Organic Photoconductors for Printers

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ABSTRACT

Fuji Electric provides a product line of negatively charged organic photoconductors in three varieties, low sensitivity, medium sensitivity and high sensitivity, for compatibility with various amounts of exposure light. Also, in response to a diversifying range of applications and the desire for more advanced functionality and higher quality, Fuji Electric uses proprietary evaluation technology, analysis technology and material design techniques to realize higher responsiveness, higher resolution, higher durability and higher reliability. For positively charged organic photoconductors, which are environmentally friendly and provide high resolution, in addition to monolayer type that provides low-speed to high-speed and high printing durability, a multilayer type that provides high sensitivity and high-speed response has been fully commercialized for the first time in the world.

1. Introduction

With recent advances in IT, the applications of electrophotographic printers are expanding from personal use to business use. Such devices must have faster printing speeds in order to keep pace with faster information-processing speeds; they must provide color and high definition printing to support increasing diverse information; and they must be more compact, not require maintenance, and have lower printing costs, in order to meet the demands for lower information-processing costs and greater energy efficiency. Electrophotography meets these demands by applying a wide range of technologies, in the charging, developing, transfer, and fusing processes respectively.

Fuji Electric develops negative-charge and positive-charge organic photoconductors (OPCs) in order to comply with the electrophotographic printer specifications of each of its customers, marketing these OPCs while expanding its lineup. This paper presents an overview of these products, and describes their features.

2. Negative Charge OPCs for Printers (Type 8)

2.1 Product overview

Figure 1 shows the layer structure of negative-charge OPCs. Fuji Electric offers three types of product series, with adjusted charge generation layer (CGL) properties in order to support a wide range of light exposures. These are Type 8 A (low sensitivity), Type 8B (medium sensitivity), and Type 8C (high sensitivity). As shown in Table 1, the material and the layer thickners can be controlled to adjust the sensitivity within a range of 0.15 to 0.80 μJ/cm², up to light exposure of −100 V.

Figure 2 shows typical spectral sensitivity characteristics for Type 8A (low sensitivity), Type 8B (medium sensitivity), and Type 8C (high sensitivity). All have nearly uniform sensitivity in the wavelength range of 600 to 800 nm, making them suitable for ordinary laser diode (LD) and light-emitting diode (LED) light sources.

These CGLs can be combined with various charge

Fig.1 Layer Structure of Negative Charge OPCs

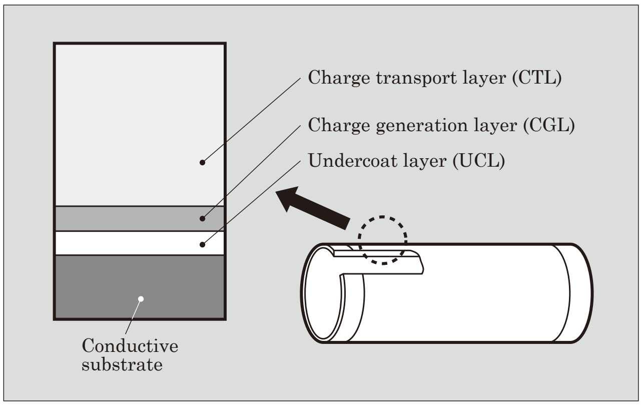

Table 1 Overview of Negative Charge OPC Products for Printers

Type	Sensitivity* (Exposure energy to −100 V)
Type 8 A (low sensitivity)	0.60 to 0.80 μJ/cm²
Type 8B (medium sensitivity)	0.40 to 0.60 μJ/cm²
Type 8C (high sensitivity)	0.15 to 0.40 μJ/cm²

*Sensitivity is the required exposure energy for the surface potential to discharge from −600 V to −100 V

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transport layers (CTLs) to supply OPCs suited to various processes, from low-speed to high-speed devices.

Using its own unique conductive substrate processing technologies and layer-formation technologies, Fuji Electric is able to produce OPCs with a diameter of 20 to 262 mm, and a length of 236 to 1,000 mm, and markets a wide range of products, from A4-size page printers to A0 plotters.

2.2 Product features

Figure 3 shows the technical challenges for providing the six characteristics required of printer OPCs: high speed, color imaging, high resolution, compact size, maintenance-free operation, and lower printing costs. Each of these features is described below.

