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# FUJI ELECTRIC REVIEW

2

2007 VOL.53

Magnetic Recording Media
Photoconductor

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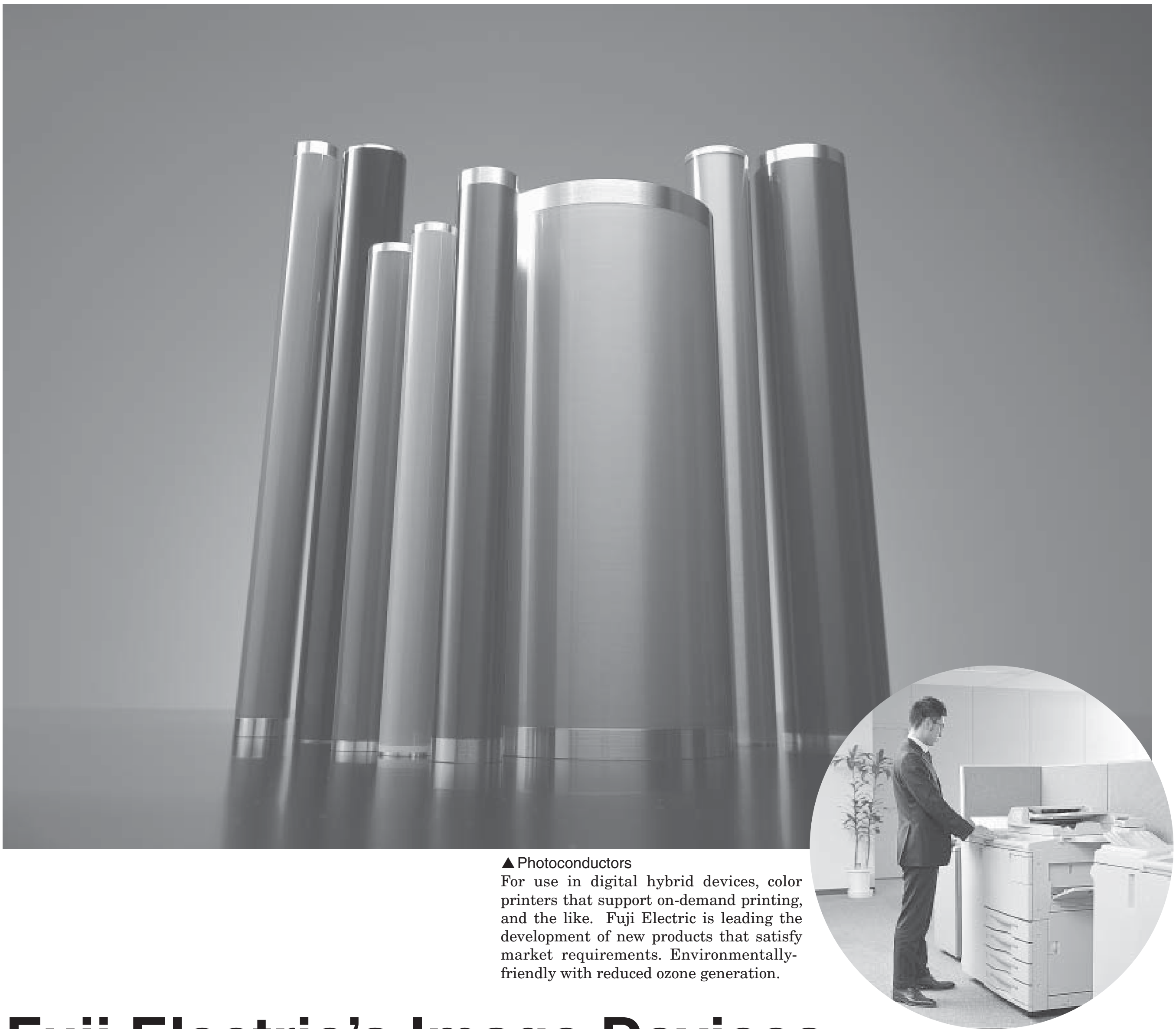

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# Fuji Electric's Image Devices

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**Cover photo:**

Hard disk drives (HDDs) with internal magnetic recording media fulfill an important role as the main devices used for recording, reproducing and storing digital data. With advances in information technology, devices capable of rapidly processing vast amounts of image information have been developed, and this market which fully utilizes the properties of HDDs is continuing to expand.

Fuji Electric has previously developed, manufactured and sold magnetic recording media, and with the recent development of a perpendicular magnetic recording method that realizes dramatically higher recording densities, is advancing the commercialization of large-capacity magnetic recording media to support the needs of the next generation.

The cover photo shows home information appliances which are increasingly being equipped with HDDs and an external view of the magnetic recording media housed inside an HDD. The size of the magnetic recording media varies according to a diverse range of uses.

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http://www.fujielectric.co.jp/eng/company/tech/index.html

# Present Status and Future Prospect for Magnetic Recording Media

Kunihiro Nakamura

## 1. Introduction

With increased areal density, hard disk drives (HDDs) have evolved towards smaller sizes and larger capacities. This evolution toward smaller sizes and larger capacities goes beyond the boundaries of traditional PCs, and has resulting in markets being established for such outstanding products as music players, video/movie players, cell phones, and other devices that are equipped with HDDs.

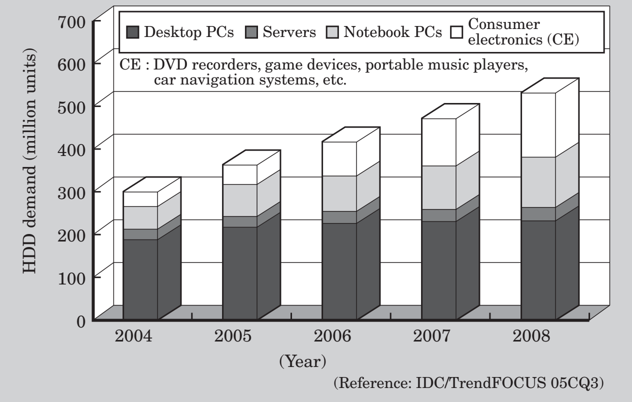
This paper describes the market trends and technical trends of HDDs, for which future growth is anticipated, and also discusses the technical development status and future prospects for Fuji Electric's magnetic recording media.

## 2. HDD Market Trends

Figure 1 shows the forecasted demand for HDDs. The number of HDD units installed in traditional applications of desktop personal computers (PCs) and servers has remained at a slightly increasing rate, but the increase in number of units installed in notebook PCs and consumer electronics (CE) devices has been remarkable. In particular, the CE market segment is expected to continue growing by more than 33 % annually. Figure 2 shows forecasted demand for HDDs to be installed in CE devices. HDD-DVD recorders are equipped with 3.5-inch HDDs having recording capacities in the range of 160 gigabytes (GB) to 1 terabyte (TB). Car navigation systems and MP3 players are equipped with 2.5-inch and smaller HDDs. This lineup includes a diverse assortment of HDD sizes of 2.5, 1.89, 1.0, and 0.85 inches, and these are effective in extending HDD applications to mobile devices and cell phones. In 2005, HDD-equipped cell phones were introduced to the market.

It is thought that CE demand will increase with time due to such factors as the 2008 Beijing Olympics, and simultaneously, the HDD market is also expected to exhibit growth.

Fig.1 HDD market forecast




## 3. Technical Trends of Magnetic Recording Media

Figure 3 shows the internal mechanical structure of an HDD. An HDD consists of such components as the magnetic recording media, a magnetic head, a head actuator, and a spindle motor.

Figure 4 shows the changes over time in areal density. Areal density has increased as a result of improved head performance, media performance and drive tracking and accuracy, as well as higher densities. In particular, areal density has improved as a result of enhanced GMR (giant magnetoresistive) head performance and better media performance through the use of an AFC (anti-ferromagnetic coupling) structure. However, adjacent bit interference, adjacent track interference and thermal stability are significant

Fig.2 Market forecast of HDDs for CE

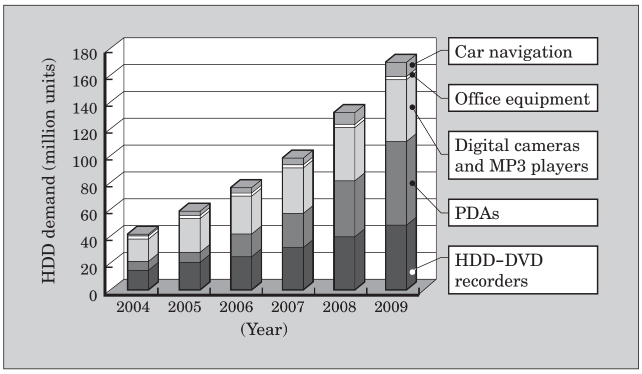


Fig.3 HDD mechanical structure

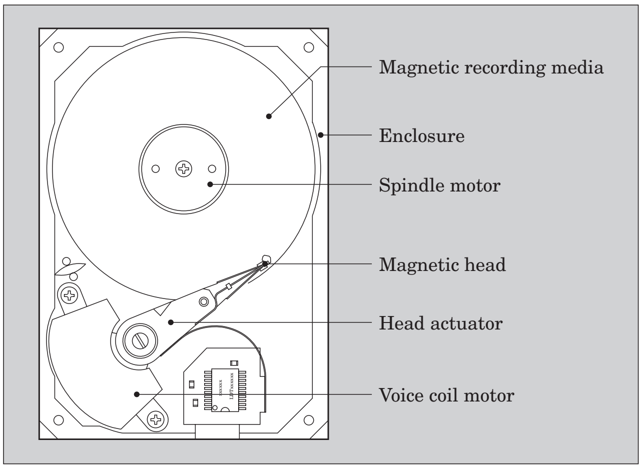
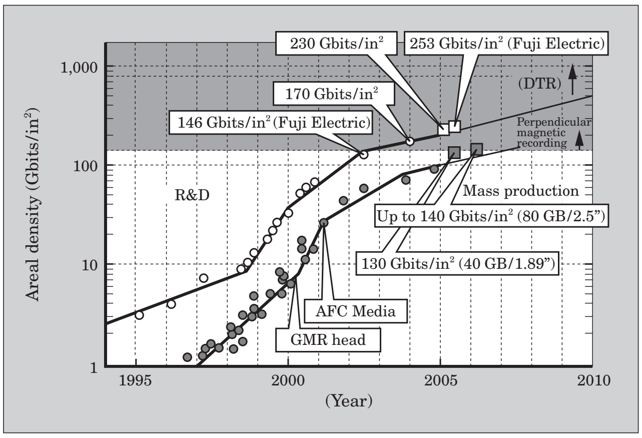



Fig.4 Changes over time in HDD areal density




factors affecting longitudinal magnetic recording media which is more than 150 Gbits/in$^2$, and further increases in the higher recording density would be difficult to implement.

On the other hand, because perpendicular magnetic recording media has, in principle, a high areal density and is magnetically stable, its performance surpasses that of longitudinal magnetic recording media. Perpendicular magnetic recording technology will drive further increases in the areal density.

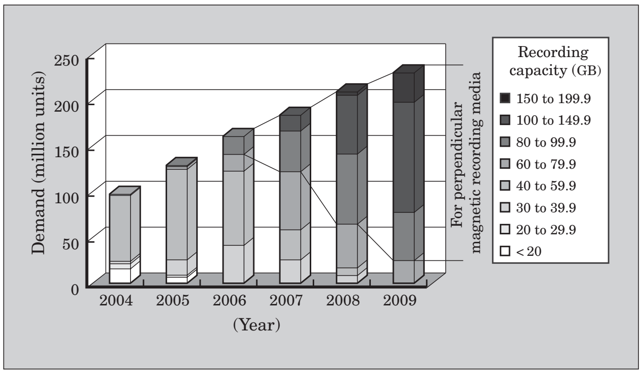
In 2006, incorporating perpendicular magnetic recording media, HDDs entered an era of even larger capacity.

## 4. Development Status of Magnetic Recording Media

### 4.1 Substrate technology for magnetic recording media

The characteristic feature of magnetic recording in an HDD is that a magnetic head which performs recording and reproduction flies with extremely low clearance above magnetic recording media that is rotating at high-speed. The distance at which the magnetic head flies above the media, i.e., the flying height, is a factor that has a large impact on recording and reproduction performance, and a flying height on the order of nanometers with low variance is required.

Fig.5 2.5-inch magnetic recording media forecast by capacity




Magnetic recording media substrate technology is required to provide substrates of good quality in order to achieve "a nanometer-order flying height with low variance" for the magnetic head flying above the magnetic recording media. In particular, improvements to the surface precision, i.e., flatness, presents a technical challenge.

Fuji Electric is producing a substrate for 3.5-inch 80 GB magnetic recording media, which is presently the mainstream product, and has also completed development of a substrate that realizes surface precision suitable for the magnetic head flying requirements of 160 GB magnetic recording media. At the same time, this substrate increases the areal density and reduces substrate surface defects which are a noticeable problem, and also contributes to a reduction in signal dropouts during recording and reproduction.

### 4.2 Longitudinal magnetic recording technology

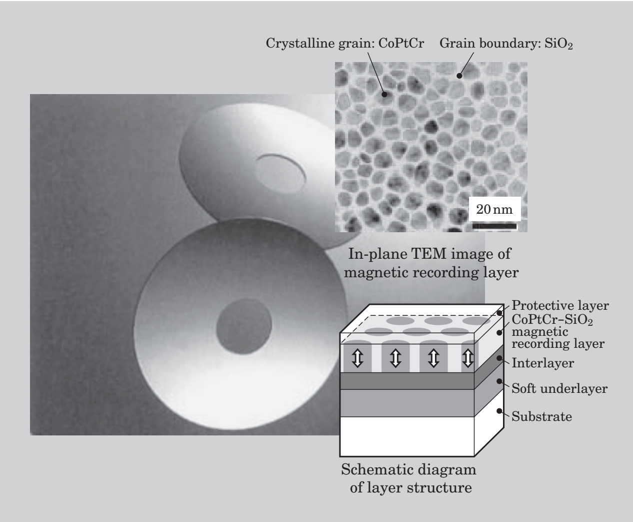
The present main product of 3.5-inch 80 GB magnetic recording media uses an AFC magnetic structure in combination with a GMR head to achieve high quality.

