Organic Photoconductors for Printers

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1. Introduction

With the widespread popularity of the Internet and the development of mobile tools, the office environment in which office automation equipment is prevalent has undergone drastic changes. Accordingly, equipment manufacturers have shifted direction, and instead of providing only hardware, are now providing their customers with the required environments and software to configure complete systems. In other words, these changes have ushered in an era of competition to increase the efficiency of the office workflow.

In the market for printers, which are the output devices in the above-described systems, monochrome printers have migrated toward the high-speed device field and their total quantity is trending downward slightly. On the other hand, color printers have finally begun to come into widespread popularity due to decreases in their price and running cost, and large growth of this market segment is predicted.

In accordance with these market trends, every year, higher levels of functionality and quality are required of photoconductors, which are a main component of printers. In response to these market requirements, Fuji Electric is developing and producing negative-charging and positive-charging organic photoconductors (OPCs) suitable for a variety of applications.

This paper presents an overview and describes the characteristics of negative-charging OPC products, including facsimile machines, plotters and multifunction peripherals (MFPs).

2. Product Overview

As can be seen in the layer structure of the negatively-charged OPC shown in Fig. 1, an undercoat layer (UCL) consisting primarily of binder resin for the purpose of blocking positive charges and preventing interference of the exposure light is formed on top of an aluminum conductive substrate, then on top of this UCL, a charge generation layer (CGL) and a charge transport layer (CTL) are sequentially laminated to form a functionally separated structure.

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

Fuji Electric provides three product lines of low, medium and high sensitivity OPCs corresponding to the CGM characteristics in order to support various light exposure doses. By using five types of CGL material and controlling the film's thickness, Fuji Electric is able to regulate sensitivity over the wide range from 0.20 to 1.50 μJ/cm² at a −100 V decay exposure as shown in Table 1.

Figure 2 shows typical spectral sensitivity characteristics for the low, medium and high type sensitivity OPCs. All three of these types of OPCs exhibit essentially panchromatic characteristics in the wave-

Fig.1 Layer structure of negative-charging OPC

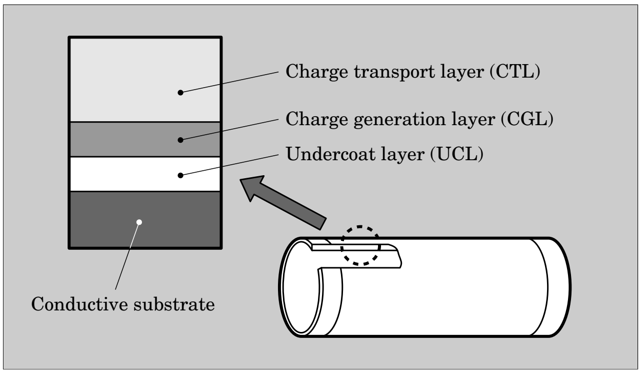


Table 1 Product summary

Type	Class	Sensitivity (at −100 V decay exposure)
8A (Low sensitivity)	8A-02	0.80 to 1.50 μJ/cm²
	8A-15	0.70 to 1.20 μJ/cm²
8B (Med. sensitivity)	8B-16	0.50 to 0.80 μJ/cm²
	8B-10	0.40 to 0.60 μJ/cm²
8C (High sensitivity)	8C-03	0.20 to 0.40 μJ/cm²

* Sensitivity : Exposure required to change the surface potential from −600 to −100 V

length range from 600 to 800 nm, and are well suited for use with typical laser or LED light sources.

By combining the various types of CTMs shown in Fig. 3 with these CGLs, Fuji Electric is able to supply OPCs suitable for a variety of processes, from low-speed machines of 20 sheets-per-minute to high-speed machines of 40 sheets-per-minute and above.

As shown in Fig. 4, OPC dimensions currently range from outer diameters of 24 to 242 mm and lengths of 236 to 980 mm, and a wide variety of products are being developed ranging from A4-size page printers to A0-size plotters.