(1) High-speed response

In order to make small-diameter OPCs (having a diameter of 20 to 30 mm) suitable for use in high-speed printers capable of printing longitudinally fed A4-size sheets at a rate of 35 ppm or higher, the potential of exposed areas to light must be uniform during the exposure-development time, which is 50 ms or less in a typical processing machine. Accordingly, Fuji Electric has developed a charge transport material (CTM) having mobility of 2×10^{-5} cm^2/(V·s) for use in practical applications. Fuji Electric has further completed the development of a high-mobility material of 8×10^{-5} cm^2/(V·s) to support even higher speeds.

Figure 4 shows the dependency of the surface potential after exposure on the exposure-development time for high-speed response. The potential is stable in any environment, and with an exposure-development time at the 30 ms level, it is commercially viable.

(2) High definition

OPCs for use in color-imaging, high-resolution printers and multi-function printers (MFPs) must have even greater color reproducibility and gradation-reproduction capability for halftone images. Fuji Electric is developing and commercializing OPCs with the optimum light-induced discharge characteristics for various machine processes. Figure 5 shows examples of light-induced discharge characteristics by OPC type. These characteristics are largely dependent on the charge-transfer performance of the CTM and the efficiency of carrier injection between layers. It can therefore be regulated via the combination of the under coat layer (UCL), CGL, and CTL. The requirement for high