Longitudinal magnetic recording media that uses the AFC structure is being developed to achieve even higher areal densities and to support the TMR (tunneling magnetoresistive) head, which is the next-generation head. Also, magnetic material technology and underlayer structure technology are being advanced, and the orientation ratio is controlled to realize magnetic recording media technology suitable for 160 GB capacity per 3.5-inch disk and 60 GB capacity per 2.5-inch disk.

### 4.3 Perpendicular magnetic recording technology

There is an increasing need for small-size yet large-capacity HDDs capable of supporting the next generation of applications. This need will be met by perpendicular magnetic recording technology, which promises dramatic improvements in areal density. Small-size HDDs are driving the practical application of perpendicular magnetic recording technology. Figure 5 shows the projected growth in recording capacity per disk in

Fig.6 In-plane TEM image and cross-sectional schematic diagram of perpendicular magnetic recording media




2.5-inch HDDs. Beginning with the 2.5-inch 80 GB generation of HDDs, perpendicular magnetic recording is predicted to become the dominant recording technology, and by the year 2008, more than half of 2.5-inch HDDs are expected to use perpendicular magnetic recording.

In response to market needs, Fuji Electric began mass-producing 2.5-inch 80 GB perpendicular magnetic recording media. This media is formed from a magnetic recording layer of granular structure and a soft underlayer beneath the magnetic recording layer, and mass-production was made possible by the development of a magnetic recording layer that supports high areal density and the use of a thinner soft underlayer of 50 nm. Additionally, the substrate surface finishing was optimized with regard to magnetic domain noise in the soft underlayer and the flying performance of the magnetic head, and newly developed carbon overcoat technology improved the corrosion resistance. Figure 6 shows an in-plane TEM image and a cross-sectional schematic diagram of perpendicular magnetic recording media.

In the future, there will inevitably be increased need for small HDDs of less than 2.5 inches in size that use perpendicular magnetic recording technology to realize larger capacities, and manufacturing technology is being advanced to support smaller sizes and larger capacities.

#### 4.4 HDI technology

The sum of the height at which the magnetic head flies above the magnetic recording media plus the thickness of a protective layer (which does not contribute to the magnetic recording) on the top of the magnetic recording media is known as the “spacing loss” and is a negative factor in magnetic recording. In order to reduce the spacing loss, the magnetic recording media must be made sufficiently flat so as to permit a low flying height of the magnetic head and the thickness of the protective layer must be reduced. Also, for the lubricant layer applied to the outermost surface, the transfer of lubricant to the head must be suppressed, and lower flying height of the magnetic head and improved flying stability are required.

To provide the required quality, density is increased and chemical stability improved in the protective layer, the fractionate condition is optimized in the lubricant layer, and HDI (head-disk interface) technology is established suitably for both longitudinal and perpendicular magnetic recording media.

#### 4.5 Measurement technology

The common characteristic shared among all the above-described technologies is that the physical dimensions to be realized require the present measurement technology to be pushed to its limits. Measurement technology is being developed through diverse paths, including crystalline analysis, physical and chemical analysis of the outermost surface of the media, micro-defect analysis in order to reduce recording defects, dynamic electrical testing, and the like. By fully utilizing these technologies, not only can state-of-the-art performance of magnetic recording media be realized, but preparations are also underway to apply this measurement technology to the quality assurance process for mass-produced products so as to support the needs of a market requiring even higher levels of product quality.

#### 4.6 Next generation recording media

Fuji Electric is advancing the development of DTM (discrete track media) as the next generation of recording media in which non-magnetic tracks are preformed in the magnetic recording media, noise factors are eliminated from adjacent tracks, and positioning information is supplied according to the formed tracks. Fuji Electric is also advancing technical development by focusing on forming ultra-fine recording units corresponding to the ordering of magnetic grains, patterned media technology that controls boundary noise, recording methods involving thermal assist, and so on.

## 5. Conclusion

In support of market needs for continuous improvement in the performance and quality of HDDs, the full-scale commercialization in 2006 of perpendicular magnetic recording-type HDDs, for which excellent performance has been claimed for many years, is a significant event. Fuji Electric is committed to pursuing larger capacities and a more complete product lineup based on the core technologies described in this paper.

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# Polished Aluminum Substrates

Youichi Tei
Michinori Nishimura
Hideki Wakabayashi

## 1. Introduction

Hard disk drives (HDDs) are a low-cost memory device capable of handling large amounts of data at rapid speeds. A market has been established for HDDs as external memory for computers, and the anticipated future applications to in-vehicle devices and home-use information appliances are expected to drive even higher rates of market growth. Accordingly, the development of higher recording densities has been remarkable and, in 2006, products that exceed 160 Gbits/in$^2$ were released to the market.

In the past, various materials have been studied for use in the substrate of magnetic recording media for HDDs, but for the types of HDDs installed in desktop PCs, servers, the recently popular HDD-DVD recorders, and the like, no alternative to high-quality and low-cost aluminum substrates has emerged, and future demand for aluminum substrates is expected to remain strong.

Fuji Electric has been developing, manufacturing and selling aluminum substrates for magnetic recording media, and has accumulated a wealth of world-class technology relating to plating and polishing and the know-how to manufacture aluminum substrates.

For aluminum substrates, technical challenges in achieving even higher recording densities are the control of 0.1 nm-order micro-waviness and surface roughness of the substrate and the reduction of surface defects of several nanometers in size so that recording and reproduction can be performed with the magnetic head flying stably above the surface of the media, even at 10 nm or lower ultra-low flying heights. Technical development is already making progress toward higher recording densities.

## 2. Aluminum Substrate Manufacturing Process

The manufacturing process for aluminum substrates is summarized below (Fig. 1(a)). Fuji Electric purchases grinded substrates and uses them to mass-produce aluminum substrates from the plating process onward.

(1) Blank process and grinding process

These processes consist of a blank process that melts, molds and rolls an aluminum alloy and then stamps out a disk shape, and a grinding process that mills inner and outer ends, performs chamfering, and then mills and planes the substrate.

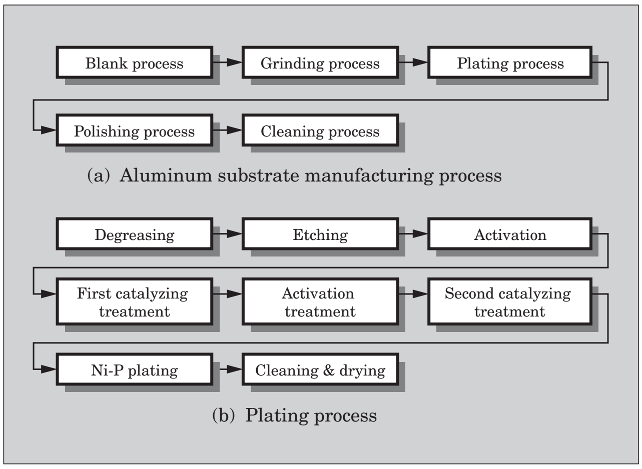
(2) Plating process

In the plating process, the surface of the grinded substrate is chemically de-oiled and cleaned by degreasing, etching, surface activation and catalyzing, and then is coated with an amorphous Ni-P film deposited to a thickness of several tens of microns by an electroless plating technique. The Ni-P film plating provides strength and hardness to the substrate so that it does not become damaged if the magnetic head crashes into the magnetic disk and also functions to provide a smooth surface by burying concave defects existing in the grinded substrate and by polishing the plated surface.

(3) Polishing process

In the precision polishing process, the substrate is heat treated to release stress created during the deposition of the film plating, and then using a foam pad, the substrate surface is polished with a polishing slurry (liquid mixture of processing liquid and polishing particles) containing freely dispersed polishing particles. The required level of quality for typical surface

Fig.1 Polished aluminum substrate and details of plating process



characteristics such as surface roughness, waviness and defects is continuing to increase toward higher recording density.

(4) Cleaning process

After polishing, precision cleaning is performed to remove completely from the substrate surface any remaining particulate residue containing slurry, residue of various component elements and dust from shavings of the film plating, and to complete the polished aluminum substrate.

## 3. Aluminum Substrate Plating Technology

The technology used in the main processes for obtaining a polished aluminum substrate, the plating and polishing processes, is described in detail below.

The processes for forming a Ni-P plating on an aluminum grinded substrate consist of pre-processing and plating processing. (See Fig. 1(b).)

(1) Degreasing process

The degreasing process removes metallic or organic residue contaminants adhering to the surface.

(2) Etching process

The etching process reduces the surface roughness of the grinded substrate, removes stray micro-pits, and removes the surface oxide film.

(3) Activating process

This process activates the surface so that catalyst particles will form uniformly and efficiently on the substrate surface in the catalyzing process that follows.

(4) Catalyzing process

This process is a surface catalyzing treatment prior to deposition of the Ni-P film plating. Differences in the composition, catalyst particle size and particle distribution of the catalyst solution cause variances in the uniformity of catalyst molecules on the substrate surface. Accordingly, this is a crucial process in which differences in stress, adhesiveness, and incidence of pit and nodule defects occur according to the control state of the initial deposition reaction of the film plating, and greatly impacts the roughness, waviness and quality of the substrate surface.

(5) Ni-P plating process

The Ni-P plating solution consists of many components, including a Ni metal salt, a reducing agent that initiates the reaction, a complexing agent for stabilizing metal ions, a buffer agent that suppresses fluctuations in the pH of the solution, a stabilizing agent that suppresses breakdown of the solution, a surface activating agent that enhances wettability of the surface, etc. In order to retain the aforementioned 0.1 nm-order surface precision, the composition of the Ni-P plating solution is also required to be highly optimized. If the composition is inappropriate, surface strength decreases, plating adhesiveness decreases, thermal resistance decreases due to increased film stress, pit and nodule defects increase, surface roughness increases, and decomposition of the plating solution causes the lifespan of the solution to decrease and other various problems to occur. Thus, in order to improve the characteristics (roughness, waviness) of a substrate surface capable of supporting the higher recording densities of the future, and to reduce surface defects and to improve throughput by increasing the lifespan of the plating solution, the pursuit of an optimized plating solution composition is becoming increasingly important for technical development.

## 4. Aluminum Substrate Polishing Techniques

(1) Advanced polishing technology

Increasingly higher levels of surface smoothness and cleanliness characteristics, i.e., surface roughness, micro-waviness, defect level, etc., are being required in aluminum substrates that support high recording densities. Table 1 lists the required surface characteristics of polished aluminum substrates. The development of polishing techniques is steadfastly continuing to achieve ultra-smooth and ultra-clean polished aluminum substrates, and polishing techniques are constantly being improved.

The polishing technique is determined by the type of foam polishing pad, polishing slurry and process conditions used, and the four main control parameters are listed below.

① Appropriateness of chemical etching components included in the slurry composition
② Appropriate control of size and shape of grinding particles (such as alumina and silica) contained in the slurry
③ Improved pad hardness and compressive elasticity modulus according to the materials and foaming process used to fabricate the polishing pad
④ Appropriate conditions for the polishing process

Aiming to improve the surface precision of present-day aluminum substrates, Fuji Electric is developing advanced new materials and improving substrate characteristics by working closely with materials manufacturers to develop jointly the representative polishing materials of slurries and pads.

Also, as methods for reducing residue, i.e., the particles and processing dust contained in the slurry during cleaning after the polishing process, Fuji Electric is

Table 1 Surface characteristics required of polished aluminum substrates

| | 80 GB substrate | 160 GB substrate |
|---|---|---|
| Surface roughness ($R_a$) | ≦ 0.30 nm | ≦ 0.20 nm |
| Micro-waviness ($W_a$) | ≦ 0.10 nm | ≦ 0.06 nm |
| Defect size | ≦ 0.20 μm | ≦ 0.10 μm |
| No. of scratches* | 1.00 | ≦ 0.03 |

* Relative number of defects where the number of defects for an 80 GB disk are denoted as 1.

Fig.2 Surface roughness of polished aluminum substrate (AFM)

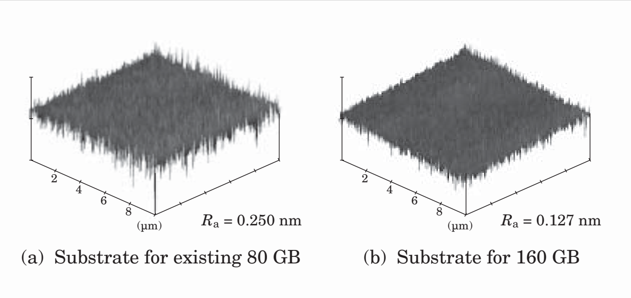
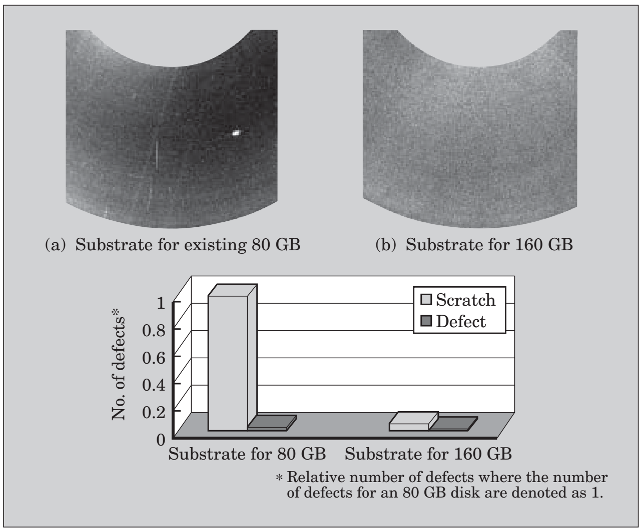



Fig.3 Surface defects of a polished aluminum substrate




studying the

① use of a slurry process solution having good detergency, and

② application of a detergent having good detergency and rinsing performance for the particles and process dust,

and is also simultaneously increasing the cleanliness of the polished aluminum substrate.

