Organic Photoconductors for Printers

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1. Introduction

With the recent advances in information technology (IT), applications for electrophotographic printers continue to expand for both personal use and business use. Moreover, printers are also being required to provide more advanced functionality, i.e., higher speed printing that supports the higher speeds of information processing, colorization and higher resolution that support more diversified types of information, and smaller size devices and maintenance-free operation that support the requests for reduced cost of information processing.

Moreover, the technology for each of the electrophotographic charging, developing, transferring and fixing processes is becoming more diverse in response to such requirements.

In order to realize the required level of performance for electrophotographic printers, Fuji Electric is developing, manufacturing and enriching its product line of negative charge type and positive charge type organic photoconductors (OPC), and is expanding this market. This paper presents an overview of Fuji Electric's OPC products and describes their features.

2. Negative Charge Type OPC "Type 8"

2.1 Product overview

Negative charge type OPCs have the layer structure shown in Fig. 1, and in order to provide compatibility with various amounts of exposure energy, Fuji Electric offers three OPC product lines of low, medium and high sensitivity. By controlling the material and layer thickness, Fuji Electric is able to regulate sensitivity over the wide range of 0.15 to 1.50 μJ/cm² at − 100 V photo sensitivity, as shown in Table 1.

Figure 2 shows representative spectral sensitivity characteristics for low, medium and high sensitivity type of OPCs. All types exhibit nearly the same sensitivity in the 600 to 800 nm wavelength region and are compatible with typical LD (laser diode) and LED (light emitting diode) light sources.

By combining these charge generation layers (CGL) with various charge transport layers (CTL), OPCs can be provided for a diverse variety of processes in low-speed to high-speed printers.

Fig.1 Layer structure of negative charge type OPC

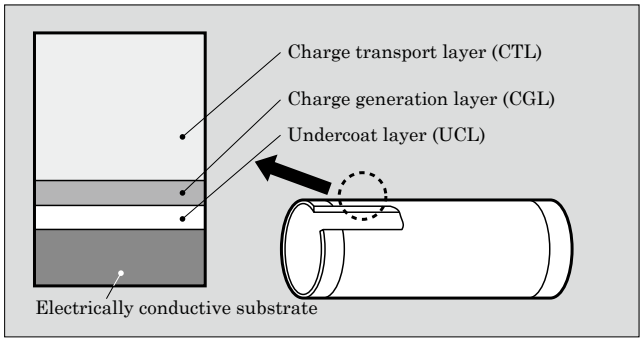
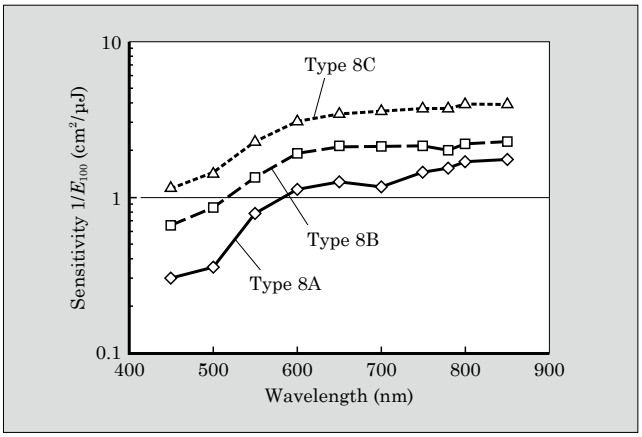


Table 1 Overview of negative charge type OPC products

Type	Sensitivity* (Exposure energy to –100 V)
8A (Low sensitivity)	0.70 to 1.50 μJ/cm²
8B (Medium sensitivity)	0.40 to 0.80 μJ/cm²
8C (High sensitivity)	0.15 to 0.40 μJ/cm²

*Sensitivity indicates the required exposure energy for the surface potential to discharge from –600 V to –100 V

Fig.2 Spectral sensitivity characteristics of negative charge type OPCs



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Using Fuji Electric's proprietary conductive substrate processing technology and coating technology, the negative charge type and the positive chargie type OPCs can be manufactured with external diameters of 20 to 262 mm and lengths of 236 to 1,000 mm, and these products are being deployed over a wide range of applications, from A4-sheet printers to A0 plotters.

