine and binder is mixed with the condition of phthalocyanine 15 wt %. Denaturalized polyester resin is used as binder. Phthalocyanine and binder is mixed by sand mill for 2 hours and is coated on aluminum evaporated PET film by dip coating method. The thickness of the photoconductive layer is 25 μm.

The photoreceptor is charged by positive corona discharge till the surface voltage becomes +700V. The photoreceptor is irradiated with the light of wavelength 450nm. Surface voltage decay curves are shown in Fig. 1. The measurement was carried out at the condition of temperature 25°C and relative humidity 55%.

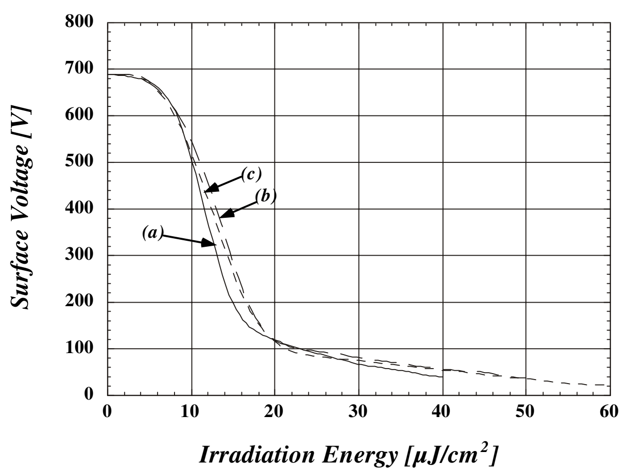

Fig. 1 Light decay curves measured for phthalocyanine binder photoreceptor at different intensity of irradiation: (a) 0.72 μW/cm², (b)1.15 μW/cm², (c) 1.98 μW/cm², wavelength 450nm, positive surface charge.

From Fig. 1 it is found that the surface voltage decay is good for digital image printing. The curves are nearly same on the axis of irradiation energy, so it can be considered that the photoreceptor satisfies approximately reciprocity principle.

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 Fig. 2.

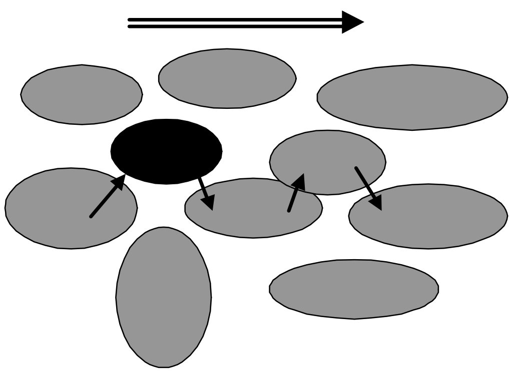

Fig. 2 Schematic diagram of carrier transport between phthalocyanine particles: shaded circles, phthalocyanine particles, ⇒ electric field, → carrier transport.

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

2) Numerical calculation

Model calculation is carried out on the base of conductivity. The model is 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 μ_0 is the mobility excluding the structural trap effect, **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 **V0** 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[7]. We express approximately as,

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

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=$2.5\text{x}10^{-5}$ [m],
I =$4.6\text{x}10^{15}$ [photons/(m^2S)],
V0=700 [V],
ε=$2.66\text{x}10^{-11}$ [F/m],
k =$1.38\text{x}10^{-23}$ [J/K],
T=300 [K],
e=$1.6\text{x}10^{-19}$ [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,

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

The value γ and Vc of Eq.(5) is determined from the experimental data[7].

3) Characteristics length dependence of structural trap

Surface voltage decay is calculated on the condition of transit time 1 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 160nm.

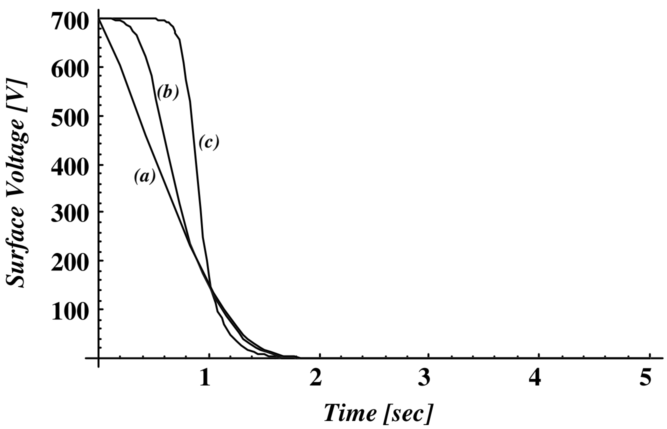

Fig. 3 Surface voltage decay curves on the case of transit time 1 m sec at different length of structural trap: (a) 40nm, (b) 80nm, (c) 160nm.