Fig.2 Spectral Sensitivity Characteristics of Negative Charge OPCs

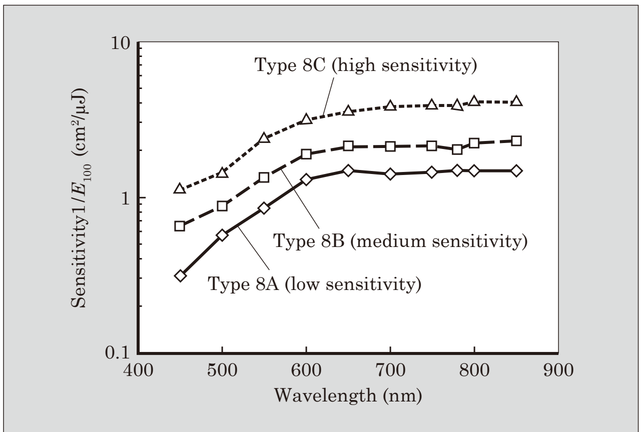


Fig.3 Required Characteristics of OPCs and Technical Challenges

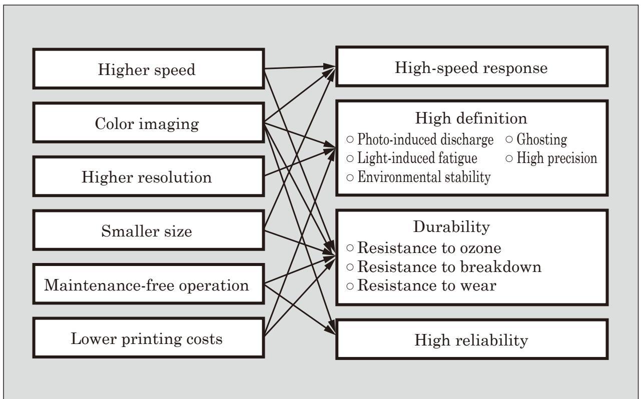


Fig.4 Photoresponsivity of Negative Charge OPCs

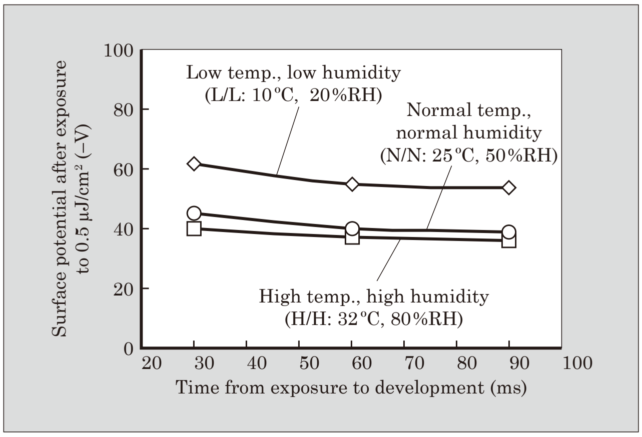
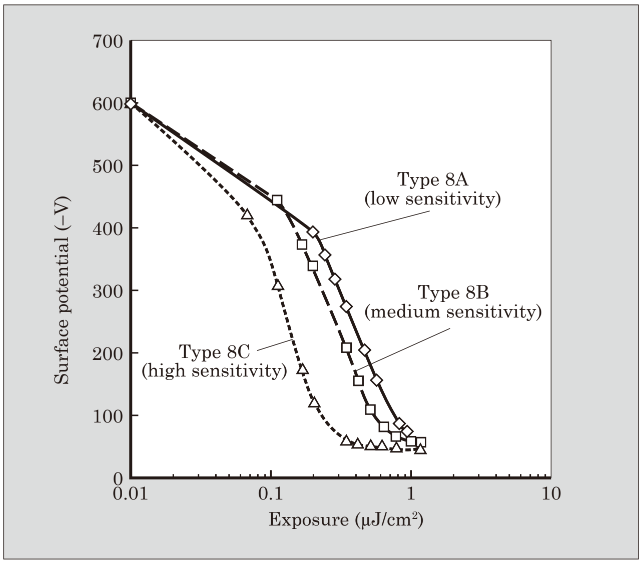


Fig.5 Photo-induced Discharge of Negative Charge OPCs



resolution can be met by developing a CTM with low horizontal charge diffusion. The fine line definition reduces the amount of toner consumed, which reduces printing costs.

The image quality of printers continues to advance. As a result, minute differences in potential on the OPC surface are more easily reproduced in the image as contrasts in image density. It is therefore preferable for OPCs to have photosensitive layers with uniform thickness, and be relatively unaffected by the application of positive polarity at transfer process, and the increase in residual potential with continuous exposure. Fuji Electric is reducing the potential difference by developing new materials for use in the UCL, CGL, and CTL functional layers, and by optimizing their combination.

In the general market, it is possible that the OPC will be exposed to indoor light or sunlight when cartridges are changed, or when there is a paper jam. The effects of this light exposure on the OPC must therefore be minimized. Fuji Electric has commercialized OPCs whose image quality is largely unaffected by exposure to fluorescent and other forms of indoor lighting, through the appropriate combination of CGL and CTL.

Color printers that print by overlaying four colors require higher dimensional precision than monochrome printers, in order to prevent color drift. Fuji Electric has technologies for processing OPC substrate tubes with a runout of 30 μm or less, and straightness of 20 μm or less, for use in these types of color printers, and it has also established a system for supplying high-precision plastic flanges.

In order to maintain the initial image quality, the characteristics of the OPC should be largely unchanged by changes in the environment or printing durability. A printing test was performed using a commercially available charging laser printer equipped with a 24 mm diameter OPC: 10,000 A4-size longitudinally fed sheets were each printed under the environmental conditions of low temperature and low humidity (L/L: 10 °C and 20% RH), normal temperature and normal humidity (N/N: 25 °C and 50% RH), and high temperature and high humidity (H/H: 32 °C and 80% RH), and the surface potential was measured after every 2,000 sheets. The data is shown in Fig. 6. In all of these environments, favorable characteristics were exhibited without any significant change in potential.

(3) Technology for higher durability

The charging unit in printers generally produce ozone. Various anti-oxidizing materials and other additives are thus used in order to provide the OPC with gas resistance. Ordinarily, using large quantities of additives improves resistance to acidic gases, but has negative effects on electrical characteristics as well, such as increasing the residual potential. Fuji Electric has ensured resistance to acidic gases by developing CTMs with low deterioration and a proprietary additive that does not impact electrical characteristics.

Contact charging is widely used in medium and low-speed printers. There is a strong requirement, however, for improved resistance to dielectric breakdown comparable to scorotron non-contact charging. Since launching a UCL equipped with an interference-suppressing function in 1995, Fuji Electric has been working continuously to develop OPCs with improved resistance to dielectric breakdown and environmental characteristics. Fuji Electric is presently developing UCL products that exhibit excellent environmental stability, and the same degree of resistance to dielectric breakdown as an anodized layer. It is also working to improve the overall performance of OPCs, including the charge-generation and charge-transport layers.

The useful service life of an OPC is determined by abrasion from such contact parts as the developing system, the paper, and the cleaning blade. Fuji Electric is independently developing resins with excellent abrasion resistance and lubricative resins, and offers OPCs optimized for various processes by selecting the appropriate combination for each process.