2.2 Product features

Printer-use OPCs must exhibit five required performance characteristics: high-speed, color imaging, high resolution, small size and maintenance free operation. Specifically, the technical challenges associated with each performance requirement can be categorized as shown in Fig. 3. Characteristics of each item are described below.

(1) High-speed response

In order for small-diameter OPCs (having a diameter of 20 to 30 mm) to be suitable for use in high-speed printers capable of printing longitudinally-fed A4-size sheets at a rate of 35 ppm or higher, the surface potential at areas exposed to light must be uniform during the exposure-development time, which is 50 ms or less in a typical processing machine. Accordingly, Fuji Electric is preparing a high-speed charge transport material (CTM) having mobility of 2×10^{-5} cm²/V·s for use in practical applications. Moreover, Fuji Electric is also completing the development of a high mobility material of 8×10^{-5} cm²/V·s to support even higher speeds.

Figure 4 shows the dependency of the surface potential after exposure on the exposure-development time for typical CGL/CTL combinations. Moreover, a type 8C "SH" OPC that uses CTM having a super high-speed carrier mobility exhibited characteristics suitable for practical application at exposure-development times of up to 40 ms.

(2) High definition

OPCs for use in color imaging, high resolution printers and multi-function peripherals (MFPs) are required to have color reproduction capability for color images and tone reproduction capability for monochrome images. Moreover, as document output becomes increasingly diverse, a higher level of image quality than in the past is desired. Fuji Electric is developing and commercializing OPCs in which the photo-induced discharge characteristics are optimized for various machine processes. Figure 5 shows an example of photo-induced discharge characteristics according to OPC type. This characteristic is largely dependent on the charge transfer performance of the CTM and the efficiency of carrier injection between layers, and can therefore be regulated according to the combination of UCL, CGL and CTL.

As printers continue to advance toward higher quality images, small potential differences on the OPC surface have become easier to reproduce in the image as contrasts in image density, and OPCs, in addition to having a photo sensitive layer of uniform thickness, are also desired to be relatively unaffected by the application of a reverse polarity at transfer sites and the increase in residual potential at sites of continuous exposure. To reduce potential differences, Fuji Electric is developing new materials for use and optimizing them in the UCL, CGL and CTL functional layers.