Fig.2 Spectral sensitivity

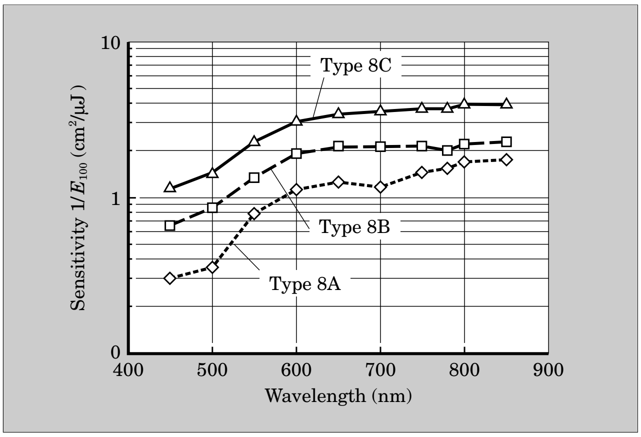


Fig.3 CTM mobility and ionized potential

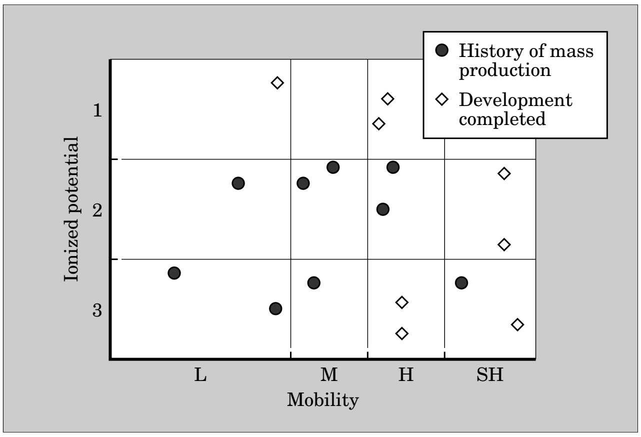
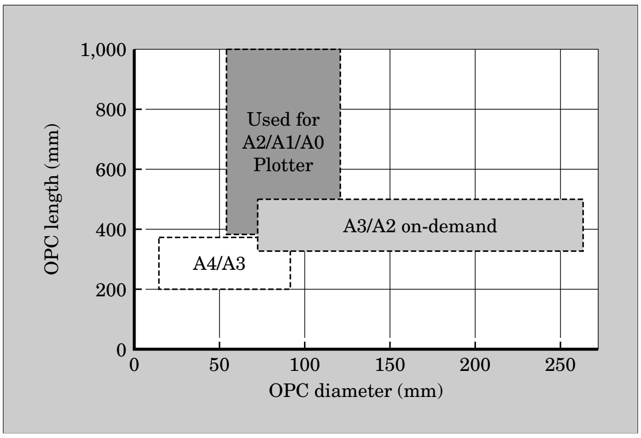


Fig.4 Applicable range of OPC length and diameter dimensions



3. Product Features

OPCs for electrophotographic printer and facsimile machines must exhibit performance that satisfies the four requirements of miniaturization, color imaging, high speed and maintenance-free operation. Figure 5 classifies these requirements according to their specific technical challenges. Product characteristics are described below for each item.

3.1 High-speed response

In order for an OPC having a diameter of 24 mm to be suitable for use in a high-speed machine that processes A4-size paper at a rate of 30 sheets-per-minute or above, the photo-response must be uniform during a processing time from exposure to development of 60 ms or less. Correspondingly, Fuji Electric is using a high-speed CTM having mobility of 2×10^{-5} cm^2/V·s in practical applications. Moreover, Fuji Electric has also completed the development of a high mobility material of 6×10^{-5} cm^2/V·s to support the higher speeds of the future.

