Organic Photoconductors for Printers

Keiichi Morita
Yutaka Ikeda
Yasushi Tanaka

1. Introduction

With the recent trends towards more widespread use of digital images, color imaging and networking, peripheral equipment such as printers, copiers and facsimile machines are handling documents and data files of extremely large size. As a result of these market trends, the functions and quality required of photoconductors, the main component in electrophotographic peripherals, are getting higher year by year. To meet these requirements, Fuji Electric has developed negatively charged and positively charged organic photoconductors (OPCs), and is developing and producing these OPCs and selling them in the marketplace. This paper presents an overview of these OPC products and describes their characteristics.

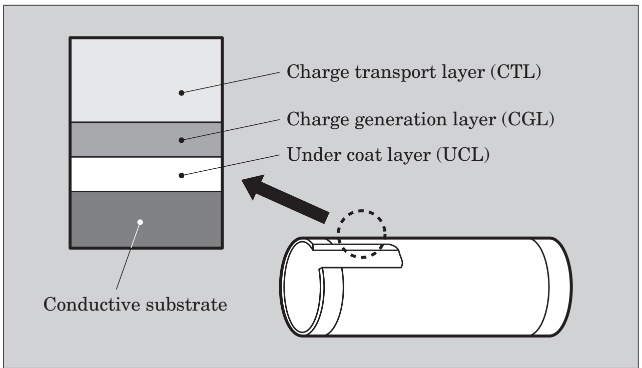
2. Product Overview

2.1 Negatively charged OPC

As shown in Fig. 1, the layer structure of a negatively charged OPC consists of an under coat layer (UCL) made of resin and formed on an electrically conductive aluminum substrate for the purpose of blocking positive charges and preventing interference by the exposure light, and a charge generation layer (CGL) and a charge transport layer (CTL) sequentially formed on the UCL to realize a functionally distributed structure.

The CGL consists of charge generation material (CGM) and resin binder, and functions to generate charge when exposed to light from a laser diode (LD) or light emitting diode (LED). Also, the CTL consists of charge transport material (CTM) and resin binder, and functions to transport the charge generated at the CGL to the CTL surface.

Fig.1 Layer structure of negatively charged OPC



In order to support various amounts of exposure energy, Fuji Electric has prepared three product lines (low sensitivity, medium sensitivity and high sensitivity) that may be used in accordance with the CGM characteristics. Using five types of CGL material and by controlling layer thickness, as shown in Table 1, the photosensitivity at −100 V can be adjusted over the wide range of 0.20 to 1.50 µJ/cm^2.

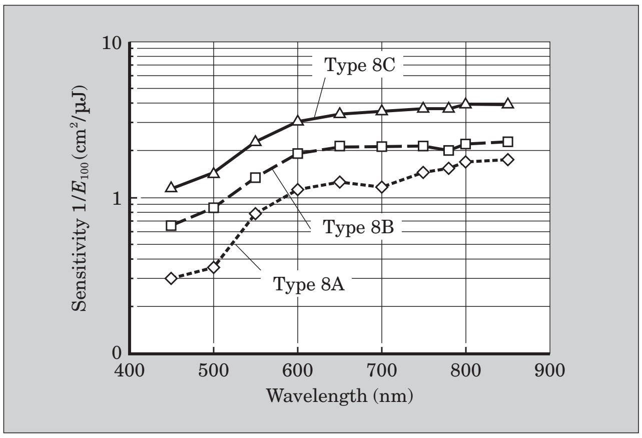
Figure 2 shows representative spectral sensitivity characteristics of the low, medium, and high sensitivity

Table 1 Product summary

Name	Category	Sensitivity (Exposure energy to reach −100 V)
Type 8A (low sensitivity)	8A−02	0.80 to 1.50 µJ/cm^2
	8A−15	0.70 to 1.20 µJ/cm^2
Type 8B (medium sensitivity)	8B−16	0.50 to 0.80 µJ/cm^2
	8B−10	0.40 to 0.60 µJ/cm^2
Type 8C (high sensitivity)	8C−03	0.20 to 0.40 µJ/cm^2

∗ Indicates the amount of exposure energy needed to discharge the sensitivity from −600 V to −100 V.

Fig.2 Spectral sensitivity of negatively charged OPC



types of OPCs. All types have a nearly constant sensitivity for wavelengths from 600 nm to 800 nm, and these characteristics are suited for typical LD and LED light sources.

The combination of various CTMs and these CGLs enables suitable OPCs to be provided for various processes, from low speed machines of 15 ppm or less to high speed machines of 35 ppm and above.