(2) Improved surface characteristic of polished aluminum substrates

As examples of the results of the technical development described above, Fig. 2 compares the surface roughness of an aluminum substrate for magnetic recording media having a conventional 80 GB/disk (3.5-inch) recording capacity and the surface roughness of a newly developed aluminum substrate with the next-generation specification of 160 GB/disk, as observed with atomic force microscopy (AFM). The amount of surface defects on these two types of media, as measured with optical defect detection equipment, is compared in Fig. 3.

With the next-generation 160 GB/disk aluminum substrate, excellent results of a halving of the surface roughness and a steep decrease in surface defects have been achieved by using mainly a new type of polishing slurry in combination with appropriate process conditions, and it has been decided that this substrate will be used in mass-production.

## 5. Conclusion

The longitudinal magnetic recording method, having been used in HDDs for many years, is approaching its technical limits. But in recent years, an innovative perpendicular magnetic recording method that breaks through these limits has advanced, and perpendicular magnetic recording media has begun to be mass-produced.

Aluminum substrate media is also slated for use in perpendicular magnetic recording in the future, and vigorous technical development is underway for that purpose. In an aluminum substrate for perpendicular magnetic recording, distinctive phenomena that could not be confirmed with the conventional longitudinal magnetic recording method have been observed, and even higher levels of surface precision are being required of polished aluminum substrates. In order to meet such difficult challenges Fuji Electric will continue to develop new technology capable of meeting these challenges and will continue to search for substrate technologies, plating technologies, polishing techniques and cleaning techniques in order to realize aluminum substrate characteristics capable of supporting the future evolution of recording methods.

# Development of Perpendicular Magnetic Recording Media

**Yasushi Sakai**
**Shunji Takenoiri**
**Hiroyuki Uwazumi**

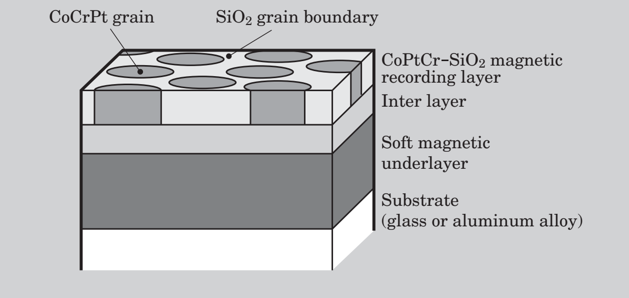
## 1. Introduction

Hard disk drives (HDDs), first used in practical applications in 1956, have recently been undergoing rapid increases in their areal densities at annual rates of 60 to 100 %, and the rate of increase is expected to continue at an annual rate of approximately 30 % in the future. As a result of such remarkable growth, the longitudinal magnetic record method, which has been used so far, is approaching its areal density limit due to the tradeoff between low noise performance and thermal stability. Thermal instability is a phenomenon in which the thermal energy at room temperature causes prerecorded magnetic bits to invert, and thus signal stability cannot be maintained. With the longitudinal magnetic record method, thermal instability increases as areal density is increased.

The method of perpendicular magnetic recording method was proposed in 1975 by Iwasaki[1] et al. Having characteristics that are opposite those of the longitudinal magnetic record method, perpendicular magnetic recording becomes more resistant to thermal instability as the areal density increases. Because the principles of perpendicular magnetic recording are well suited to higher areal density, many trials relating to magnetic recording media and magnetic recording heads have been conducted, and in the Spring of 2005 an HDD that uses perpendicular magnetic recording method was finally introduced to the market.

Having begun developing perpendicular magnetic recording media in 1999, Fuji Electric has focused on practical application of a magnetic recording layer that successfully overcomes the technical challenge of simultaneously realizing low-noise, high thermal stability and good overwrite performance, and on practical application of the soft magnetic underlayer for which improved manufacturability is needed. Figure 1 shows a schematic image of the perpendicular magnetic recording media developed by Fuji Electric. The use of a Co-based amorphous alloy film as the soft underlayer (SUL) and CoPtCr-$SiO_2$ as a granular type magnetic recording layer provides the perpendicular magnetic recording media with good performance, and the film thickness of each layer of the perpendicular magnetic recording media is relatively thin.

Fig.1 Schematic image of perpendicular media




Fuji Electric is aiming to begin mass production of its first perpendicular magnetic recording media, and is making preparations for mass production.

This paper describes the development status of perpendicular magnetic recording media at Fuji Electric, including the effect of a texturing process on the soft underlayer, optimization of the soft underlayer, structural control of perpendicular magnetic recording media having a granular structure, and the like.

## 2. Development of the Soft Underlayer (SUL)

The SUL is a characteristic feature of perpendicular magnetic recording media. The existence of the SUL enables the head recording field to be set to approximately 1.5 times that of the longitudinal magnetic recording method, and this is very advantageous. However, spike noise, which is generated at magnetic domains of the SUL is a significant problem and must be suppressed. In consideration of manufacturability, the SUL should be made as thin as possible, and with the recent debut of shielded pole type heads, there is no need for SUL film to be as thick as in the past, and the reduction of SUL film thickness is a challenge of extreme importance for manufacturability.

### 2.1 Effect of texturing

In longitudinal magnetic recording media that uses aluminum alloy substrates, texturing is currently being performed to enhance the magnetic properties and

HDI (head-disk interface) properties. In perpendicular magnetic recording media, as long as the magnetic recording head design does not change significantly from that of a conventional design, some sort of surface treatment is thought to be necessary for the HDI. Therefore, using aluminum substrates textured with various modified conditions, perpendicular magnetic recording media sputtered with those same conditions were evaluated, and the results are presented below.

Spike noise and recording performance were evaluated using a spin-stand tester and a shielded pole type head. Spike noise was evaluated for output signals after DC erasing, by computing the number of signals that exceed a threshold value of 1.2 times of the white noise level. Figure 2 shows the incidence of spike noise corresponding to the surface roughness ($R_a$) of the aluminum substrates used. In cases where $R_a$ is approximately 0.2 nm or less, the spike noise incidence is shown to remain at a low value of less than 100 spikes, but when $R_a$ increases from 0.2 nm, the spike noise incidence is seen to increase suddenly.

Next, to verify the effect of texturing on the R/W (Read/Write) performance, a signal is written with areal density of 150 kfci (fci: flux change per inch), and then an OTP (off-track profile: track profile of a signal which is measured by shifting the magnetic head from side to side centering around the signal writing point with 10 nm pitch.) measurement is taken, and the output voltage at a distance of 230 nm from the center of the signal is computed and is defined as the height at the edge of the OTP. The relationship between the OTP edge height and Ra is shown in Fig. 3. The figure shows examples of OTPs of media having large and small edge heights. Similar to the case of spike noise, if $R_a$ is smaller than 0.2 nm, the edge height remains at a low voltage of approximately 0.01 mV. However, if $R_a$ becomes greater than 0.2 nm, the edge height increases rapidly and the OTP has a step-like shape at its left and right sides, and the signal spreads out horizontally.

To investigate these causes, the magnetic anisotropy of each media's SUL was examined. The results showed that when $R_a$ increases, the orientation of SUL magnetic anisotropy changes from the radial direction required for perpendicular magnetic recording media to the circumferential direction along a textured groove. Accordingly, from the perspective of the control of SUL anisotropy, the $R_a$ of the substrate is preferably small. However, even when $R_a$ is small, some substrates exhibited poor performance, and conversely, when $R_a$ is large, some substrates exhibited good performance, and therefore, rather than sole dependence on $R_a$, the density, profile and direction of texturing are surmised to also exert influence on these performance.

On the other hand, an improved polishing technique enables $R_a$ to be controlled and surface defects to be reduced in perpendicular magnetic recording media having a glass substrate, without the use of a texturing process. The first generation of perpendicular magnetic recording media to be mass-produced will be made without a texturing process.

Using an aluminum substrate as an example, the effect of texture shape on magnetic characteristics and R/W performance was studied, and the results are presented below. Previously, it has been reported that the increase in c-axis distribution of CoPtCr grains that accompanies an increase in $R_a$ caused a decrease in coercivity $H_c$. However, according to the results of this study, the value of $H_c$ is approximately constant relative to $R_a$. Additionally, the signal-to-noise ratio (SNR), which is one of the R/W performance evaluated, also exhibits an approximately constant value relative to $R_a$. We surmise that these tendencies are caused by a value of $R_a$ that was smaller in this study than in prior reports, and by the selection of processing conditions that made it difficult for the effect of texturing to become noticeable in the SUL.

The dependency of the byte error rate (ByER), an important parameter for HDD performance, on $R_a$ is shown in Fig. 4. The value of log(ByER) remains approximately constant at −2.5 while $R_a$ is greater than approximately 0.15 nm. However, for values of $R_a$ less than 0.15 nm, ByER is observed to increase

Fig.2 Spike noise dependency on surface roughness ($R_a$)

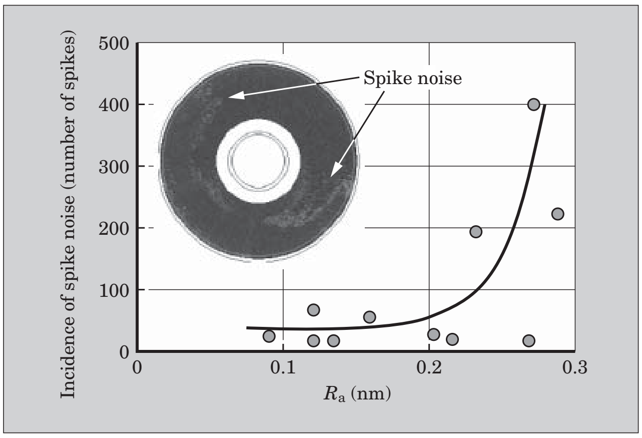



Fig.3 OTP edge height dependency on surface roughness ($R_a$)

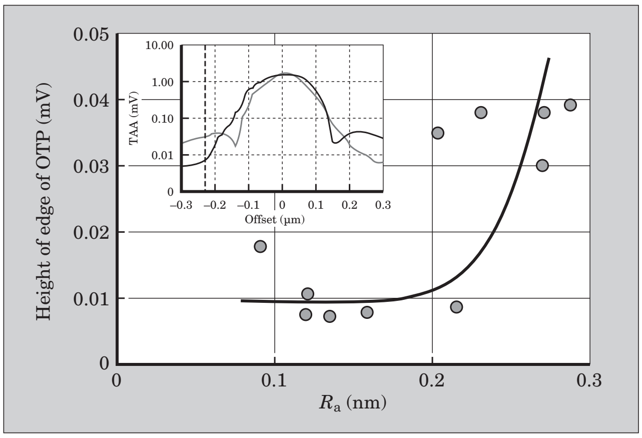


Fig.4 ByER dependency on surface roughness ($R_a$)

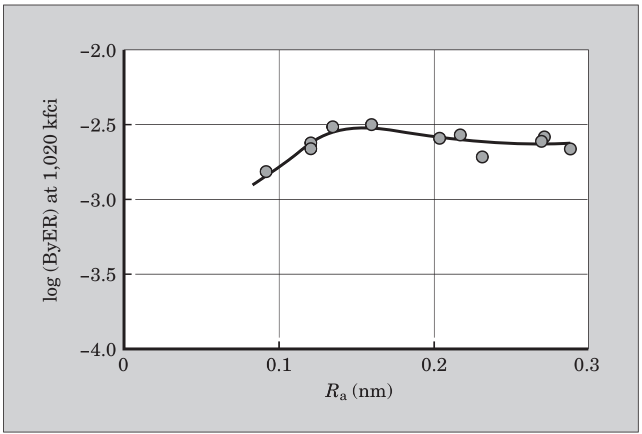
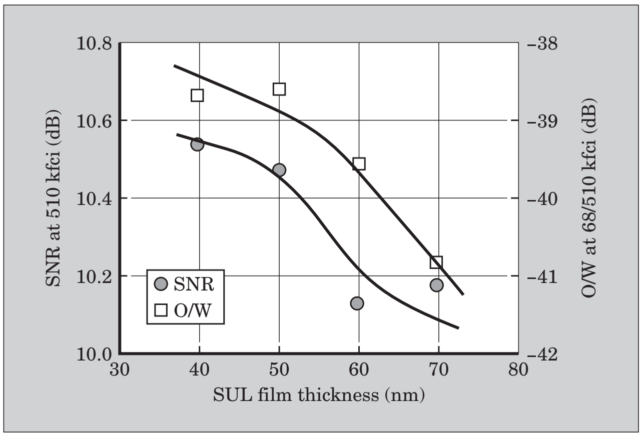


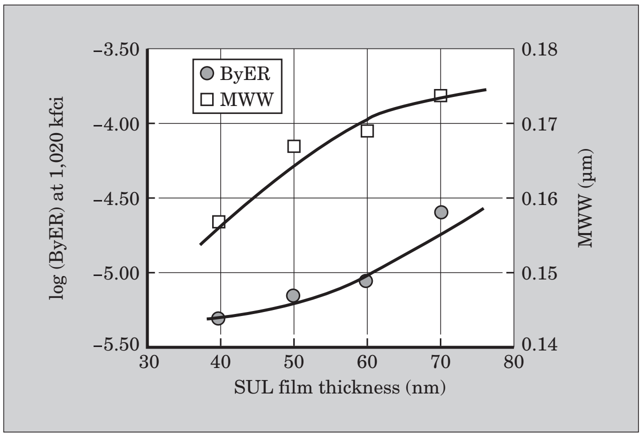

Fig.5 SNR and O/W dependency on SUL film thickness




monotonously. Since $H_c$ and the SNR exhibit approximately constant values relative to $R_a$, it is thought that modification of the $R_a$ value of a magnetic recording layer will not result in any structural or other changes. Thus, the cause of the increase in ByER for values of $R_a$ less than 0.15 nm is, as described above, surmised to be due to the decrease in spike noise that accompanies a reduction in the $R_a$ value.