In order to improve image quality, the particle diameter of toners is being reduced, and manufacturers are moving from mechanical toner to chemical toner.

Fig.6 Surface Potential Stability of Negative Charge OPCs During Environmental Printing Life Tests

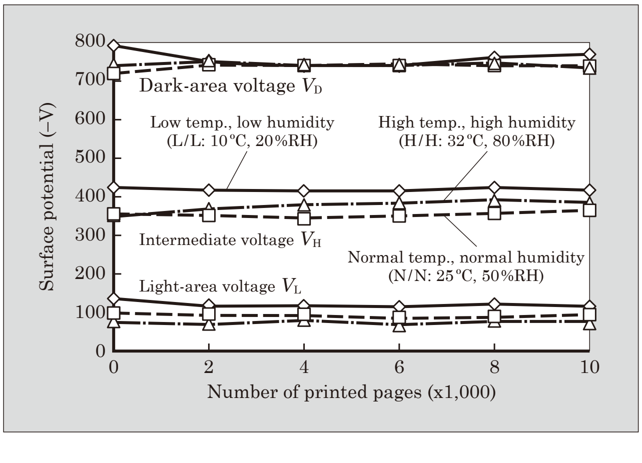
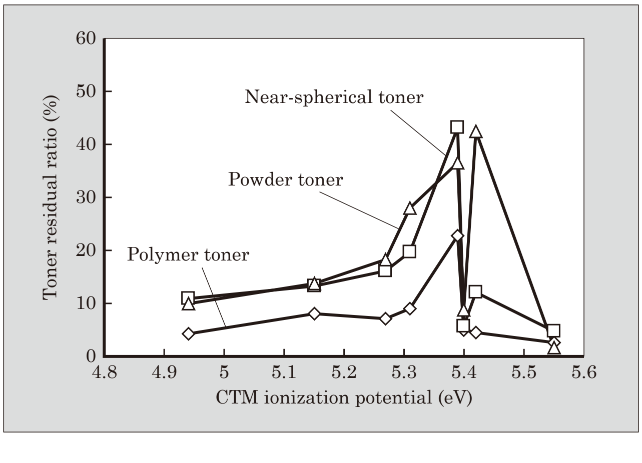


Fig.7 CTM Dependence of Toner Residual Ratio



This makes the toner adhere strongly to the OPC surface ("filming"), and low-filming performance is therefore required. Fuji Electric develops and employs methods to evaluate the adhesive strength of toner using the toner residual ratio[1]. Figure 7 shows the CTM ionization potential and toner residual ratio of each toner. Fuji Electric is developing the optimum OPCs for each type of toner.

(4) High reliability

OPCs should maintain stable characteristics in a variety of environments, and remain stable in response to external mechanical and chemical stresses.

Starting from the stage of materials development, Fuji Electric independently establishes a list of inspection items, and evaluates the reliability of each product, including long-term storage characteristics. This enables it to develop and produce highly reliable OPC products.

3. Positive Charge OPCs for Printers (Type 11 & Type 12)

3.1 Overview of Fuji Electric's Products

Fuji Electric offers a line of positive-charge OPC products. These products feature higher image resolution than typical negative-charge OPCs, and demand for them is growing. The charged parts also produce less ozone, making it friendlier to the environment as well.

There is also strong demand to increase the sensitivity of OPCs, in order to conserve energy by enabling the energy consumption of the device's exposure laser to be reduced. However, positive-charge OPCs have less leeway in material design than negative-charge OPCs, in order to provide the required characteristics, and the difficulty in increasing sensitivity is a challenge for this type of OPC. Fuji Electric has developed a positive-charge CTM through the application of its proprietary computational chemistry and organic synthesis techniques, and has commercialized a new type of multilayer OPC, Type 12, by combining this with its photoconductor technologies to increase sensitivity.