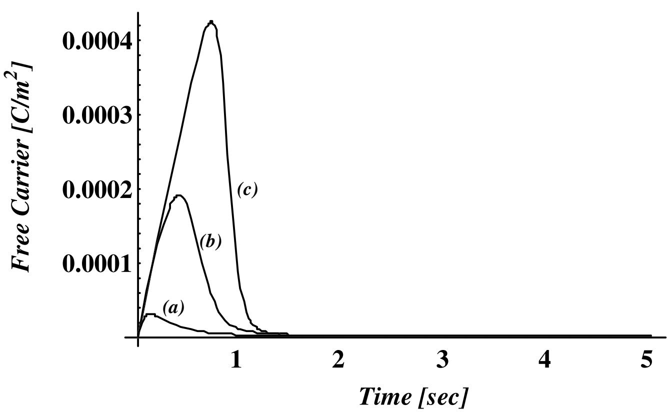

Fig. 4 Time dependence of number of free carrier on the case of transit time 1msec at different length of structural trap: (a) 40nm, (b) 80nm, (c) 160nm.

It is found that the induction effect becomes obvious when the length of structural trap increases. On the other hand, when the length is 40nm, the structural trap can be neglected and the surface decay curve becomes nearly as charge generation limited case. It is considered that if the length increases, the depth of trap increases and the amount of carrier necessary for screening the trap potential increases.

Concerning the amount of positive free carrier, the amount starts to increase by light irradiation, then the amount decreases because of carrier neutralization at the base electrode of photoreceptor. As the characteristic length of structural trap increases, the peak of free carrier amount increases. The reason is considered as follows: the length increases, the amount of free carrier needs to screen the trap potential increases.

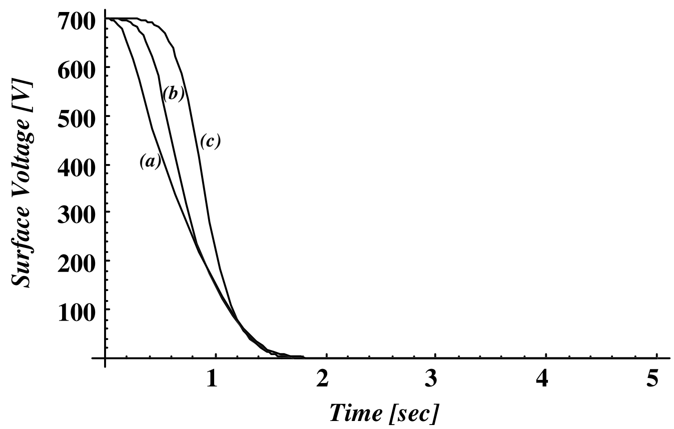

Fig. 5 Surface voltage decay curves on the case of structural trap length 80nm at different transit time: (a) 0.1msec, (b) 1msec, (c) 10msec.

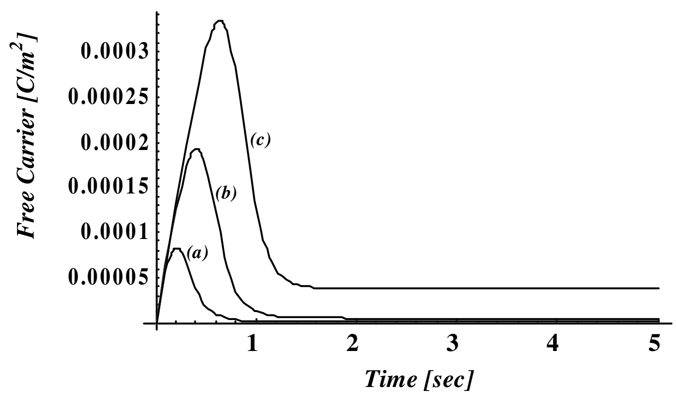

Fig. 6 Time dependence of number of free carrier on the case of structural trap length 80nm at different transit time: (a) 0.1msec, (b) 1msec, (c) 10msec.

4) Transit time dependence of carrier transport

The calculation is carried out on the condition of the characteristic length of structural trap 80nm. On the cases of transit time 0.1 m sec, 1 m sec and 10 m sec, calculation is carried out.

It is found that the induction phenomenon becomes obvious as the transit time increases. When the transit time is short, the carrier detrapped from the structural trap neutralizes surface charge rapidly.

Concerning the amount of positive free carrier, when the carrier transit time increases, the peak of free carrier amount increases. This is considered, as the transit time increases, the free carrier is accumulated because of the increase of the time needed for the neutralization.

In this calculation, the surface voltage decay is analyzed on the base of simplified conductivity model. Carriers in organic photoconductor are considered to be localized. The improvement by the model that carrier moves with certain mobility is considered to be necessary as a next step[8].

The structural trap model can explain the surface voltage decay phenomena, but it is expected to get evidences of structural trap.

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.

Acknowledgement

Authors would like to express their sincere thanks to Dr. Y. Yamaguchi of Fuji Xerox for his kind discussion and his supply of references.

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Biography

Hoshino Yasushi is Professor of Nippon Institute of Technology. He gained Bs., Ms. and Dr. degrees from The 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 89cm/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.

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