Accordingly, in perpendicular magnetic recording media, because the shape of the substrate surface has a large impact on the media performance, development of the surface shape required for perpendicular magnetic recording media is being advanced with a comprehensive perspective that includes consideration of the HDI performance.

Fig.6 ByER and MWW dependency on SUL film thickness




### 2.2 Thinner SUL

When the media is used in combination with a conventional single pole (or mono pole) head, the SUL must have a thickness of more than 100 nm. Presently, however, with the advent of the shielded pole type head, which is the main type of head used with perpendicular magnetic recording media, a thick SUL is no longer necessary. This effect is believed to be attributed to the action of the effective recording field at a tilted angle to the easy axis of the recording layer when a shielded pole head is used. For example, as has been reported[(2)] in a simulation-based study, in the case of a magnetic recording layer thickness of 15 nm and a flying height of 10 nm, an optimally efficient recording magnetic field angle of 45 degrees can be obtained when the interlayer thickness is 10 nm. However, the ability to perform highly efficient writing also means that simultaneous erasing is also easy to implement. Thus, we investigated changes in R/W performance and changes in adjacent track erasures (ATE) to study the possibility for making the SUL thinner.

Figure 5 shows the SUL thickness dependency of the SNR measured at 510 kfci and of overwriting (O/W) a 68 kfci signal on a 510 kfci signal. By reducing the SUL thickness from 70 nm to 40 nm, the O/W performance decreases from −41 dB to −38.5 dB. However, the amount of decrease is at most approximately 2.5 dB, and even with an SUL thickness of 40 nm, O/W that significantly exceeds −30 dB can be obtained, and therefore, it is thought that sufficient overwrite performance can be obtained in this SUL thickness range. Next, we consider the SNR, and although some variance does exist, it is understood that the SNR improves as the SUL thickness is reduced. Since the magnetic characteristics of the recording magnetic layer remain nearly constant regardless of the SUL thickness, the difference in SNR is presumed to be caused by the SUL.

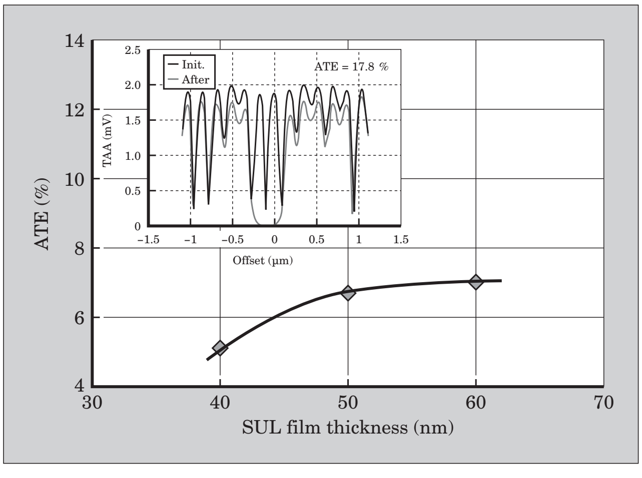
Figure 6 shows the SUL thickness dependency of the ByER at 1,020 kfci and of the MWW (magnetic write width). From the figure, it can be understood that the thinner the SUL, the more ByER improves and MWW becomes smaller. This result means that a thinner SUL results in a simultaneous improvement in both the bpi (bits per inch) and tpi (tracks per inch). Reduction of the noise originating in the SUL is thought to be one important factor for achieving higher densities.

Next, we studied the ATE, which is an important item for evaluation because of the existence of the SUL in the perpendicular magnetic recording media. In the ATE evaluation, a low-frequency signal was written to multiple tracks on left and right sides of a central location, and then the level of signal output with a magnetic head was measured. Then, a high-frequency signal is written multiple times (1,000 to 10,000 times) to the central location, and again the level of signal output with a magnetic head was measured. The amount of attenuation of the signal output, before and after writing the high-frequency signal to the central location, is computed and this is the ATE value. Figure 7 shows the ATE measurement results for media with varying SUL thicknesses. As an example, the actual output waveform obtained is also shown in the same figure. Because SUL anisotropy is uncontrolled, a large drop of approximately 17 % in the ATE value is observed. In the perpendicular magnetic recording media used, the anisotropy and surface shape of the SUL are controlled, and therefore even at an SUL thickness of 60 nm, the ATE value is suppressed to a low value of approximately 7 %. As the SUL becomes thinner, the ATE decreases monotonously, and at a 40 nm SUL thickness, the ATE value is a low value of approximately 5 %. Therefore, from the perspective of ATE as well, with the sufficient O/W value, a thinner SUL is preferable.

With the head and media combination described herein, the O/W value still has some degree of leeway, and an SUL of 40 nm or less can be realized. Also, if recording is performed with a tilted writing field while using a shielded pole head, there is optimum thickness of the magnetic recording layer and interlayer for efficient recording. With these points in mind, Fuji Electric is committed to developing even higher densities media.

As has been described, Fuji Electric's perpendicular magnetic recording media is made with a thin SUL and is optimized so that even an SUL film thickness of about 50 nm will provide good performance in an HDD. This good performance results from Fuji Electric's use of a thinner non-magnetic interlayer and optimized magnetic recording layer that enable the media overall to be easily written to with a magnetic head, even if the SUL film is thin. As a result of these efforts, and in order to improve manufacturability and lower production costs, Fuji Electric is aiming to begin mass-production.

Fig.7 ATE dependency on SUL film thickness

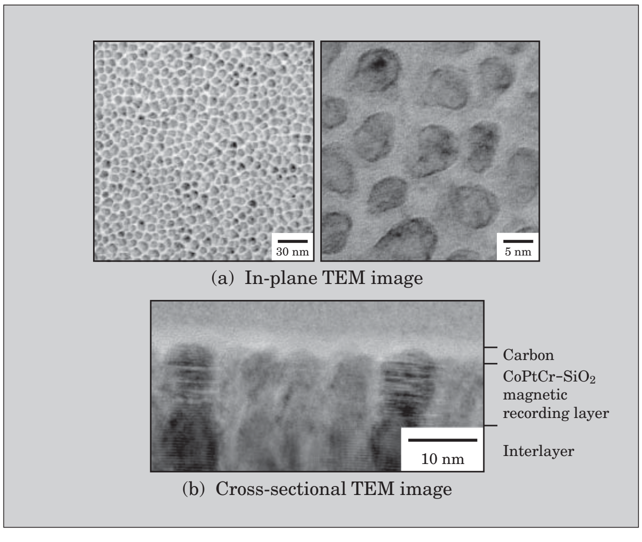



## 3. Microstructure and Crystalline Orientation of $CoPtCr\text{-}SiO_2$ Perpendicular Media

Ahead of other companies, Fuji Electric has actively reported[(3)(4)] that the use of CoPtCr with an $SiO_2$ additive as the recording layer material makes it possible to realize perpendicular magnetic recording media having large uniaxial anisotropy and a well-segregated grain structure, and that the performance of the media exhibits low noise and good thermal stability. Figure 8 shows in-plane and cross-sectional lattice images of the perpendicular magnetic recording media obtained by using transmission electron microscopy (TEM). The average grain size in the CoPtCr layer is 4.5 nm, and the average grain boundary width is 2.4 nm. Also, the interlayer is known to have a crystalline grain size of 7.4 nm, and sum of the CoPtCr crystalline grain size and the grain boundary width approximately matches the crystalline grain size of the interlayer. From the cross-sectional TEM image, it can be seen that the interlayer and the CoPtCr layer grow in a 1:1 ratio, that the c-plane lattice structure is continuous from the interlayer to the CoPtCr layer, and that the CoPtCr grains are well-segregated by amorphous grain boundaries from the initial layer of the recording layer. Furthermore, the results of X-ray diffraction show that the c-axis distribution $\Delta\theta_{50}$ is 2.5 degrees in both the interlayer and the CoPtCr layer, and that c-axis distribution is less than in conventional media.

The grain size of the perpendicular magnetic recording media shown in Fig. 8 is reduced to approximately 65 % that of conventional media. However, if the grain boundary width is included, the size compared to conventional media is reduced to only ap-

Fig.8 TEM images of $CoPtCr\text{-}SiO_2$ perpendicular magnetic recording media



proximately 80 %. The reduction in crystalline grain size results in an actual decrease in media noise, but the technique of expanding the grain boundary width and reducing the grain size is limited when considering the trend toward higher bpi. In the future, in order to maintain the number of crystalline grains in the bpi direction at a certain level per bit, it is desirable to reduce the grain size while increasing the packing density. For this purpose, reduction of the grain size in the interlayer and optimization of the amount of $SiO_2$ additive in the CoPtCr layer are thought to be necessary.

## 4. Conclusion

In recent years, HDD usage has been expanding over a wide range of applications, and with higher recording densities enabled by the utilization of perpendicular magnetic recording, the range of applications is expected to expand further and the usage is expected to increase.

Fuji Electric has been developing perpendicular magnetic recording media since 1999 and began mass-production in the Spring of 2006. Fuji Electric intends to continue to develop and investigate technology for realizing more advanced mass-production technology and higher recording densities.

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# Reliability of Perpendicular Magnetic Recording Media

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**Kengo Kainuma**
**Makoto Isozaki**

## 1. Introduction

Perpendicular magnetic layer technology that provides low-noise and high recording density is a fundamental technology for perpendicular magnetic recording media, but in order to ensure good reliability in an actual hard disk drive (HDD) device, the substrate, cleaning technology, soft underlayer, protective layer, etc. must be optimized for use with perpendicular magnetic recording media. This paper describes the design of the substrate and soft underlayer, and the cleaning technology and protective layer technology, including the HDI (head-disk interface) technology, for use with perpendicular magnetic recording media.

## 2. Substrate and Soft Underlayer Design for Use with Perpendicular Magnetic Recording Media

The substrate and soft underlayer designed for use with perpendicular magnetic recording media are technical components that support the recording density of perpendicular magnetic recording media. The soft underlayer constitutes a magnetic circuit together with a recording head, and functions to enhance the recording resolution by causing an abrupt change in the strength of the head's magnetic field applied to the magnetic recording layer and in the magnetic field gradient when a magnetized bit is being written. However, since the soft magnetic material has low magnetocrystalline anisotropy, it is susceptible to the effects of shape anisotropy, and depending on the shape of the substrate surface, a complicated structure with many different separated magnetic domains, each having their own magnetic orientation, is likely to result. A large magnetostatic leakage field occurs at the boundaries (domain walls) between magnetic domains, causing a large noise known as "spike noise" when a signal is being reproduced.

In conventional longitudinal magnetic recording media, the media is textured in the circumferential direction in order to make it anisotropic in that direction. However, when this type of textured substrate is used in perpendicular magnetic recording media, the aligning of the soft underlayer in the circumferential direction creates a problem. This is because the soft underlayer is affected greatly in the direction of the shape anisotropy, and the easy axis of magnetization could become aligned in parallel with the grooves of the texturing. The soft underlayer aligned in the circumferential direction forms a 180° domain wall at a location in the circumferential direction. A large magnetostatic leakage field is generated from the domain wall, and this creates spike noise during signal playback. Figure 1 shows mapped envelopes of the playback signal. When looking at the output waveform, the waveform appears to be stepped, and thus is not suitable for perpendicular magnetic recording media.

For perpendicular magnetic recording media requiring a recording density of 150 Gbits/in$^2$ or above, a greater degree of surface flatness than ever before is needed. Also, in terms of tribology, when roughness is reduced so that the surface becomes flat, frictional force increases and takeoff performance deteriorates. "Takeoff performance" describes the performance of a magnetic head, after have crashed, flying over the media surface again.

In order to satisfy these requirements, a surface that is flat and random, with high uniformity is required. In consideration of these requirements, Fuji Electric has developed technology for controlling ultra-flat random roughness.