Figure 6 shows the dependency of the surface

Fig.5 Required OPC performance and quality

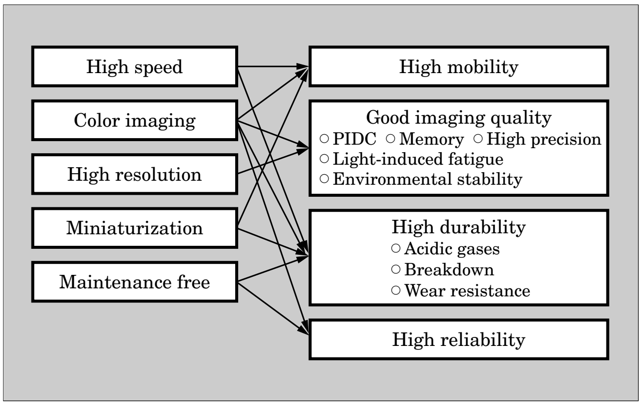
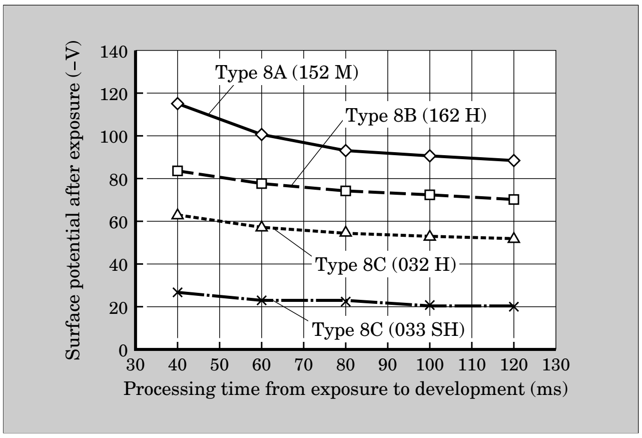


Fig.6 Photo response



potential on the processing time from exposure to development for typical CGL/CTL combinations. Product M, having a CTM of moderate mobility, and product H, having a high mobility CTM, exhibit essentially uniform characteristics for processing times from exposure to development of up to 80 ms and 60 ms, respectively, and exhibit characteristics that adequately support the abovementioned processes. Moreover, a super high-speed product SH, although not yet mass-produced, exhibited characteristics suitable for practical application at processing times from exposure to development of up to 40 ms.

3.2 Good imaging quality

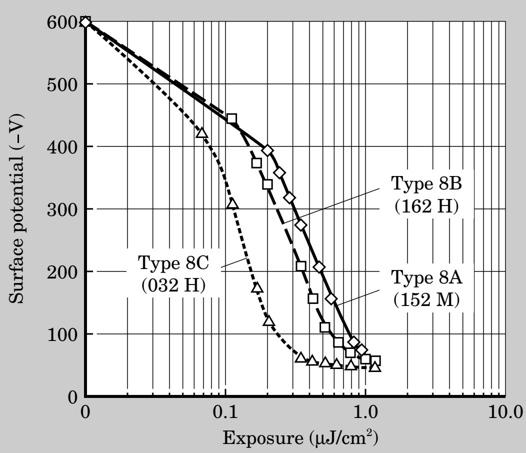
(1) Photo-induced discharge characteristics

Similar to an OPC for use in a digital plain paper copier (PPC), an MFP equipped with a copying function is required to have the capability for density tone reproduction of halftone images. For color printers or high resolution monochrome printers of 1,200 dpi or above, peripheral processes are being improved through the miniaturization of the toner size and the precision control of laser beam light, for example, and a higher level of graphic image quality is desired than in the past. Fuji Electric is developing and commercializing OPCs that provide photo-induced discharge characteristics optimized for various machine processes.

Figure 7 shows an example of the different types of photo-induced discharge characteristics of Fuji Electric's OPCs. The photo-induced discharge characteristic is largely dependent on the efficiency of carrier injection from the CGL to the CTL and therefore it can be regulated according to the combination of CGL and CTL.

Figure 8 shows printing samples for an OPC in which the photo-induced discharge characteristics were adjusted to improve the reproducibility of a 600 dpi 1-dot black spot and the reproducibility of a 1-dot white line at the same resolution.