2.2 Positively charged OPC

In contrast to a conventional negatively charged multilayer OPC, the positively charged monolayer OPC uses a positive charge potential and implements both charge generation and charge transport functions with a single photoconductive layer. The positively charged monolayer OPC has the following features.

(1) Since the positive charge process generates less amount of ozone, measures against ozone are not extremely necessary, thus enabling devices to be made smaller and at lower cost.

(2) Due to the monolayer construction, the absorption of exposure light and subsequent generation of charge occurs in the vicinity of the OPC surface, thus resulting in less scattering and diffusion of exposure light and charge and enabling higher resolution.

On the other hand, compared to a negatively charged OPC, it is more difficult for a CTM design to achieve the desired characteristics in a positively charged OPC. Fuji Electric has applied proprietary computational chemical engineering and organic synthesis chemical engineering to develop CTM for positively charged OPCs, and has combined this with photoconductor technology to commercialize positively charged OPCs.

Figure 3 shows the layer structure and operating principle of the positively charged monolayer OPC. The photoconductive monolayer structure consists of a UCL made of resin or the like and formed on an aluminum tube or other electrically conductive substrate, CGM, hole transport material (HTM) types of CTM and electron transport material (ETM), and resin.

Table 2 lists Fuji Electric's product lines of positively charged monolayer OPCs, and Fig. 4 shows the spectral sensitivities for the four product lines of types 11A to 11D. The spectral sensitivities of the four types of positively charged OPCs are all approximately flat for wavelengths of 600 nm and above, and thus are suitable for LDs, LEDs and the like. Also, as shown in Fig. 5, a wide range of half decay exposure energies of 0.15 to 0.38 μJ/cm^2 supports low-speed (15 ppm or less) to high-speed (35 ppm and above) printers, facsimile machines, copiers and the like. In particular, type 11D can be used in recent high-sensitivity high-speed machines, and as shown in Table 3, each of the functional materials is being improved to realize even high levels of OPC performance.

Positively charged and negatively charged OPCs having external diameters ranging from 24 mm to 262 mm and lengths ranging from 236 mm to 1,000 mm are being manufactured, and a wide range of products, from A4-size page printers to A0-size plotters, are being developed.

Table 2 Product summary of positively charged OPC

Name	Chara-cteristic	Recommended machine (ppm)	Printing service life (A4 intermittent printing, 30 mm external diameter, converted)
Type 11A	Low speed	Up to 12	20,000 pages
Type 11B	Medium speed	10 to 18	30,000 pages
Type 11C	Medium and high speed	12 to 24	140,000 pages
Type 11D	High speed, high durability	≧ 30	200,000 pages (Outer size of 120 mm, A4 continuous printing, converted. Usable up to 1 million pages)