Using this technology, various characteristics were

Fig.1 Envelope map of reproduced signal

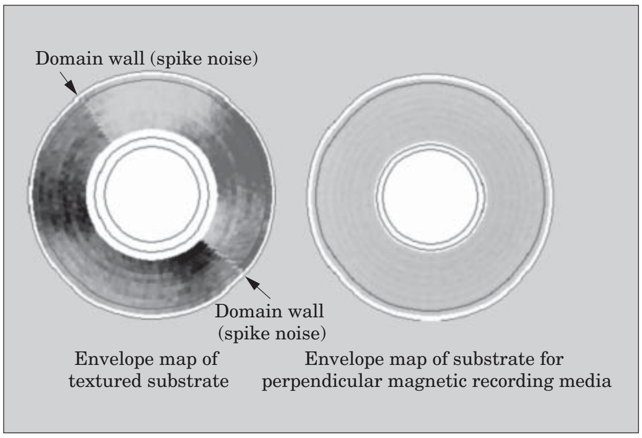


Fig.2 Surface roughness vs. flying characteristics

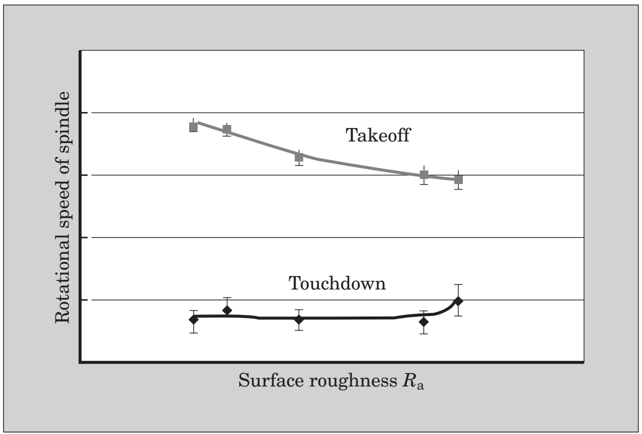



Fig.3 LUL durability in a reduced pressure environment

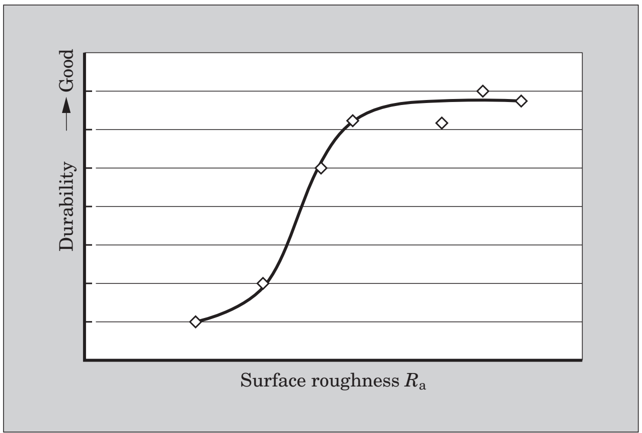



Fig.4 Surface roughness vs. parametrics

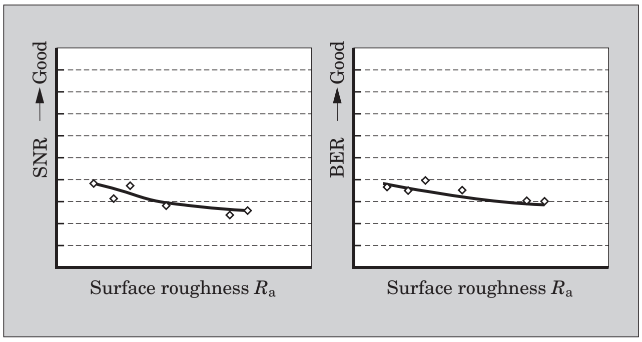
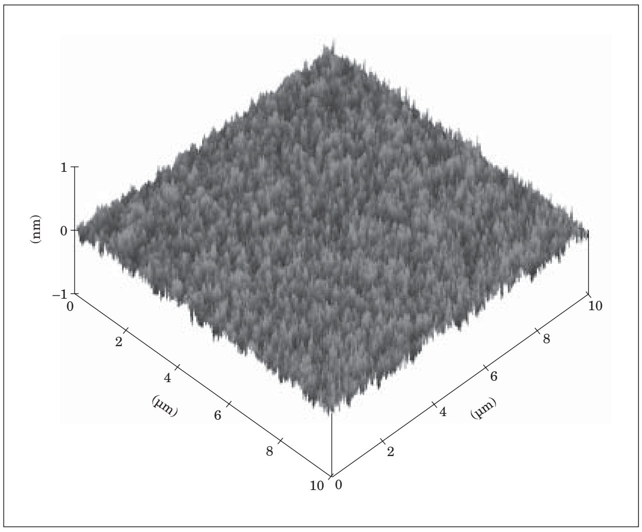



Fig.5 Surface profile of substrate for perpendicular magnetic recording media




measured while controlling the surface roughness of the media.

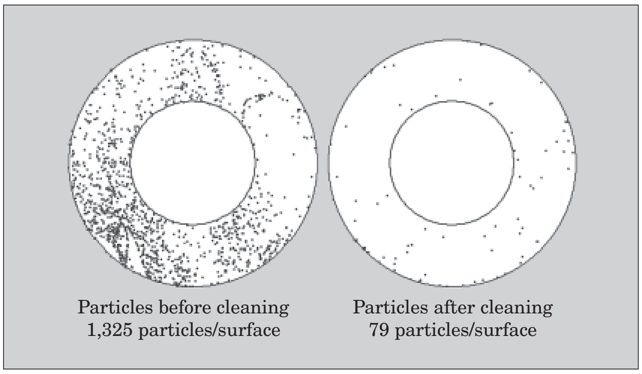
The floating performance was evaluated with two types of criteria: the rotational speed at which a magnetic head flying above magnetic media touches down and makes contact with that media due to a reduction in rotational speed of the spindle, and the rotational speed at which a magnetic head in physical contact with the media takes off and begins to fly above the media due to an increase in rotational speed of the spindle. As can be seen in the results shown in Fig. 2, as the surface roughness increases, take-off becomes easier and the floating performance improves. The touchdown speed exhibits no dependency on roughness, but appears to worsen if the surface becomes excessively rough.

The durability was evaluated by conducting an LUL (load/unload) test, which is typically performed with 2.5-inch HDDs. The LUL test evaluates durability by repeatedly moving the magnetic head from its ramp load position in a standby state towards and away from the surface the magnetic media. With this evaluation, no significant difference is observed at usual atmospheric pressure, but in an environment of reduced pressure, a trend as shown in Fig. 3 is observed. By increasing the roughness of the surface, an improvement in LUL characteristics is observed in a reduced pressure environment.

As described above, we have verified that the provision of random roughness on the substrate surface results in improvement to both the flying performance and durability characteristics. However, by increasing the surface roughness, the crystalline c-axis (easy axis of magnetization) that forms the perpendicular magnetic layer becomes susceptible to anisotropic dispersion due to the effect of the roughness, and the magnetic characteristics deteriorate. As a result, the parametrics also deteriorated when measured with the magnetic head. Specifically, there is slight deterioration in the SNR (signal-to-noise-ratio) and the BER (bit error rate) of the parametrics. This is shown in Fig. 4.

Ultimately, by controlling the roughness to an optimal value, we designed a substrate for low-defect perpendicular magnetic recording media having stable flying performance, and good durability and parametrics. Figure 5 shows a surface profile of this substrate. By creating a roughness that is both gently sloping and random, the dispersion of the c-axis is reduced, thereby enabling the production of perpendicular magnetic recording media having excellent durability and flying

Fig.6 Particles after precision cleaning




performance.

## 3. Cleaning Techniques for Perpendicular Magnetic Recording Media

The substrate for perpendicular magnetic recording media has a multi-layered construction, and the adherence of contaminants to the substrate will cause major defects.

When cleaning the substrate of perpendicular magnetic recording media, the cleaning is required to be more powerful than that used for a substrate of longitudinal magnetic recording media. The use of powerful cleaning in the case of a substrate of longitudinal magnetic recording media has the effect of etching scratches in the texture, and this is a problem because the OR (orientation ratio) decreases. However, with a substrate for perpendicular magnetic recording media, the soft underlayer must not be aligned, and therefore a powerful cleaning technique such as etching may be used. Figure 6 shows substrate particle data before and after cleaning to remove contaminants while etching the glass substrate surface. It can be seen that the cleaning of perpendicular magnetic recording media reduces particles dramatically.

## 4. Protective Film Technology

Perpendicular magnetic recording media was predicted to have poor corrosion characteristics because its soft underlayer is thick. Therefore, the protective film was provided with a two-layer construction consisting of a high-density layer and a stabilization layer, and film deposition conditions were optimized for the high-density layer to improve the corrosion characteristics.

Specifically, since the CVD (chemical vapor deposition) film is rich in $SP^3$, film properties of high hydrophobic and lubricating performance were chosen. Figure 7 shows actual results measured by Raman spectroscopy. The film deposition conditions and gas components were controlled to changeover from the conventional $SP^2$ rich film to an $SP^3$ rich film. As a result, cobalt corrosion is suppressed, and a highly durable protective film can be formed.

Fig.7 Control of carbon film properties

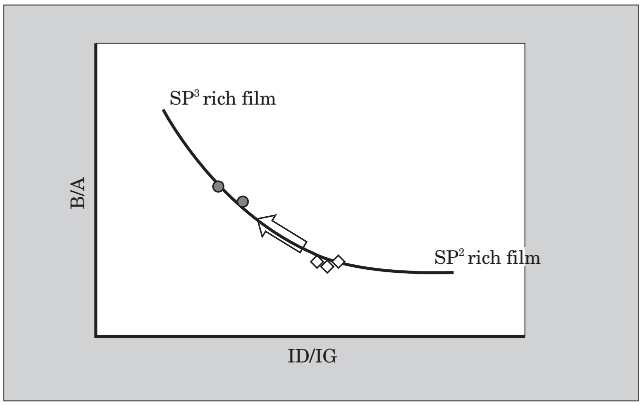



Fig.8 Results of corrosion evaluation of media left at high-temperature and high-humidity

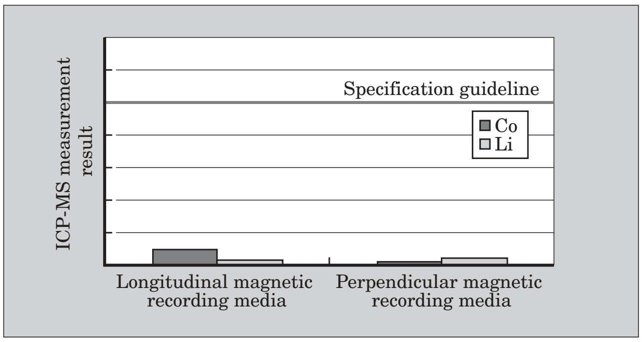



Figure 8 shows the results of a corrosion evaluation performed by ICP-MS (inductively coupled plasma-mass spectrometry) after 96 hours in a high-temperature and high-humidity environment of 80°C and 80 %RH. Both Co and Li could be suppressed to values of 1/10th or less than those of the in-house specifications.

## 5. Evaluation of HDI Characteristics

We performed evaluated the HDI of the final perpendicular magnetic recording media. The evaluation consisted of the following items.

(1) LUL tests in various environments
- ○ Hot and wet (70°C and 80 %RH)
- ○ Normal temperature and normal humidity
- ○ Cool and dry

(2) High-speed seek tests
(3) Head slap test
(4) LUL tests in reduced pressure environment
(5) Take-off, touchdown tests

The results of (1) LUL tests in various environments, and especially under the severe conditions of 70°C and 80 %RH, are shown for 200 hours and 400,000 cycles in Fig. 9. Even in a high-temperature and high-humidity environment, observation of the media surface with an OSA (optical surface analyzer) verified the absence of carbon wear and lubricant “moguls”, and that there is no decrease in mass. Also,

Fig.9 Load/unload test results

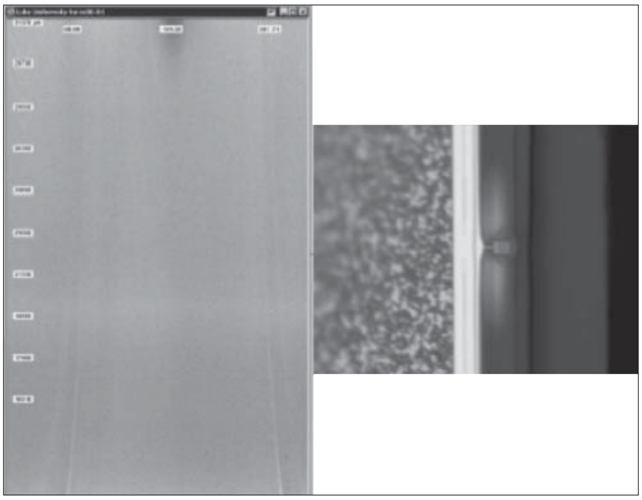
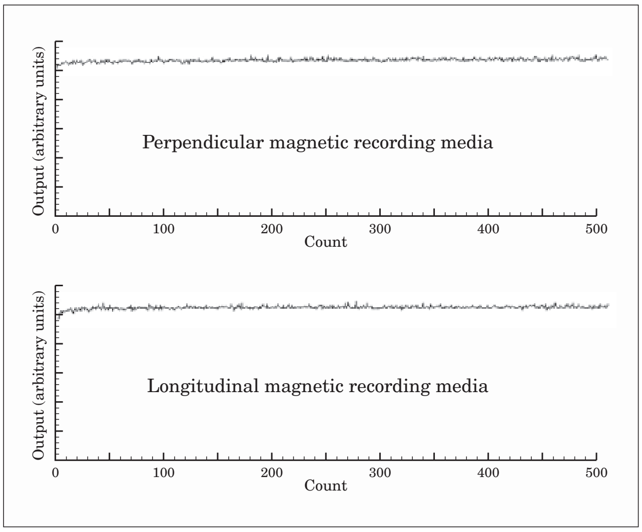


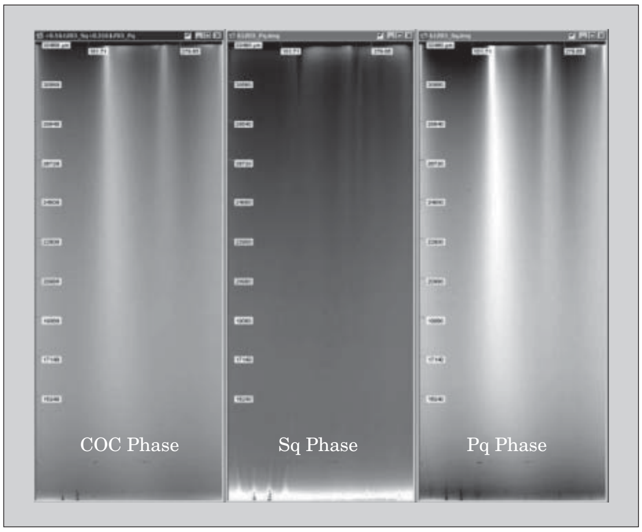
Fig.10 High-speed seek test results




observation of the magnetic head verified the absence of contamination adhering to the slider or pole-tip assemblies.