When a cartridge is replaced or when paper jams

Fig.3 Required OPC characteristics and technical challenges

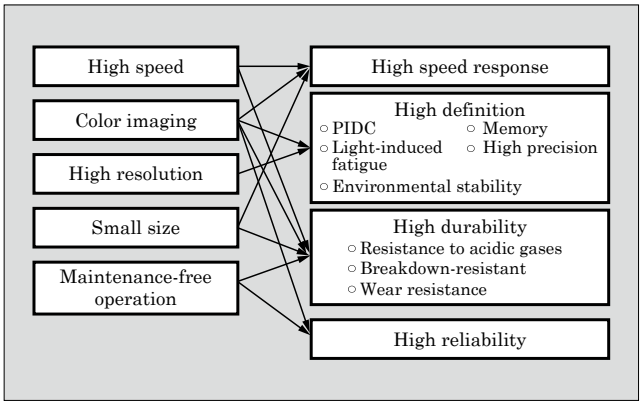


Fig.4 Photoresponsivity of negative charge type OPC

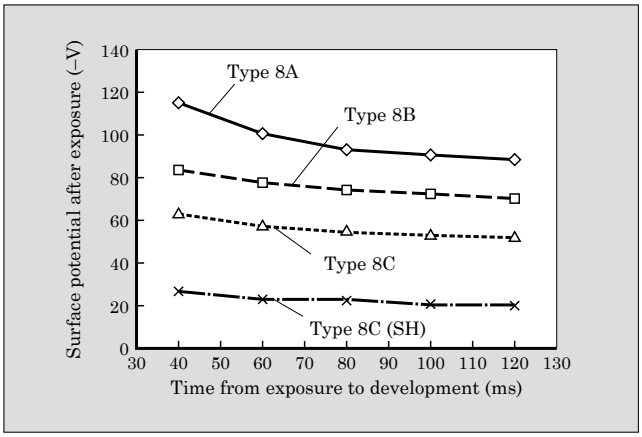
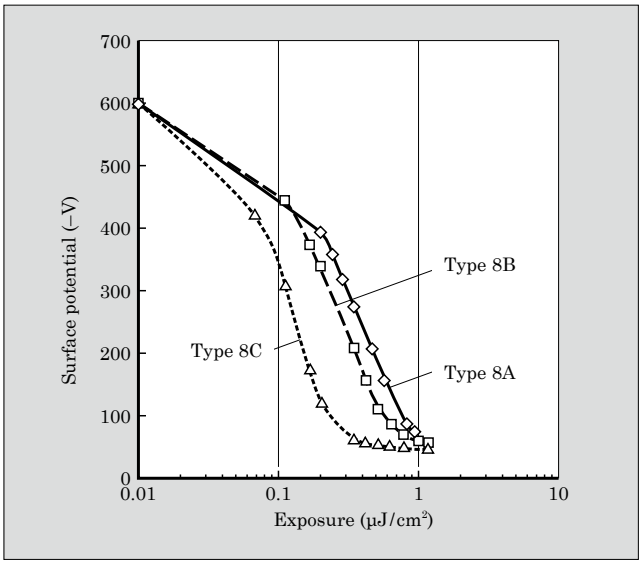


Fig.5 Photo-induced discharge of negative charge type OPC



occur, the OPC may be exposed to indoor light or sunlight and therefore an OPC that is largely unaffected by such light exposure is required for the general market. Fuji Electric combines CGL and CTL layers to realize OPCs whose image quality is largely unaffected by exposure to indoor lighting such as fluorescent lights, and that are suitable for use in practical applications.

Color printers that print by overlaying four colors require relatively high dimensional precision in order to prevent out-of-color-registration problems. Fuji Electric possesses technology for processing OPC-use element tubes, which have a run-out of 50 µm or less and straightness of 20 µm or less, and that are suitable for use in these types of color printers, and has established a system for supplying high precision plastic flanges.

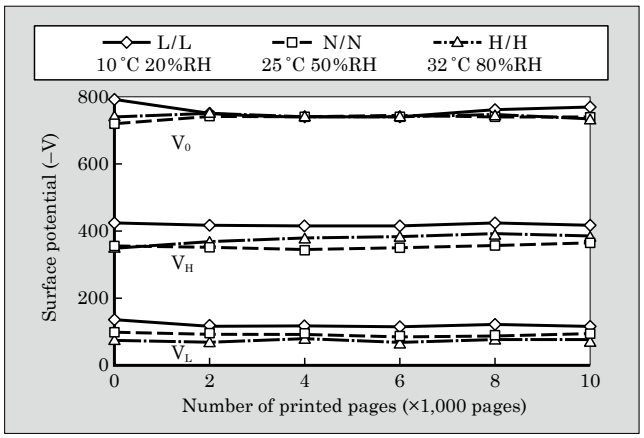
In order to maintain the initial image quality, the OPCs are desired to have characteristics that exhibit little change in response to environmental changes and printing. Using a commercially available contact electrification-type laser printer equipped with a 24 mm-diameter OPC, 10,000 A4-size longitudinally fed sheets were each printed under the environmental conditions of normal temperature and normal humidity (N/N: 25 °C and 50%RH), low temperature and low humidity (L/L: 10 °C and 20%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. This data is shown in Fig. 6. In all of these environments, favorable characteristics were exhibited without any significant change in surface potential.

(3) Technology for higher durability

OPCs must be resistant to the ozone gas generated by the chargers used in printers and to other active gases in the environment.

Various anti-oxidizing agents and other additives are used in OPCs. Increasing the amount of an additive usually improves the resistance to acidic gases but also leads to increased residual potential and also negatively affects other electrical characteristics. To ensure resistance to acidic gases, Fuji Electric has developed CTM that exhibits almost no deterioration and a proprietary additive that has little effect on electrical characteristics.