Fig.3 Layer structure and materials of positively charged monolayer OPC

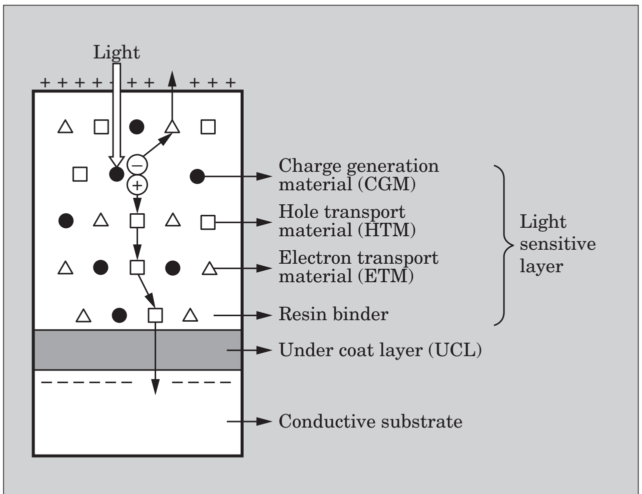


Fig.4 Spectral sensitivity of positively charged OPC

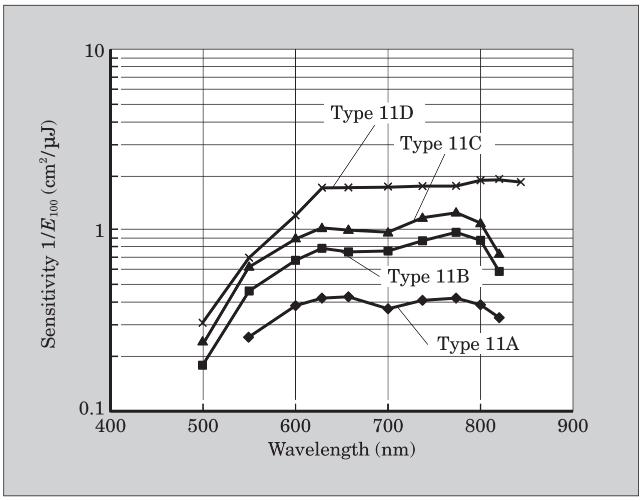


Fig.5 Photo-induced discharge characteristic (PIDC) of positively charged OPC

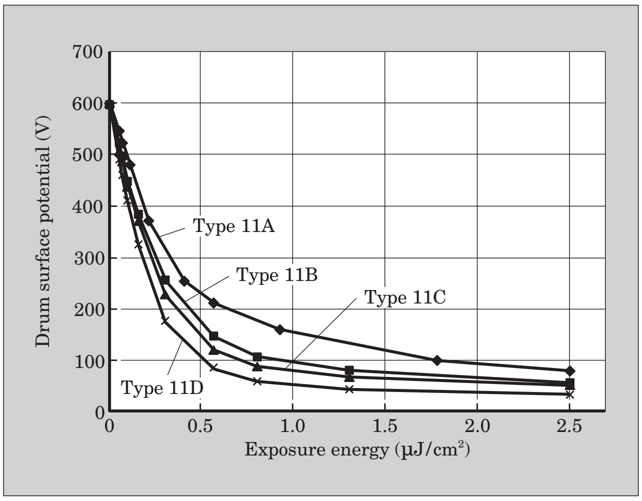


Table 3 Relationship between type 11D characteristics and materials

Characteristic	Material-based characteristic
High sensitivity	CGM → increased quantum efficiency
High speed response	HTM → increased hole mobility ETM → increased electron mobility
High strength	Resin binder → high glass transition temperature → increased surface hardness
Leak-proof	UCL → thicker film (conductivity control)

3. Characteristics of Negatively Charged OPC Products

OPCs for electrophotographic printers and facsimile machines must provide performance that supports the four required characteristics of miniaturization, color imaging, high speed and maintenance-free operation. Specific technical challenges are listed by category in Fig. 6. Characteristics of each item are described below for negatively charged OPC products.

3.1 High-speed responsiveness

In order for a 24 mm-diameter OPC suitable to be for use in an A4-size vertical-feed 30 ppm or faster high-speed machine, although there is dependency on the allocation of processes, the photo response must be uniform during the 60 ms or less of processing time from exposure to development. To meet this requirement, Fuji Electric is using CTM that has a high-speed response of 2×10^{-5} cm^2/V·s. Additionally, to support even high speeds in the future, Fuji is completing development of materials having high mobility of 8×10^{-5} cm^2/V·s.

Figure 7 shows the time dependence of the light exposure potential during the processing time from exposure to development for typical combinations of CGL and CTL. In the case where a CTM of super high (SH) carrier mobility is used, the characteristics during the processing time from exposure to development, up to 40 ms, are suitable for use in practical applications.

Fig.6 Required OPC performance and technical challenges

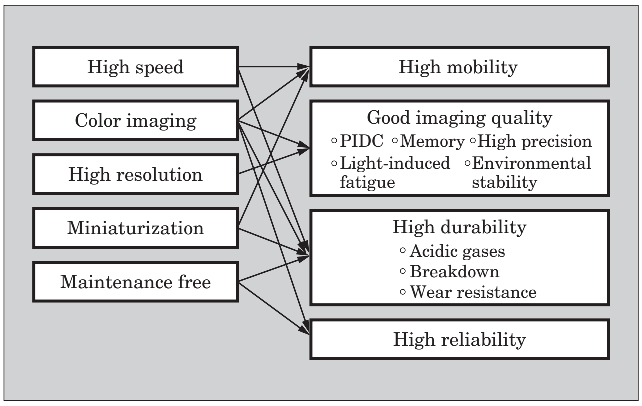
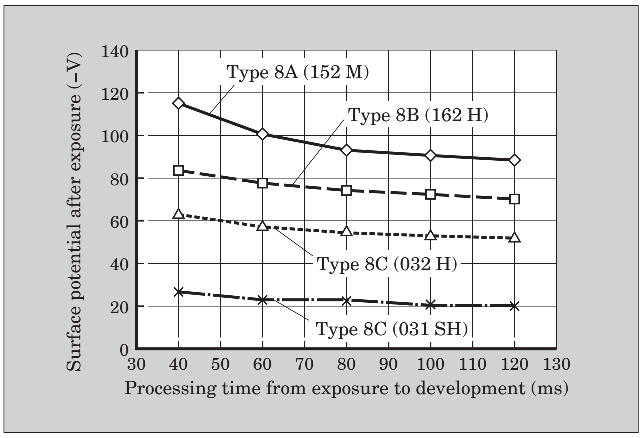