The results of (2) high-speed seek tests are shown in Fig. 10. The magnetic head performed high-speed seek operations at a speed of 10 Hz, and the AE (acoustic emission) signal was measured for 500,000 cycles. In terms of the AE signal, a trouble-free waveform, compared to that of the longitudinal magnetic recording media, was observed, and the absence of damage to the magnetic recording media on the magnetic head side was also verified.

Fig.11 Head slap test results




The (3) head slap test is a technique for accelerated evaluation of the durability during magnetic head loading and unloading, and is performed by suddenly dropping the magnetic head from the ramp load position while the magnetic media is rotating at a high-speed. Even in this evaluation, as shown in Fig. 11, no wear is generated on the carbon on the media side, and the results were problem-free without verifying a reduction in lubricant.

Items (4) and (5) are dependent upon surface roughness, and as has been reported previously, the surface roughness was controlled and the media was optimized.

As described above, the reliability of perpendicular magnetic recording media has been improved to equal or exceed that of longitudinal magnetic recording media.

## 6. Conclusion

The application of perpendicular magnetic recording media to HDDs has begun with glass magnetic recording media, and is expected to expand to aluminum magnetic recording media. Ultimately, it is expected that all pre-existing longitudinal magnetic recording media will be replaced with perpendicular magnetic recording media. To achieve this goal, higher recording density and guaranteed reliability of the perpendicular magnetic recording media are crucial, and Fuji Electric intends to continue to innovate and improve technology for this purpose.

# Present Status and Future Prospects for Photoconductors

**Mitsuru Narita**
**Teruo Yamamoto**

## 1. Introduction

In the future, information and communication technologies will continue to advance, and NGNs (next generation networks) will be deployed to link various types of devices. Accordingly, office and home environments linked to these networks will also change and the external transmission of information will become increasingly important.

The network functionality of image input and output devices, such as the familiar examples of digital still cameras, cell phones, scanners, printers and digital copying machines has increased rapidly, and the distribution of color image information over the Internet is rapidly becoming prevalent.

Under these circumstances, the role of printers and copiers that display and record color information and images will increase in importance, and color images may become the norm in the near future.

This paper discusses the market trends of these printers and copiers, especially the trends of electrophotographic-type printers and copiers, and describes Fuji Electric's photoconductors that support these devices.

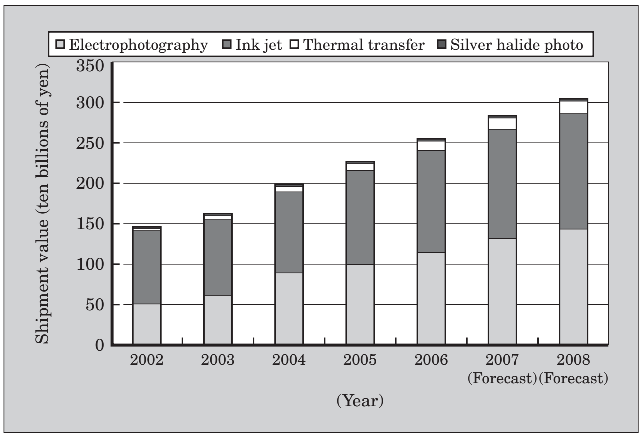
## 2. Market Trends of Printers and Copiers

Fuji Electric has used soft copies (displayed images) and hard copies (printouts of that information) as a means for transmitting text and images.

Soft copies, as typically shown on liquid crystal and organic EL (electroluminescence) displays, have made remarkable progress and will become even more prevalent in the future. Hard copies, as a paper medium, have continued to exhibit solid growth in their volume of consumption, and this growth is believed to be attributable to the many functions of paper, i.e., display, writing, storing and transmission, and because paper is a lightweight and highly convenient media.

Meanwhile, as a third technology that is a successor to paper and displays, electronic paper and other new technologies are being advanced. In the mid- and long-term, these electronic media are expected to increase relative to paper media. Also, due to the synergistic effects of both media, the amount of information handled will continue to increase, and as a result, continued growth is forecast for both types of media.

Fig.1 Changes in worldwide value of shipments of color hardcopy machines




The hardcopy output from computers or the like can be broadly categorized as an inkjet method that is dominant in the personal-use sector and an electrophotographic method that is dominant in the office-use sector. The inkjet method which uses special paper has the advantages of inexpensive equipment cost and color-compatibility, while the electrophotographic method which uses plain paper has the advantages of inexpensive running cost and speediness.

Figure 1 shows the market forecast for color hardcopy machines. Shipments of electrophotographic color printers and color copiers have risen rapidly since 2004, and have been increasing by approximately 16 % over the past several years, and significant future growth is also predicted. The inkjet and electrophotographic methods will continue to compete against one another in the future, but their markets will also continue to grow as the individual characteristics of each are best utilized.

## 3. Trends of Electrophotography

The demand for color electrophotographic printers and copiers has been increasing over the past several years, and particularly with the above-described developments in networking, colorization is advancing for both electrophotographic printers and copiers.

It is also thought that environmental changes will drive technological evolution and changes in structural models.

### 3.1 Printers

The volume trends of electrophotographic type monochrome printer and color printer shipments are shown in Figs. 2 and 3. In 2003, the shipment volume of monochrome printers was approximately 11.8 million units, while the color printer shipment volume remained at approximately 1.2 million units. Over the past several years, however, the color printer shipment volume has exhibited growth on the order of 20 % annually, and this market is expected to expand in the future.

Fig.2 Changes in worldwide volume of shipments of electrophotographic monochrome printers and color printers

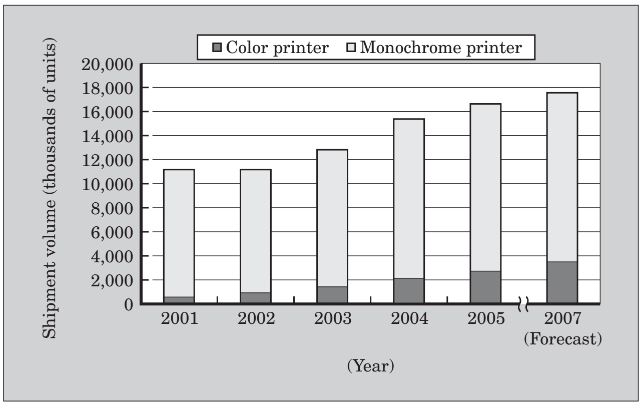
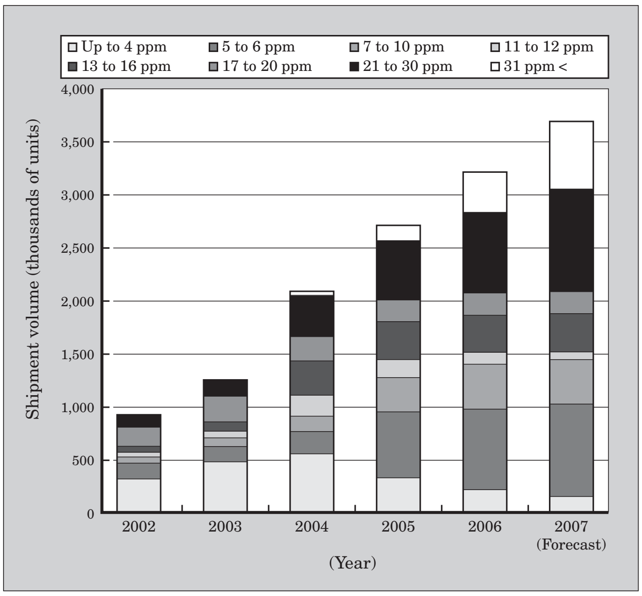



Fig.3 Changes in worldwide volume of shipments of color laser printers by speed




As can be seen in Fig. 3, shipments of low-speed color printers having image output speeds of 4 ppm (pages per minute) or slower are decreasing, and 5 ppm and faster printers have become the mainstream type of printer since 2005. Low-speed printers use a printing method whereby four colors are printed with a single photosensitive drum (4-cycle engine), while medium-speed and high-speed printers have four photosensitive drums arranged in series and use a method of printing one color with each drum (tandem engine). The tandem engine method is expected to become the mainstream printing method.

The photoconductors used in color printers are required to improve image quality, especially the image resolution, and to have stable optical attenuation characteristics which are necessary for good color reproducibility. Also, among the abovementioned processes, in the tandem engine process in particular, photoconductors are required to have high dimensional precision in order to suppress color drift among the four colors.

Another trend in the printer sector is the progress toward quick printing. The networking of information is driving widespread use of on-demand printers. Specifically, quick printing is used for newspapers, magazines, catalogs and other types of small-lot printing and onsite printing jobs, and this is a new market sector that utilizes the high-speed performance and convenience of electrophotography. The photoconductors used in these applications are required to have high sensitivity that supports the printing speed, high-speed responsiveness and good durability, i.e., long service life, and high resolution near that of offset printing. The optimal photoconductor has been reported to be a positive charge monolayer-type photoconductor that does not decrease in resolution even if the film is trimmed away. Also, there have been some announcements made of high resolution printers that use liquid toner instead of the conventional dry toner, and photoconductors that support these printers are being developed.

### 3.2 Copiers

The trend toward digitization is also advancing in the market sector for copiers. Figure 4 shows the changes in volume of copier shipments. The overall shipment volume is decreasing, and although monochrome digital copiers are exhibiting a rapid decrease, shipments of color digital copiers are increasing. This trend is due to printers becoming MFPs (multifunction peripherals) and replacing copiers. Figure 5 shows the changes in volume of shipments of digital copiers according to speed. Shipments of medium- and high-speed copiers having an image output rate of 21 cpm (copies per minutes) or faster are exhibiting solid growth, but shipments of 20 cpm and slower copiers are decreasing.

The photoconductors used in digital copiers are re-

Fig.4 Changes in worldwide volume of shipments of copiers

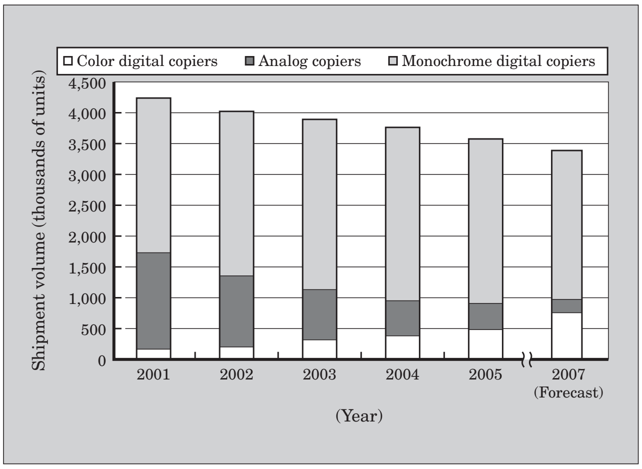
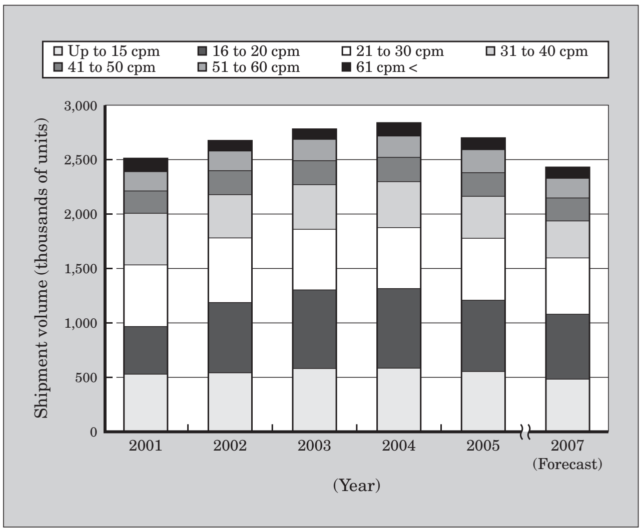



Fig.5 Changes in worldwide volume of shipments of monochrome digital copiers by speed

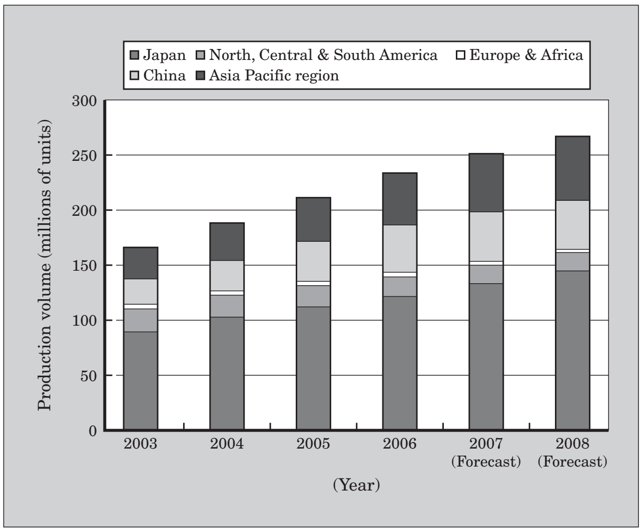



quired to have the characteristics of high-speed responsiveness, good durability, grayscale capability to reproduce halftones in a graphic image and the like, and the capability to realize optical attenuation suitable for the copier process.