Fig.7 Photo induced discharge characteristics



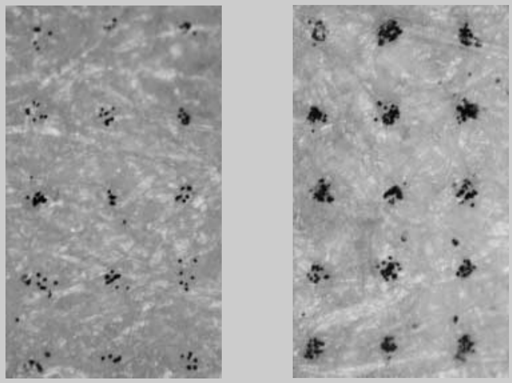
(2) Uniformity of the halftone potential

Because a negatively charged OPC is used in a reverse development process, a positive charge having the opposite charge as the charged portion is applied by the transfer unit to the drum. When this positive charge is applied to the OPC, it will counteract the negative surface charge at the next charging process, thereby generating local potential differences that appear as differences in shading on the halftone image. (This is known as "positive charge-induced memory.")

In a separate phenomenon, differences in the conditions at the junctions between each of the UCL, CGL and CTL layers cause residual potentials to increase in areas that are continuously exposed to light, generating potential differences between these residual potentials and the potentials of non-exposed rear areas, and similarly, these potential differences appear as differences in shading on the halftone image. (This phenomenon is known as "cycle-up.")

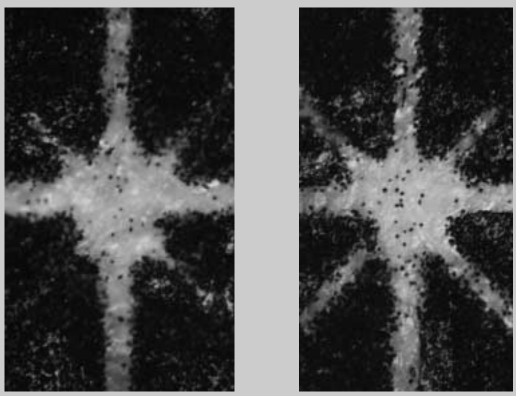
With the increasingly higher image quality of printers, minute potential differences on the OPC surface have become easier to reproduce in the image as differences in print shading, and OPC resistance to the abovementioned external factors is desired. Fuji Electric is developing and optimizing new materials for use in the UCL, CGL and CTL functional layers in

Fig.8 Printing samples



Before adjustment of PIDC After adjustment of PIDC

(a) 1-dot black spot



Before adjustment of PIDC After adjustment of PIDC

(b) 1-dot white line

order to reduce potential differences.

(3) Light-induced fatigue

A printer differs from a copier in that it typically contains wearable parts that the user replaces as a unit. When these parts are replaced or when a paper jam occurs, the OPC may possibly be exposed to indoor light or to sunlight, and therefore the OPC is required to be largely unaffected by such light exposure.

Fuji Electric suitably combines CGL and CTL layers in order to commercialize OPCs whose image quality is largely unaffected by exposure to indoor lighting from fluorescent lights and that the like, as shown in Fig. 9.

(4) High dimensional precision

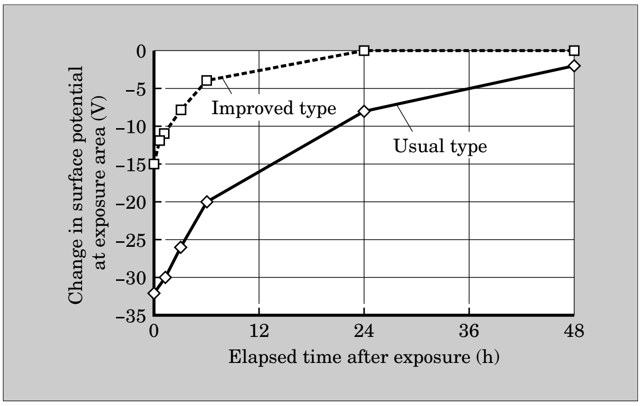
Printers are classified as either a 4-cycle type that uses a single OPC and a transfer drum or transfer belt to superimpose four colors onto the transfer object, or a tandem type that uses four OPCs to directly superimpose four colors onto a sheet of paper. In order to prevent the misalignment of the colors, a higher degree of dimensional accuracy than in a monochrome printer is required for both of these types. Fuji Electric supplies element tubes and plastic flanges for use in OPCs suitable for use with both 4-cycle and tandem type printers and having a deflection of 50 µm or less and straightness of 20 µm or less.

(5) Environmental stability

In order to maintain the initial image quality, the OPC is desired to have characteristics that are durable and remain relatively unchanged despite changes in the environment.