Fig.7 Photo response of negatively charged OPCs



3.2 High resolution

(1) Photo induced discharge characteristics

In multifunction peripherals (MFPs) that combine printing and copying functions, halftone reproduction capability is required as in OPCs for plain paper digital copiers. Also, for color printers or 1,200 dpi (dots per inch) or above high-resolution monochrome printers, peripheral processes are becoming more advanced with finer particles being used for toner, LD light emission being precisely controlled and so on, and better graphic image quality than in the past is desired. Fuji Electric is developing and commercializing OPCs having optimal photo induced discharge characteristics for various machine processes.

Figure 8 shows an example of photo induced discharge characteristics according to OPC type. This characteristic is largely dependent on carrier injection from the CGL to the CTL, and can be adjusted according to the combination of the CGL and CTL.

(2) Uniformity of the halftone potential

With the increasingly higher image quality of printers, small potential differences on the OPC surface have become easily reproducible in the image as

Fig.8 Photo induced discharge characteristics

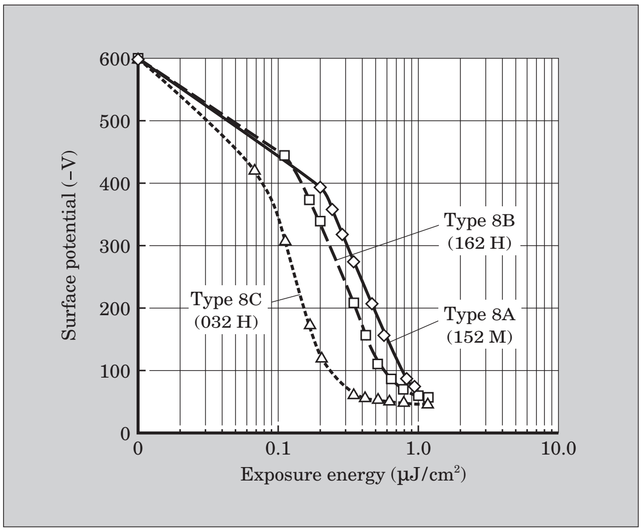
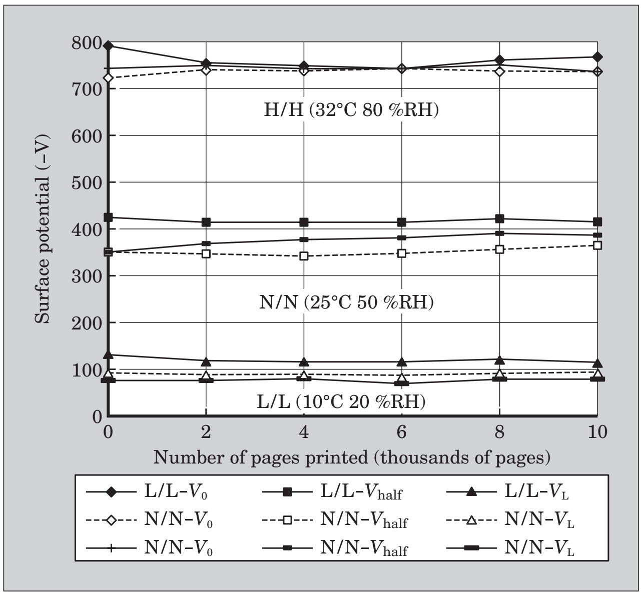


Fig.9 Negatively charged OPC's potential stability during environmental life test



printed contrast, and it is desired that the OPC is not easily affected by the opposite polarity voltage applied to the transfer area and by the increase in residual potential at areas continuously exposed to light. Fuji Electric is developing and optimizing new materials for use in the UCL, CGL and CTL functional layers in order to reduce the potential difference.

(3) Suppression of light-induced fatigue

Differing from copiers, printers contain consumable parts including OPCs that are typically replaced as a unit by the user. At the time when these units are being replaced, or when a paper jam occurs, the OPC may possibly be exposed to interior room light or to sunlight, and therefore an OPC that is little affected by such exposure is desired.