### 3.3 Photoconductors

The photoconductors used in the above-mentioned electrophotographic printers and copiers are OPCs (organic photoconductors), selenium photoconductors, amorphous silicon photoconductors and the like. Figure 6 shows the changes in production of photoconductors according to region. It can be seen that production is increasing at a solid annual growth rate of 5 to 10 %. Also, although Japan is presently the site of the majority of production, in the future, the majority of production is expected to come from China and the Asia Pacific region. As electrophotographic equipment that uses these photoconductors, the widespread usage

Fig.6 Changes in worldwide volume of production of photoconductors




of color printers, on-demand printers and digital copiers is anticipated, potentially forming a new market, and further growth is expected.

The following characteristics are required of photoconductors to support new developments in the future.

(1) Color printers: High resolution, color reproducibility and element tube precision are required
(2) On-demand printers: High sensitivity, high-speed responsiveness and durability are required
(3) Color digital copiers: High-speed responsiveness, durability and grayscale capability are required

## 4. Overview of Fuji Electric's Products

Fuji Electric commercialized and began to sell selenium photoconductors in 1973 and OPCs in 1988. Then, quickly and flexibly responding to the rapid advances in electrophotographic technology, Fuji Electric deployed a global business for developing, manufacturing and marketing photoconductors, the core component of printers and copiers, and their peripheral equipment.

Three sites of production, in Japan (Matsumoto area), in the United States by U.S. Fuji Electric in the United States, and in China (ShenZhen area) by Fuji Electric (ShenZhen) Co., Ltd., will be integrated into the ShenZhen area site during the first half of 2006 in order to meet global demand more efficiently.

Fuji Electric (ShenZhen) Co., Ltd. manufactures various peripheral products including developing sleeve and toner cartridges. Many printer manufacturers and copier manufacturers are assembling equipment in China and other Asian countries, and it is thought that manufacturing photoconductors and their peripheral components in China provides significant convenience.

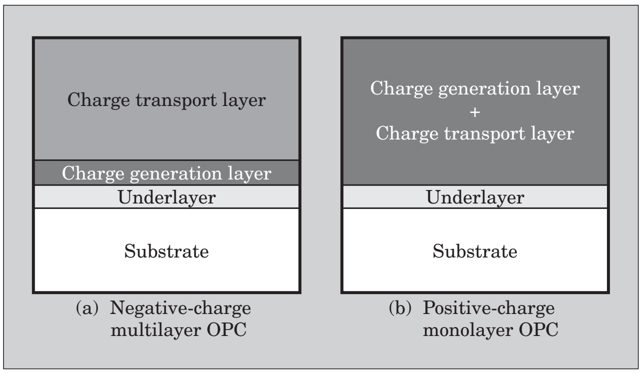
### 4.1 OPC

Fuji Electric is poised to respond to individual re-

Table 1 OPC product lines

| Type | Characteristic feature | | Use |
|---|---|---|---|
| | Charge polarity | Layer structure | |
| Type 8 | Negative | Multilayer | Printers, facsimile machines, multifunction devices |
| Type 9 | Negative | Multilayer | Analog copiers |
| Type 10 | Negative | Multilayer | Digital copiers, multifunction devices |
| Type 11 | Positive | Monolayer | Printers, facsimile machines, multifunction devices, quick printing devices |

Fig.7 OPC layer configuration




quests from a diversity of customers, and in order to obtain sharp images, Fuji provides a product line of various photoconductors with wavelengths suitable for various printer and copiers.

Table 1 lists a lineup of four types of OPC product lines. Figure 7 shows the OPC layer structure.

(1) OPCs for printers

The type 8 product line has been commercialized for printer-use OPCs; it supports a wide range of potential differences and a wide range of sensitivities, for low-speed to high-speed devices. For organic materials (charge generating material, charge transport material, and the like) in particular, development continues day and night into many types of material design techniques including the computer-based molecular design of materials, dispersion techniques for applying coating solutions to the material, and coating techniques for the OPC. The high resolution, color image reproducibility and so on required by color printers make it possible to support a wide range of customer requests.

Also, the dimensional precision of the drum maintains excellent rotational stability due to advances in element tube processing technology and a high precision design.

(2) OPCs for copiers

OPCs for copiers are commercialized with two product lines, the type 9 OPC line for use in analog copiers and the type 10 OPC line for use in digital copiers.

Product lines are arranged to satisfy the copier requirements for high-speed responsiveness, high durability and grayscale capability, and new materials are being designed and developed to improve performance further. In particular, because long service life and potential difference stability are required for OPCs used in digital copiers, molecular design technology and various potential difference stabilization agents are applied to the OPC binder material in order to commercialize higher performance photoconductors.

(3) Positive charge monolayer OPCs

While expanding OPC product lines appropriate for the negative charge method, Fuji Electric also worked to develop positive charge type photoconductors able to realize high image quality with ease and to reduce the amount of ozone generated. The development of high mobility electron transport material was indispensable for realizing these photoconductors. Fuji Electric successfully synthesized proprietary materials, and in 1999 realized those products. The OPC layer configuration is shown in Fig. 7.

As is well known, the generation of ozone by positive charge-type OPCs is small, even when using a charging process based on corona discharge. Also, positive charge-type OPCs are able to provide high resolution since light absorption and charge generation occur at the photoconductor surface. Additionally, compared to a multilayer structure, because responsiveness and environmental performance are better, and because the coating process is simple, manufacturability is also better. These various characteristics will be fully applied to develop positive charge monolayer OPCs for monochrome printers, color printers and on-demand printers, to make improvements to achieve higher sensitivity, and to expand the range of applications to encompass high-speed devices.

### 4.2 Selenium photoconductors

Leveraging its wealth of experience with selenium materials technology, selenium refining technology, vacuum deposition technology and the like, Fuji Electric has constantly been the leader in this product sector, and has continued to meet customer needs. However, due to a drop in demand, Fuji Electric plans to cease production of selenium photoconductors and to withdraw from the selenium business in 2007.

### 4.3 Peripheral products

Based on electrophotographic process technology acquired over many years, Fuji Electric has developed, designed and even manufactured process units that integrate a charging part for which a photoconductor is the main component, a developing part and a cleaning part. In particular, the developing sleeve used in the developing part is being applied to both monochrome printers and color printers due to its advanced surface micro-processing technology and thin film coating technology enabled by element tube processing technology for photoconductors.

Most of these products are manufactured at the aforementioned Fuji Electric (ShenZhen) Co., Ltd. in China.

## 5. Conclusion

With the development of the Internet, applications of electrophotographic technology are increasing rapidly as the use of digital and color images becomes more widespread. Photoconductors are expected to provide sharper images, greater durability and so on, and their level of performance is continuing to increase. Fuji Electric intends to respond to these market requests, to take on the challenge of improving materials design, product development and production technology, and to develop attractive products for its customers.

### Reference

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# Material Technology for Organic Photoconductors

Yoichi Nakamura

## 1. Introduction

With advances in the digitization, coloration and network connectivity of photoconductor-equipped devices such as printers, copiers, facsimile machines, variable printing presses, and the like, more and more corporate and personal documents that contain higher densities and greater amounts of information are being handled.

These market trends request for photoconductors to provide higher sensitivity, higher responsiveness, higher resolution and higher stability, and to be smaller in size and have lower cost. In order to satisfy these requests, Fuji Electric is commercializing organic photoconductors having various characteristics.

This paper presents an overview and describes the characteristics of material technology and chemical technology, which are the fundamental to such organic photoconductors.

## 2. Organic Photoconductors

Organic photoconductors (OPCs) use the potential difference created on their photosensitive surface to form an image, and in principle, the polarity of the potential, whether positive or negative, makes no difference.

An OPC having an image forming potential that is positive is known as a positive charge OPC, and if negative, is known as a negative charge OPC. Figure 1 shows a negative charge multi-layer type OPC, and Fig. 2 shows the layer structure and operating principle of a positive charge mono-layer type OPC.

The negative charge multi-layer type OPC is fabricated by first forming an under coat layer (UCL) made of resin or the like on a conductive substrate such as an aluminum tube. Next, a charge generation layer (CGL) formed from charge generation material (CGM) and resin or the like is provided on top of the UCL, and then a charge transport layer (CTL) formed from a hole transport material (HTM), which is a type of charge transport material (CTM), and resin or the like is provided on the CGL to fabricate a photosensitive functional multi-layered structure.

The positive charge mono-layer type OPC is fabricated by first forming a UCL made of resin or the like on a conductive substrate such as an aluminum tube, and then forming a layer of CGM, HTM, and electron transport material (ETM), which is a type of CTM, to fabricate a photosensitive mono-layer structure.

Fig.1 Layer structure and operating principles of negative charge multi-layer type OPC

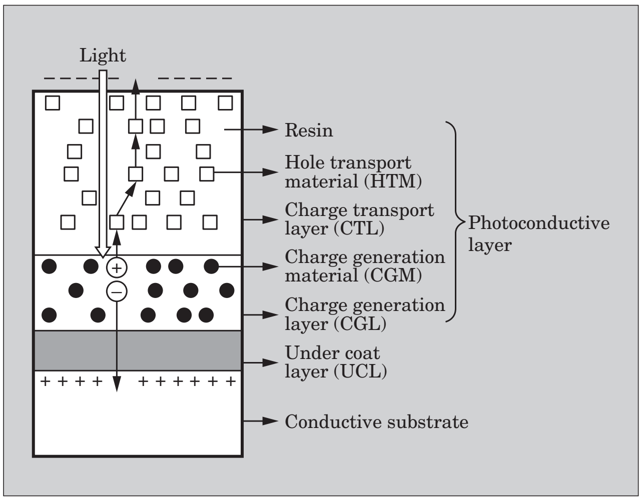
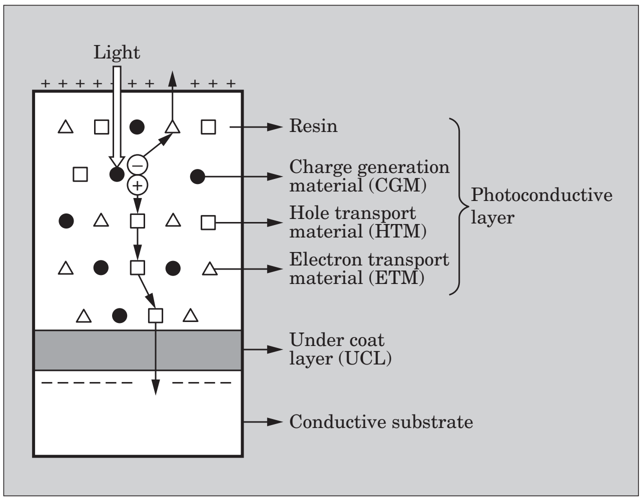



Fig.2 Layer structure and operating principles of positive charge mono-layer type OPC



When the surface of a photoconductive layer is charged and then exposed, both positive and negative charges are generated at the CGM. The positive charges travel in the HTM, and in the case of a negative charge type OPC, arrive at a photoconductive layer, while in the case of a positive charge type OPC, the positive charges pass through the UCL and arrive at the substrate. On the other hand, negative charges, in a negative charge type OPC, pass through the UCL and arrive at the substrate, while in a positive charge type OPC, the negative charges travel in the ETM and arrive at a photoconductive layer. Thus, charge on a photosensitive surface is neutralized, and the potential difference with surrounding areas causes an electrostatic latent image to be formed. Then, visualization of the latent image by the toner (colored resin ink powder) and the transfer, heating, melting and fixing of the toner to paper complete the printing process.

## 3. Material Technology and Chemical Technology

### 3.1 OPC materials

Table 1 lists the main materials used in an OPC. Functional materials of the UCL, CGM, HTM, ETM and the like consist of film formation material, such as various resins, and high-performance additives.

For OPCs to be widely accepted into the marketplace, the performance of each material, i.e., functional material, film formation material, additives, etc., must be designed for optimal balance. This is one of the complex aspects of OPC material technology, and Fuji Electric provides materials with market-leading new performance capabilities by applying its proprietary materials technology to meet market needs.

### 3.2 Molecular design technology

Figure 3 shows an example of the process flow in obtaining a molecular design. OPC material is designed on a molecular level using chemical technology, and in the past, this design work was based largely on prior experience and on a trial and error approach, but there is a need for greater efficiency in order to match the rate of technical innovation in the information technology industry.

Computer-based molecular design technology is becoming feasible for use in practical applications due to improved computational algorithms and high-speed computers.

Fuji Electric is installing molecular design systems, and is configuring proprietary hardware suitable for OPC materials, improving software, and analyzing data to establish computer-based molecular design technology.