Table 2 shows the product series for Type 11 and Type 12 positive-charge OPCs. Figure 8 shows the spectral sensitivity characteristics of the five series from Type 11A to Type 12. All the positive-charge OPCs have nearly uniform sensitivity in the wavelength range of 600 to 800 nm, making them suitable for ordinary LD and LED light sources. As shown in Fig. 9, types are available with a wide range of sensitivities, with a range of half-decay exposure from 0.15 to 0.38 μJ/cm^2, and they are suitable for use with printers from low speed (15 ppm or lower) to high speed (35 ppm or higher). As shown in Table 3, the newly developed type 12 in particular has improved sensitivity through boosts to the performance of the various functional materials. This enables the amount of energy consumed by the laser to be reduced by about 30%. As

Table 2 Overview of Positive Charge OPC Products for Printers

Type	Features	Recommended machine (ppm)*	Printing life (Converted to A4 intermittent printing, 30 mm external diameter)
11 A	Low speed	< 12	20,000
11B	Medium speed	10 to 18	30,000
11C	Medium & high speed	12 to 24	140,000
11D	High-speed & high printing durability	≥ 30	200,000 Converted to 120 mm external diameter & A4 continuous printing; up to 1 million pages can be used
12	High-speed & high printing durability	≥ 35	≥ 200,000

*ppm: page per minute

Fig.8 Spectral Sensitivity Characteristics of Positive Charge OPCs

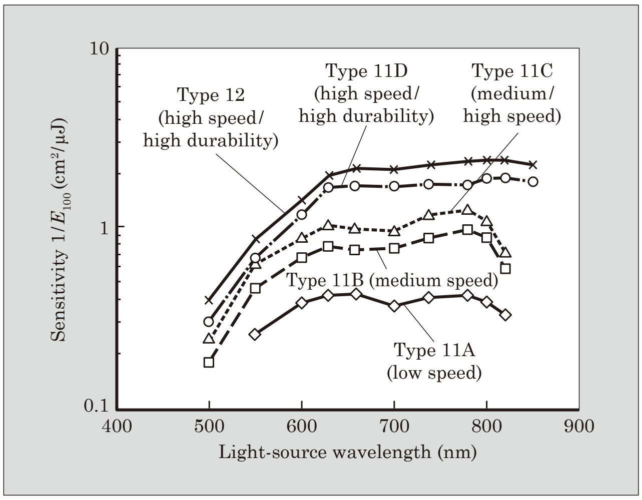
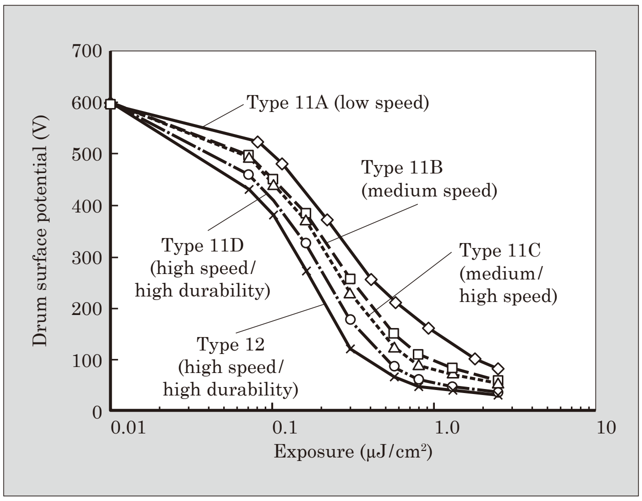


Fig.9 Photo-induced Discharge (PIDC) of Positive Charge OPCs



a result, they are able to meet the demands for higher sensitivity and response speed, while contributing to device design that takes energy efficiency into account.

3.2 Features of Positive Charge OPC Products

Here, the authors describe the features of positive-charge OPC products, with regard to technical challenges common to negative-charge OPCs.

(1) High-speed response

Table 3 Relationship between Characteristics and Material for Type 12

Feature	Characteristics of material
Higher sensitivity	CGM→increased quantum efficiency
High-speed response	HTM→increased hole mobility ETM→increased electron mobility Optimized balance between hole and electron transport
Higher strength	Resin binder→higher glass transition temperature →increased surface hardness
Resistance to breakdown	UCL→thicker layer (electrical conductivity control)