Fuji Electric combines the CGL and CTL appropriately to realize OPCs that exhibit little effect on the picture quality when exposed to fluorescent light or other interior room light, and Fuji is using these OPCs in practical applications.

(4) High dimensional precision

In order to prevent out of color registration, higher dimensional precision is required of printers that superimpose four colors than a monochrome printer. Fuji Electric is making arrangements to supply element tubes and resin flanges having a run-out tolerance of 50 μm or less and straightness tolerance of 20 μm or less for use in OPCs.

(5) Environmental stability

In order to maintain the initial level of image quality, it is desired that the OPC characteristics exhibit little change in response to environmental changes and printing.

Figure 9 shows data of the potential voltage measured every 2,000 pages when vertically feeding 10,000 pages of A4-size paper in each of the environments of normal temperature and normal humidity (N/N: 25°C, 50 %RH), low temperature and low humidity (L/L: 10°C, 20 %RH) and high temperature and high humidity (H/H: 32°C, 80 %RH) with a commercially available contact electrification type laser printer equipped with a 24 mm-diameter OPC. Good characteristics were exhibited in all environments, without any significant change in the voltage potential.

3.3 High durability

(1) Resistance to acidic gases

The charger used in a printer typically generates ozone gas, and therefore the OPC must be resistant to ozone.

Various anti-oxidizing agents are used in OPCs, and increasing the amount of such additives usually improves resistance to acidic gases, but also has a negative impact on electrical characteristics, such as increasing the residual potential, for example. To maintain sufficient resistance to acidic gases, Fuji Electric has developed a CTM that is resistant to deterioration and a proprietary anti-oxidizing agent that does not affect the electrical characteristics.

(2) Improved resistance to dielectric breakdown

In the medium-speed and low-speed market sector, contact electrification is the method most commonly used with printers and MFPs, and compared to the non-contact electrification method of scorotron charging, improved resistance to dielectric breakdown is strongly requested. In 1995, Fuji Electric placed on the market a UCL also equipped with an interference suppression function, and since then, has been advancing development with the aim of improving resistance to dielectric breakdown and improving environmental stability. The newly developed UCL has the equivalent resistance to dielectric breakdown as does an anodized layer (ALM), and has excellent environmental stability.

(3) Wear resistance

The service life of an OPC is determined by the wear of parts and materials that make physical contact, such as the developing system, paper and the cleaning blade, scratches that cause printing defects, and by the adhesion (filming) of toner and paper dust on the OPC surface. The OPC parts and materials that make physical contact, as well as the process design, are required to provide appropriate low-wear, high-hardness and low-filming performance.

Fuji Electric is independently developing wear-resistant resin and lubricative resin, and formulates the resin appropriately for a particular process to provide an OPC that is optimally suited for that process.

3.4 High reliability

It is desirable for an OPC to maintain stable characteristics under various environments, and to remain stable when subjected to external, mechanical and chemical stresses.

From the materials development stage, Fuji Electric establishes inspection items and then advances the development of those materials, and evaluates reliability, including long-term storage characteristics, for each product to develop and manufacture highly reliably OPC products.

4. Characteristics of Positively Charged OPC Products

Described below are characteristics of positively charged OPC products, which as in the case of negatively charged OPCs, strive to overcome technical challenges.

4.1 High-speed responsiveness

Figure 10 shows the photo response of positively charged OPCs. All positively charged OPCs can also be used in devices where the processing time from exposure to development is up to 75 ms. In particular, the type 11D OPC exhibits only a small rise in potential at the light area, even 30 ms after exposure, and can be used in small, high-speed devices where the processing time from exposure to development is even shorter.

4.2 High resolution

In positively charged OPCs, because the absorption of exposure light and subsequent generation of charge occurs in the vicinity of the OPC surface, there is less scattering and diffusion of exposure light and charge in the light sensitive layer, making these OPCs well suited for higher resolution.

Adjustment in combination with the UCL increases the uniformity of the halftone potential, and further reduces memory defects.

Light-induced fatigue is low, with a light exposure of 1,000 lx for 10 minutes causing little change in dark area potential, and the recovery time after exposure is quick.

Figure 11 shows the environmental characteristics of light area voltage (V_L) and dark area voltage (V_D). The characteristics of all the positively charged OPCs exhibit low variation in response to environmental changes, and the potentials of the dark and light areas remain stable under temperature and humidity conditions ranging from L/L (5°C and 20 %RH) to H/H (35°C and 80 %RH).