Fig.6 Surface potential stability during environmental life test for negative charge type OPC



The method of contact electrification is widely used in medium- and low-speed printers, however improved resistance to dielectric breakdown, comparable to that of the scorotron non-contact electrification method, is strongly required. Since launching a UCL equipped with an interference suppressing function in 1995, Fuji Electric has been working to develop OPCs with improved resistance to dielectric breakdown and improved environmental characteristics. Fuji Electric is presently developing UCL products that exhibit excellent environmental characteristics and the same degree of resistance to breakdown as an anodized layer, and is endeavoring to improve the overall performance of OPCs, including the CGL and CTL layers.

Factors that determine the useful service life of an OPC include abrasion from contact parts such as the developing system, the paper and the cleaning blade, scratches that cause printing defects, and the adhesion (filming) of toner and paper dust particles on the OPC surface, and accordingly, OPCs are required to exhibit properties of low wear, high hardness and low filming. Fuji Electric is independently developing wear-resistant resin and lubricative resin, and appropriately combines these resins to provide OPCs optimized for each process.

(4) High reliability

OPCs are desired to maintain stable characteristics in a variety of environments and are also desired to remain stable in response to external mechanical and chemical stresses.

During the stage of materials development, Fuji Electric independently establishes a list of inspection items, and then in the course of development, evaluates the reliability, including long-term storage characteristics, for each product in order to develop and produce highly reliable OPC products.

3. Positive Charge Type OPC "Type 11"

3.1 Overview of Fuji Electric's products

Fuji Electric is developing positive charge type OPC products that provide higher image resolution and are more effective against ozone than the typical negative charge multi-layer type OPCs.

When designing CTM for positive charge use, the required characteristics are more difficult to realize than in the case of CTM for negative charge use. Fuji Electric is commercializing positive charge type OPCs that combine photoconductor technology with positive-charging-use CTM which has been developed through the application of computational chemistry techniques and synthetic organic chemistry techniques.

Table 2 lists Fuji Electric's line-up of type 11 positive charge type OPC products. Figure 7 shows the

Table 2 Overview of positive charge type OPC products

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

Fig.7 Spectral sensitivity characteristics of positive charge type OPCs

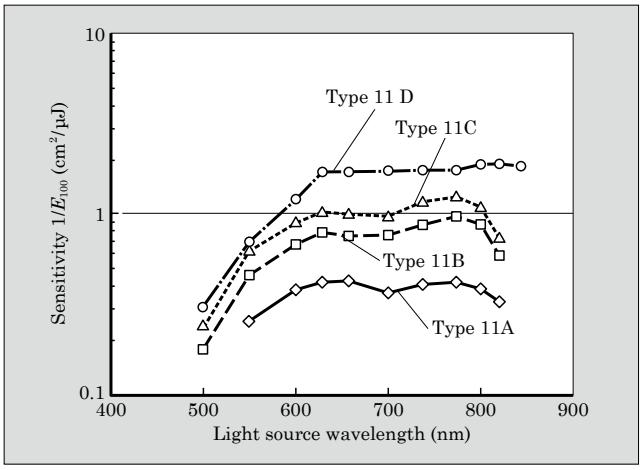
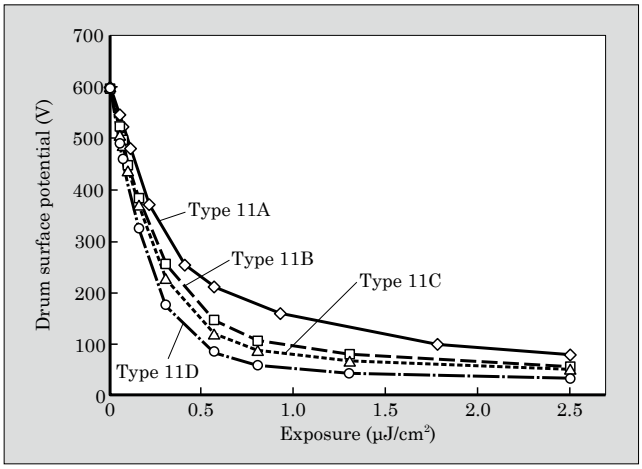


Fig.8 Photo-induced discharge characteristics (PIDC) of positive charge type OPCs



spectral sensitivity characteristics of types 11A to 11D. All of the positive charge type OPCs exhibit essentially the same sensitivity in the 600 to 800 nm wavelength region, and are compatible with typical LD and LED light sources. Moreover, sensitivities over the wide range of half-decay exposure from 0.15 to 0.38 μJ/cm² are provided as shown in Fig. 8, and are suitable for use with low-speed (15 ppm and lower) printers to high-speed (35 ppm and higher) printers. In particular, as shown in Table 3, due to performance improvements of each functional material, the type 11D realizes enhanced OPC characteristics, and is able to satisfy the growing demands for high sensitivity and high-speed response.