Fig.10 Photoresponsivity of Positive Charge OPCs

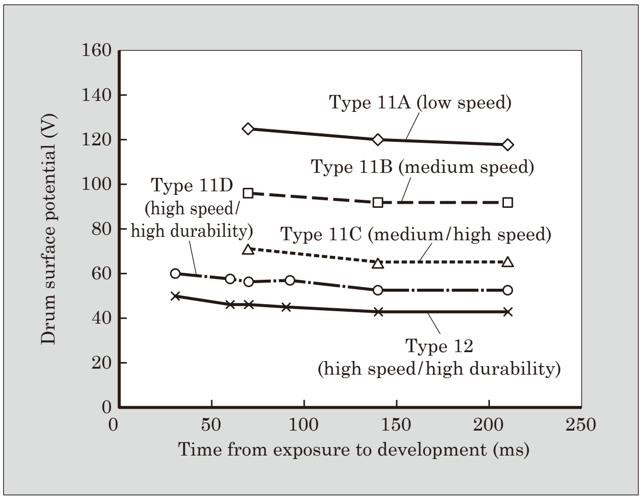


Fig.11 Comparison of 1-dot Latent Images of Positive and Negative Charge OPCs

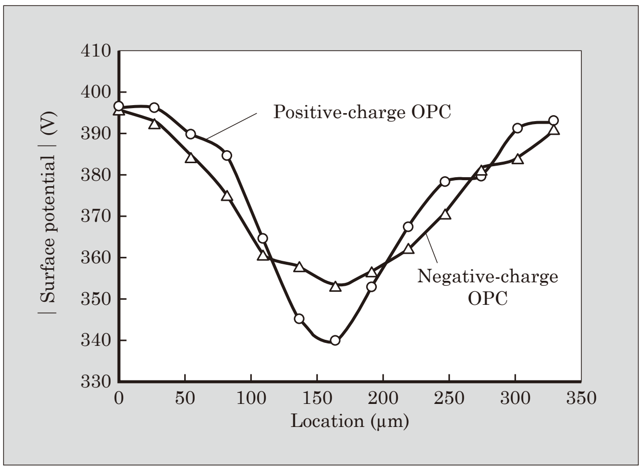


Figure 10 shows the photoresponsivity of positive-charge OPCs. All of the positive-charge OPCs are suited to devices with times from exposure to development of 75 ms or greater. Type 12 in particular has little increase in exposed-area voltage even after 30 ms of exposure, making it suited to compact, high-speed devices with shorter times from exposure to development.

(2) High definition

Positive-charge OPCs are well suited for use in high-resolution applications, since the absorption of exposure light and the subsequent generation of charge occurs near the OPC surface, because there is little scattering or diffusion of exposure light and charge within the photosensitive layer. Figure 11 shows the results of measuring the electrostatic latent-image width at the area of 1-dot exposure writing[2]. Spreading of the latent image can be observed in the negative-charge OPC, and indicates the extent of the high resolution performance of the positive-charge OPC.

The optimal regulation of the UCL and GTL, even during durability testing, enables better uniformity of the halftone image quality and suppresses the phenomenon of residual images. All types had favorable light-induced fatigue characteristics. Exposure to light at 1,000 lx for 10 minutes caused little change in the dark-area voltage in any of the types, and the recovery time after the light exposure was short.

Figure 12 shows the environmental characteristics of light-area voltage V_L and dark-area voltage V_D. All of the positive-charge OPCs have stable dark-area voltage and light-area voltage, and exhibit little environmental fluctuations with the range of low temperature and low humidity (L/L: 5 °C, 20% RH) to high temperature and high humidity (H/H: 35 °C, 80% RH).

(3) High printing durability

Fig.12 Environmental Dependence of Exposed-area Voltage V_L and Dark-area Voltage V_D of Positive Charge OPCs