4.3 High durability

In all the positively charged OPCs, there is a temporary drop in charging potential immediately after exposure to ozone gas at density of 5 ppm for 30 minutes, but after being left for 24 hours at room temperature, the charging potential returns to its original state. The type 11A and 11D OPCs are particularly resistant to ozone and exhibit only a slight drop in charging potential immediately after exposure.

In a durability test of the type 11D OPC with a printer using a two component development system,

Fig.10 Photo response of positively charged OPCs

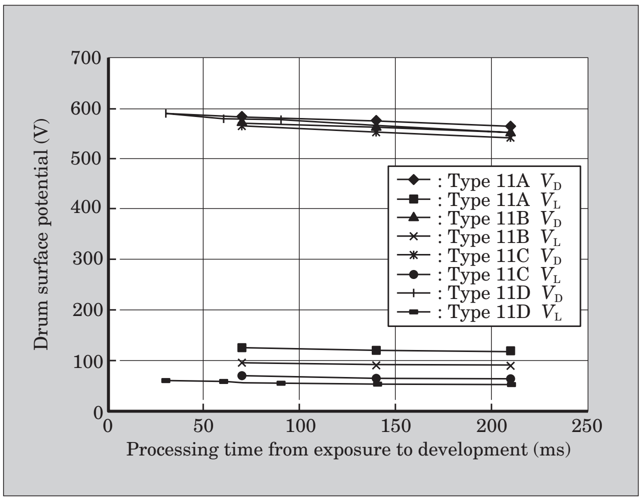


Fig.11 Environmental dependence of positively charged OPC's light area voltage (V_L) and dark area voltage (V_D)

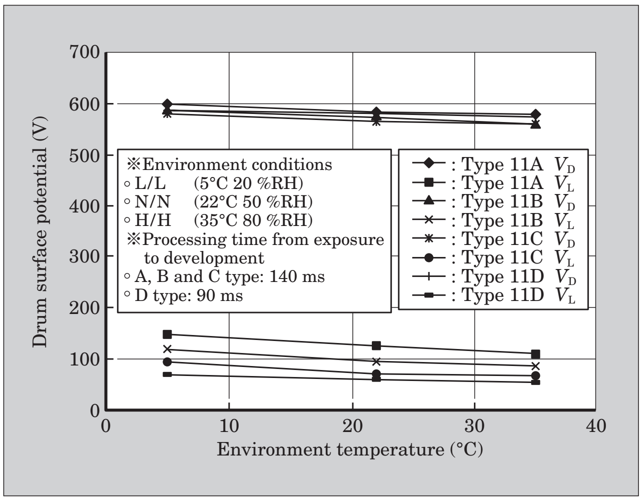


Table 4 Variation in characteristics due to environmental testing of positively charged OPCs

Test item	Test condition	Amount of change before and after testing	
		Degree of variability of potential at dark area	Degree of variability of potential at light area
High temperature storage	45°C for 1,000 hours	< ±5 %	< ±10 %
High temperature, high humidity storage	35°C and 90 %RH for 1,000 hours	< ±5 %	< ±10 %
Heat cycle (10 cycles)	−20°C : 1 hour → Normal temperature, normal humidity : 0.5 hours → 45°C : 1 hour → Normal temperature, normal humidity : 0.5 hours → −20°C : 1 hour →	< ±5 %	< ±10 %
Roller contamination test	Roller material : NBR, urethane rubber, silicon rubber 50°C and 90 %RH : 250 hours	None	None
		No image defects	

the light area potential and dark area potential were both stable and no image defects were observed. The printing life was approximately 200,000 pages.

4.4 High reliability

Table 4 shows the variation in characteristics due to various environmental tests of positively charged OPCs. Reliability is high for all the test items, and the variation in dark area voltage does not exceed 5 % and the variation in light area voltage does not exceed 10 %.

In particular, in a roller contamination test, a roller made of acrylonitrile-butadiene rubber (NBR), urethane rubber, silicon rubber or the like presses against each photoconductor, and after being left in an environment of 50°C and 90 %RH for 250 hours, it was verified that no cracks occurred in the photosensitive layer, and that the characteristics of the photoconductor did not change.

5. Conclusion

The trends toward higher speed operation, multifunctionality and higher quality for electrophotographic printers are expected intensify in the future, and accordingly, higher performance will be required of photoconductors. Fuji Electric intends to continue to contribute to society by utilizing and developing chemical technology and photoconductor technology to provide high performance photoconductors that meet the needs for more advanced information output.