Table 3 Relation between characteristics and material of type 11D

Characteristic	Characteristic of material
High sensitivity	CGM→increased quantum efficiency
High-speed response	HTM → increased hole mobility ETM→increased electron mobility
High strength	Resin binder →higher glass transition temperature →increased surface hardness
Resistance to breakdown	UCL→thicker layer (electrically conductive control)

3.2 Characteristics of positive charge type OPC products

As has been described for negative charge type OPCs, positive charge type OPC product characteristics and their associated technical challenges are described below.

(1) High-speed response

Figure 9 shows the photoresponsivity of positive charge type OPCs. Any of these positive charge type OPCs can be used with devices in which the time from exposure to development is 75 ms. In particular, the type 11D, even 30 ms after exposure, exhibits little rise in the potential at light exposure areas, and is suitable for use with small-size high-speed printers having shorter times from exposure to development.

(2) High definition

Positive charge type 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 and there is little scattering and diffusion of exposure light and charge within the photosensitive layer. Figure 10 shows the results of measuring the electrostatic latent image width at the sites of 1-dot exposure writing. Spreading of the latent image can be observed in the negative charge type OPC, and indicates the extent of the high resolution performance of the positive charge type OPC.

The optimal regulation of the UCL and GTL, even during endurance testing, enables better uniformity of the halftone image quality and suppresses the phenomenon of residual images.

As for light-induced fatigue characteristics, regardless of the OPC type, exposure to light at 1,000 lx for 10 minutes caused little change in the dark area voltage, and the recovery time after the light exposure was quick.

Figure 11 shows the environmental characteristics

Fig.9 Photoresponsivity of positive charge type OPCs

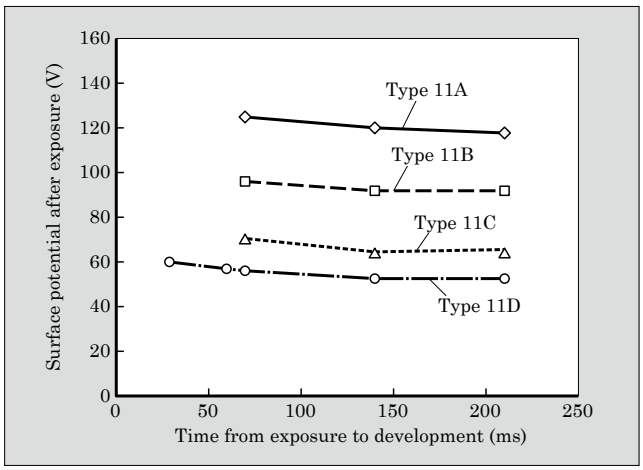


Fig.10 Comparison of 1-dot latent image for positive charge type and negative charge type OPCs

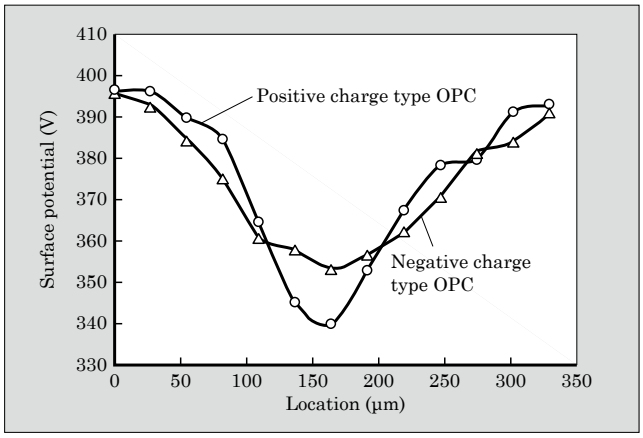
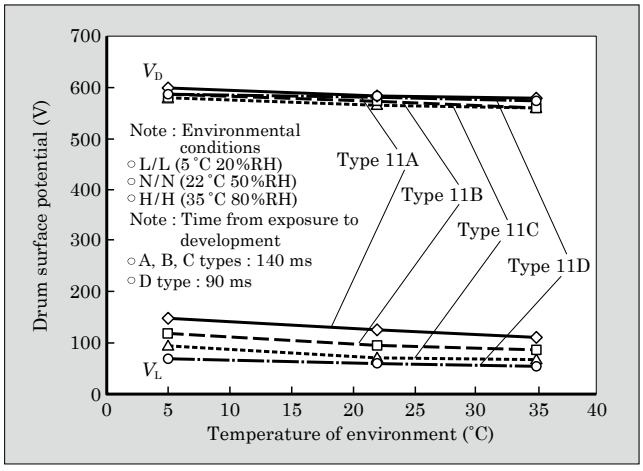