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), low temperature and low humidity (L/L), and high temperature and high humidity (H/H), and the surface potential was measured after every 2,000 sheets. This data is shown in Fig. 10. Fuji Electric's OPC was compared to another company's OPC made of anodic oxide film (ALM), and good characteristics were observed without any large change in surface potential in all environments.

Fig.9 Light-induced fatigue characteristics



3.3 Technology for higher durability

(1) Resistance to acidic gases

The charging method in widespread use in page printers and personal-use MFPs is the method of contact electrification using rollers, brushes and the like. With this contact electrification, the amount of ozone generated is much less than in the case of charging with a scorotron, however when contact electrification is used in a process that does not require cleaning or in a process where there is almost no film wear, the top surface will not be renewed by abrasion, and therefore, the ability to resist gases is also required during the contact electrification process.

Fig.10 Surface potential stability during printing

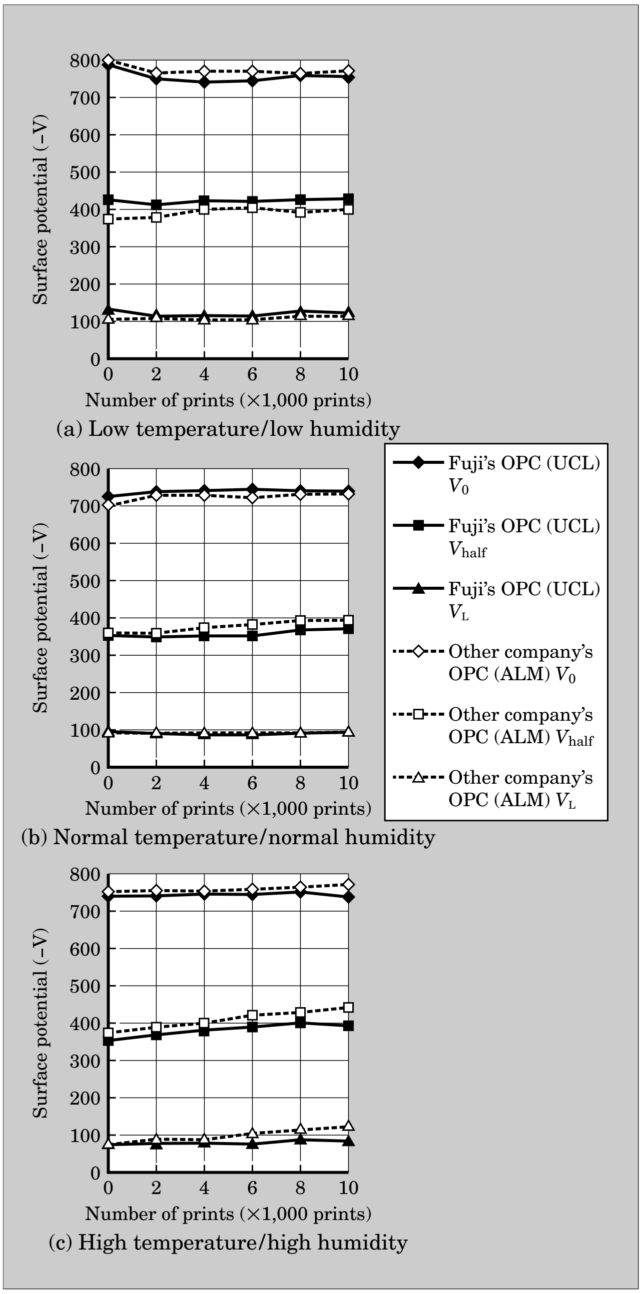


Fig.11 Resistance to ozonized gases

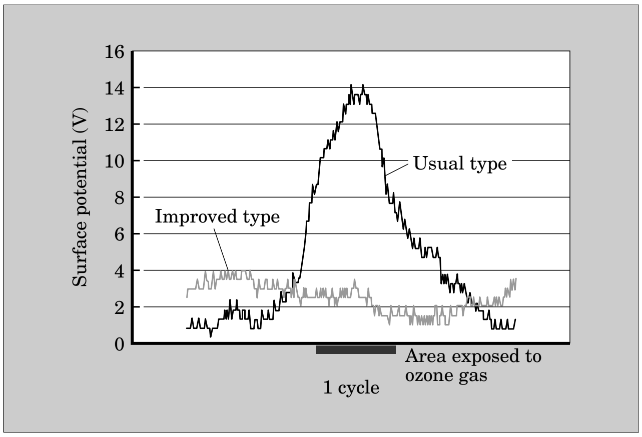
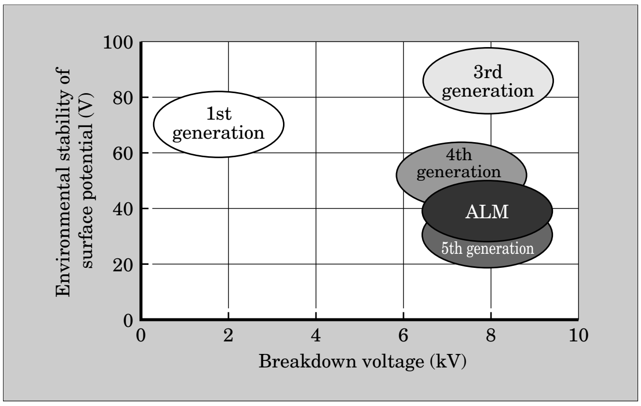


Fig.12 Resistance to dielectric breakdown



Moreover, the scorotron method of charging is still typically used with large printers and plotters, and here too, the ability to resist acidic gases such as ozone is, of course, required.

Various anti-oxide materials are used in OPCs, and increasing the amount of usual additives improves the resistance to acidic gases but also increases the residual potential and negatively affects other electrical characteristics. Fuji Electric ensures resistance to acidic gases by using various material technologies such as non-degrading CTM, anti-oxide material, and a resin binder. Figure 11 shows the surface potential during a portion of one cycle for an OPC that was exposed to a 10 ppm ozone atmosphere for two hours and then left in darkness for one hour. It can be seen that ozone exposure causes the usual type of OPC to increase to a surface potential of about 10 V, but that the improved type of OPC remains at an increased potential of about 1 V.

(2) Improved resistance to dielectric breakdown