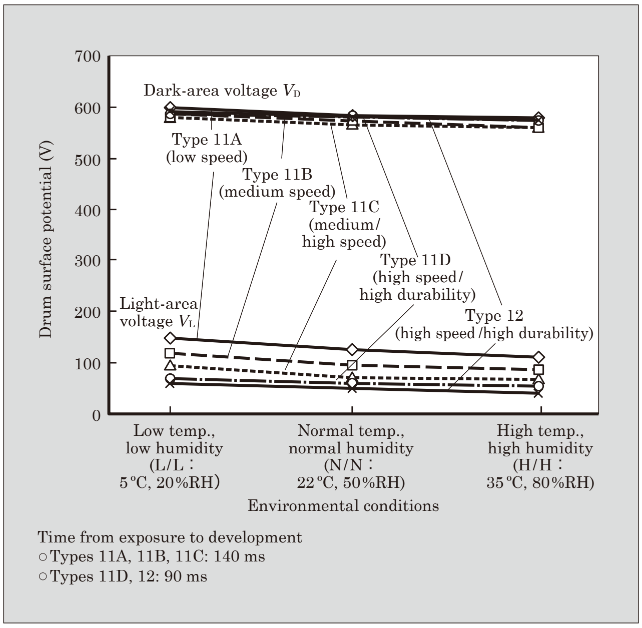


Table 4 Changes in Characteristics in Reliability Tests

Test item	Test conditions	Change in characteristics before and after test	
		Dark-area voltage fluctuation	Exposed-area voltage fluctuation
Exposure to high temperature	45°C: 1,000 hours	< ±5%	< ±10%
Exposure to high temp. and high humidity	35°C, 90% RH: 1,000 hours	< ±5%	< ±10%
Heat cycles 1 to 5 (10 cycles)	(1) −20°C: 1 hour (2) Normal temp./humidity: 0.5 hours (2) Normal temp./humidity: 0.5 hours (3) 45°C: 1 hour (4) −20°C: 1 hour (5) Normal temp./humidity: 0.5 hours	< ±5%	< ±10%
Roller contact test	Roller materials: NBR, polyurethane rubber, silicon rubber; 50°C, 90% RH: 250 hours	None	None
		No image faults	

As shown in Fig. 13, all of the positive-charge OPCs exhibit a temporary drop in charging potential shortly after exposure to ozone for 30 minutes at a concentration of 5 ppm, but then recover to their initial charging potential after being left to stand at room temperature for 24 hours. OPC types 11A, 11D, and 12 are particularly resistant to ozone, and exhibited only slight drops in charging potential immediately after exposure.

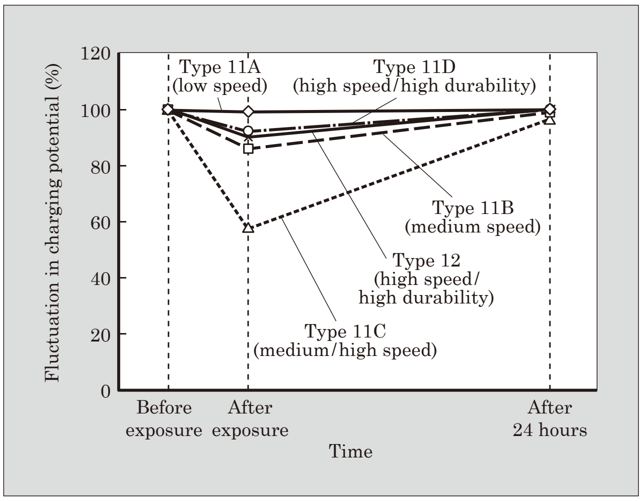
In a printing-duration evaluation using a two-component development printer, the Type 11D OPC exhibited stable light-area voltage and dark-area voltage with no observable image defects, and had a printing life of approximately 200,000 sheets. Type 12 is expected to have an even longer useful service life, and further environmental measures are being advanced as well.

(4) High reliability

Table 4 shows changes in characteristics as a result of various reliability tests. The tested OPCs exhibited high reliability: for all of the test items, fluctuation in dark-area voltage was no more than 5%, and fluctuation in exposed-area voltage was no more than 10%.

In a roller contact test in particular, rollers formed from acrylonitrilebutadiene rubber (NBR), polyurethane rubber, silicon rubber, and the like are pressed against each photoconductor, and even after the OPC was left standing in an environment of 50°C and 90% RH for 250 hours, cracking did not occur in the photosensitive layer, and the photoconductor characteristics did not change.

Fig.13 Ozone Resistance of Positive Charge OPCs



4. Postscript

The trends toward higher speed, greater functionality, higher image quality, and lower cost will continue to advance for electrophotographic printers, and performance requirements for photoconductors will become more diverse. Fuji Electric will continue to utilize and develop chemical and photoconductor technologies to provide a variety of high-functionality photoconductors, suitable to meet the increasingly diverse needs for information output, and in doing so, to fulfill its social responsibility toward environmental conservation, and to make a positive contribution to society.

References

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(2) Ueno, Y. and Aizawa, K. Simulation and Measurement Technologies in Electrophotography. The Imaging Society of Japan, 2003 Symposium. 2003, pp.40-46.