Fig.11 Environmental dependency of light area voltage V_L and dark area voltage V_D for positive charge type OPCs



of the light area voltage V_L and dark area voltage V_D. For all positive charge type OPCs, the dark area voltage and the light area voltage are stable and exhibit little environmental fluctuations in the temperature and humidity range from L/L (5 °C and 20%RH) to H/H (35 °C and 80%RH).

Fig.12 Ozone characteristics

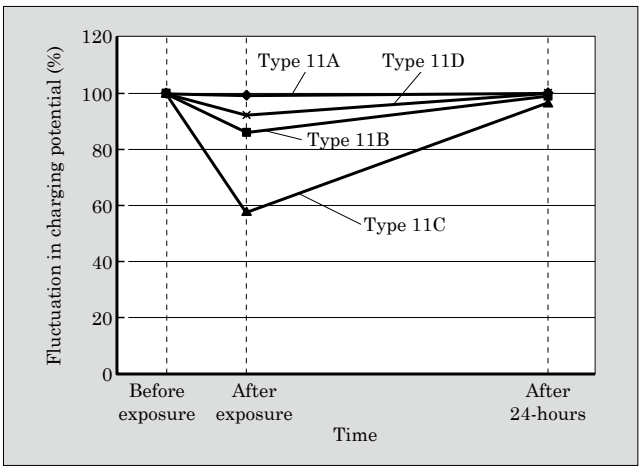


Table 4 Change in characteristics due to reliability test of positive charge type OPC

Test item	Test conditions	Change in characteristics before and after test	
		Dark area voltage fluctuation	Light area voltage fluctuation
High temperature exposure	45 °C : 1,000 h	< ±5 %	< ±10 %
High temperature, high humidity exposure	35 °C, 90 %RH : 1,000 h	< ±5 %	< ±10 %
Heat cycle (10 cycles)	− 20 °C : 1h→ Normal room temperature and humidity : 0.5h→ 45 °C : 1h→ − 20 °C : 1h→ Normal room temperature and humidity : 0.5h→	< ±5 %	< ±10 %
Roller contamination test	Roller material : NBR, polyurethane rubber, silicone rubber	None	None
		No image faults	

(3) High durability

As shown in Fig. 12, for all positive charge type OPCs, after exposure to ozone for 30 minutes at a concentration of 5 ppm, the charging potential initially drops, but then returns to the original charging potential after having been left to stand at room temperature for 24 hours. Type 11A and 11D OPCs have particularly high resistance to ozone, and therefore only experience slight drops in charging potential immediately after exposure.

In a printing duration evaluation using a two component development printer, the OPC type 11D exhibited stable light area voltage and dark area voltage with no observable image defects, and had a printing life of approximately 200,000 sheets.

(4) High reliability

Table 4 shows the changes in characteristics as a

result of various reliability tests. Light area voltage fluctuations of less than 10% are considered to provide high reliability, and in all the tests, the fluctuation in dark area voltage did not exceed 5%.

In a roller contamination test, 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.

4. Postscript

The trends toward higher speed, greater multi-functionality, high image quality and lower cost will continue to advance for electrophotographic printers, and performance requirements for photoconductors will become more diverse. Fuji Electric intends to continue utilizing and developing chemical technology and photoconductor technology to provide a variety of high-function photoconductors suitable to meet the needs for information output, and in doing so, to make a positive contribution to society.