As described in paragraph (1) above, the method of contact electrification is widely used in medium and low-speed printers and MFPs, however improved resistance to dielectric breakdown, comparable to that of the scorotron non-contact electrification method, is strongly required. In 1995, Fuji Electric brought to market a 3rd generation UCL that also provided the capability to suppress interference fringes, and since then has been working to develop OPCs with improved environmental characteristics and improved resistance to dielectric breakdown. Figure 12 shows the development trends of improved resistance to breakdown voltage and improved environmental stability of surface potential. The UCL currently being developed exhibits a resistance to dielectric breakdown comparable to that of anodic oxide film (ALM) and also exhibits excellent environmental stability.

(3) Wear resistance and photoconductor surface properties

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, scratching that adversely affects the printing, and the adhesion of toner and paper dust particles (filming) on the OPC surface. Accordingly, the OPC is required to exhibit properties of low wear, high hardness and low filming which are compatible with the contact parts and the process design.

Fuji Electric is independently developing resin having excellent wear resistance and resin that is lubricative, and appropriately combines these resins according to each process to provide OPCs optimized for those processes.

3.4 High reliability

OPCs are desired to maintain stable characteristics in a variety of environments and are also desired to exhibit high reliability and minimal deterioration in response to external stress factors.

At the material development stage, Fuji Electric establishes characteristics to be inspected and then in the course of development, evaluates those characteristics, including long-term storage characteristics, for each product in order to ensure high reliability.

4. Conclusion

The trends toward higher speed, greater multi-functionality and high image quality will continue to advance for electrophotographic printers, and higher level performance will be required of photoconductors. Fuji Electric will continue to advance the development and product commercialization of OPCs that satisfy market needs. Moreover, Fuji Electric intends to continue to advance its development and production of peripheral components, such as developing sleeves and cartridges suitable for use with the color imaging technology of non-magnetic single-component development that leverages Fuji's high level of processing technology and surface processing technology acquired through OPC development, and to continue to provide environmentally friendly and distinctive products.