Figure 4 shows an example of a molecular orbital of the OPC material. By determining the molecular structure based on computations and consideration of the OPC performance, chemical reactivity during syn-

Table 1 Example of OPC materials

| Layer | | Constituent material | |
|---|---|---|---|
| Photoconductive layer | Charge transport layer (CTL) | Hole transport material (HTM) | Arylamine, pyrazoline, hydrazone, stilbene, benzidine, etc. |
| | | Electron transport material (ETM) | Azoquinone, etc. |
| | | Film formation material | Polycarbonate, polyester, etc. |
| | | Additive | Photosensitivity enhancing material, film formation ancillary material, coating solution anti-aging material, etc. |
| | Charge generation layer (CGL) | Charge generation material (CGM) | Phthalocyanine, azo, etc. |
| | | Film formation material | Polyvinylacetate, polyketal, etc. |
| | | Additive | Photosensitivity enhancing material, film formation ancillary material, coating solution anti-aging material, etc. |
| Under coat layer (UCL) | | Conductive material | Metal oxide, etc. |
| | | Film formation material | Polyamide, polyester, melamine, etc. |
| | | Additive | Photosensitivity enhancing material, film formation ancillary material, coating solution anti-aging material, etc. |

Fig.3 Example of molecular design process flow

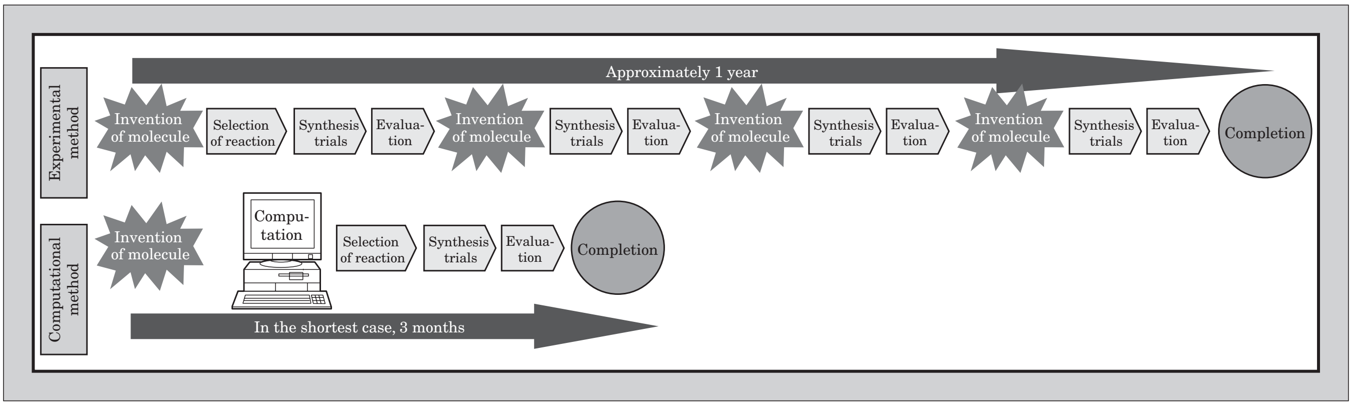
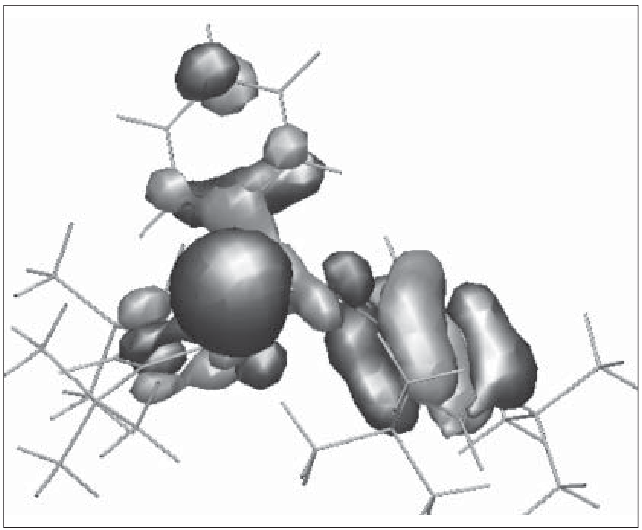


Fig.4 Example molecular orbital of OPC material



thesis, cost of raw materials and so on, the compound can be completed within 3 months of conception and realize the intended design performance.

### 3.3 Synthesis technology

(1) Synthesis reaction technology

Molecularly-designed OPC material is synthesized by chemical technology, and a high purity, high yield reaction must be selected as the synthesis reaction.

In recent years, synthesis route design technology such as retrosynthesis[1] and innovative high reactivity, high purity and high yield reactions such as Suzuki reactions[2] have advanced and are being utilized in accordance with the intended objective.

(2) Process control technology

For the process control during synthesis, it is necessary to change one's viewpoint from that of material synthesis for chemical-use to that of material synthesis for electronics-use.

Table 2 lists an example of temperature control during a synthesis reaction. For a set value, under the conditions of a temperature allowance of ±0.5°C while the reaction is stable, an OPC material having its intended performance was not synthesized, but under the same conditions with a ±0.1°C temperature allowance, material having the intended performance was obtained with a high yield.

Fuji Electric utilizes plant technology and process control technology, and precise synthesis reaction control as used by electrical machinery manufacturers, to manufacture high purity and high yield OPC material.

### 3.4 Purification technology

Table 3 lists an example of purification technology. Purification technology is an important technology for realizing the OPC performance.

Fuji Electric uses individual purification technologies such as recrystallization, column, distillation, and sublimation according to the intended objective, and pays attention to water and air quality, including the clean room and plant location conditions, to maintain quality.

Table 2 Example of process control technology

| OPC material | Temperature control item | Control temperature | Yield (%) |
|---|---|---|---|
| A | Overshoot | Over 1.0°C | 0 |
| | | 0.5°C | 12 |
| | | 0.1°C | 95 |
| | Undershoot | Under 0.1°C | 91 |
| | | 0.5°C | 43 |
| | | 1.0°C | 24 |
| B | Stable temperature | Allowance ±0.5°C<br>±0.1°C | 0<br>94 |

Table 3 Example of purification technology

| Purification principle | Purification method |
|---|---|
| Solubility | Recrystallization, etc. |
| Distribution of absorption and release | Charcoal absorption, alumina absorption, silica gel absorption, zeolite absorption, column chromatography, etc. |
| Boiling point | Distillation at normal pressure, vacuum distillation |
| Sublimation point | Vacuum sublimation, etc. |

Table 4 Example of material inspection technology

| Inspection-related technology | Inspection method |
|---|---|
| Separation technology | High performance liquid chromatography, ion chromatography, gel permeation chromatography, etc. |
| Optical analysis technology | Infrared absorption spectrum, UV-VIS absorption spectrum, X-ray diffraction spectrum, atomic absorption spectrum, laser diffusion particle spectrum, etc. |
| Thermal analysis technology | Melting point, differential scanning calorimetric spectrum, etc. |
| Mass analysis technology | Mass spectrum, etc. |
| Other | Various semiconductor characteristics, various photoconductor characteristics, etc. |

### 3.5 Material inspection technology

Table 4 shows an example of material inspection technology. Various technologies, such as chromatography analysis technology, optical analysis technology, thermal analysis technology, mass analysis technology, and the like are used according to the objective.

### 3.6 Coating liquid technology

Table 5 lists an example of a coating solution technology, which is an anti-aging technology. The coating solution is in an environment that is extremely susceptible to aging due to the inclusion of and exposure to dust, aluminum filings, coating film filings, moisture, oxygen and the like.

Table 5 Example of anti-aging technology

| Hole transport agent (HTM) | Aging-suppressing additive for coating solution | Residual voltage change (V) during retention period | | | |
|---|---|---|---|---|---|
| | | Initial | After 1 week | After 1 month | After 1 year |
| C | None | 10 | 55 | 127 | 136 |
| | D | 10 | 11 | 10 | 11 |
| E | None | 10 | 39 | 61 | 85 |
| | D | 10 | 21 | 44 | 52 |
| | F | 10 | 11 | 11 | 10 |

* The residual potential is a type of photoconductor characteristic, and preferably does not increase with time.

Table 6 System for verifying safety

| Verification phase | Verifying entity | Verification method |
|---|---|---|
| Molecular design | Fuji Electric | Exclusion of known dangerous molecular structures |
| Synthesis design | Fuji Electric | Verification of raw material contaminants, by-products, etc. |
| Coating solution design | Third party | Ames test, acute toxicity, etc. |
| Photoconductor design | Third party | Test method conforming to laws of the destination country |

With the development of an aging-suppressing additive for the coating solution, Fuji Electric is able to select a wide range of suitable materials to suppress aging of OPC material that has been coated with the coating solution. As a result, the OPC realizes enhanced performance and stabilized quality, and the coating solution is environment-friendly with extremely small scrap loss.

### 3.7 Safety technology

Table 6 shows the system for verifying safety. Safety verification is essential for new OPC material, and according to the laws of the destination country and Fuji Electric's regulations, safety is verified by third parties at key development sites. Safety verification testing must fully satisfy all criteria of the destination country.

## 4. Conclusion

Fuji Electric leverages its proprietary materials technology and chemical technology to develop and produce OPC materials, and then to supply those materials as OPC products.

These OPC materials are being developed and produced using computer-based molecular design technology and materials technology, and by collectively using the plant technology, process control technology and other chemical technology of affiliated and partner companies.

To improve the overall performance of OPC materials in the future and, in particular, to contribute to making OPC-equipped devices become maintenance-free, OPC performance tolerances are being reduced and stability is being improved.

Through leveraging these materials and chemical technologies, and expanding their range of use, Fuji Electric intends to continue to contribute to society by supplying OPC products capable of stably reproducing large amounts of color and high-resolution information.

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(1) Corey, E. J. ; Cheng, X.-M. The Logic of Chemical Synthesis, Wiley, New York. 1995, (ISBN0-47111-594-0).

(2) Suzuki, A. ; Brown, H. C. Organic Syntheses via Boranes.Volume 3 Suzuki Coupling, Aldrich Chemical Co., 2003, 314p. (ISBN0-97084-419-0).

# 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.

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

Fig.1 Layer structure of negatively charged OPC

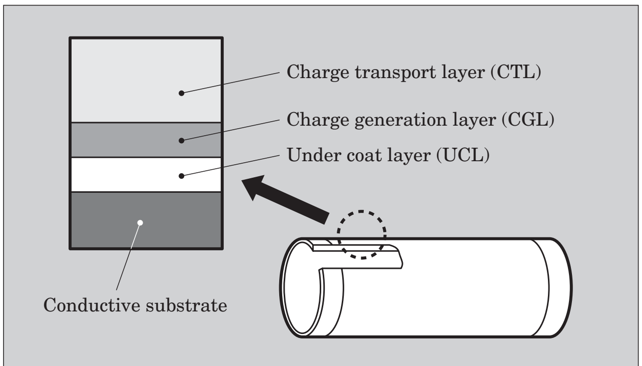
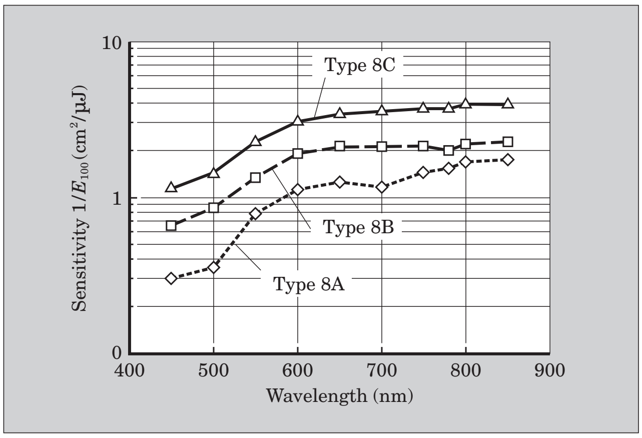



Table 1 Product summary

| 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

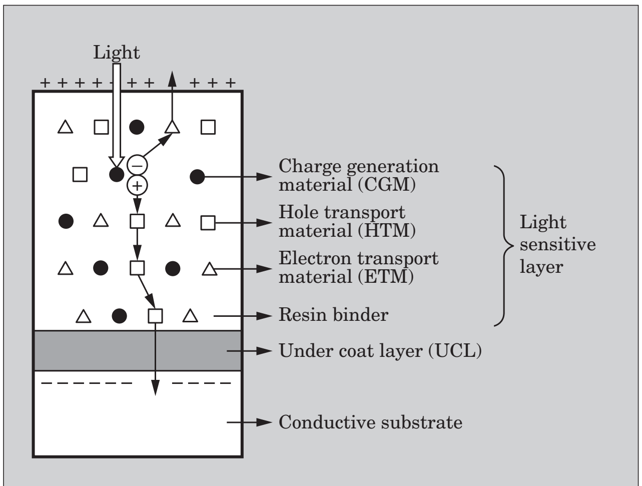



Fig.4 Spectral sensitivity of positively charged OPC

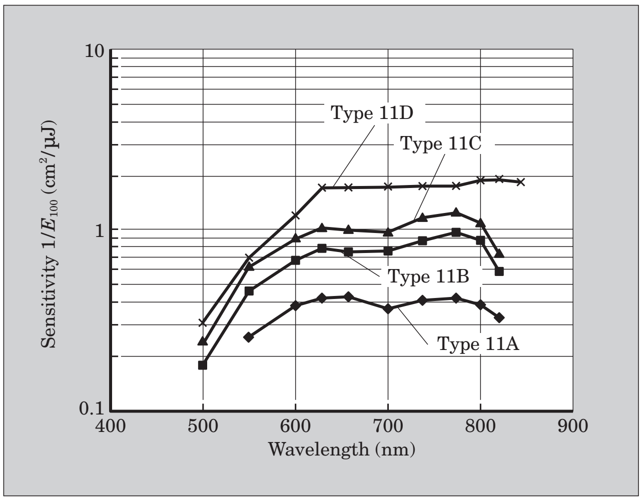


Fig.5 Photo-induced discharge characteristic (PIDC) of positively charged OPC

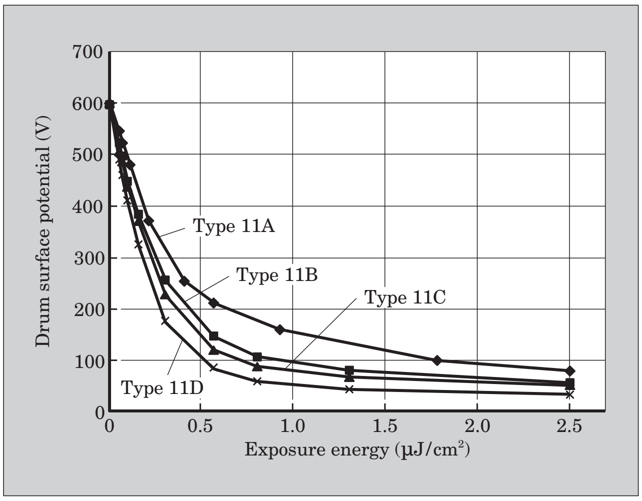



Fig.6 Required OPC performance and technical challenges

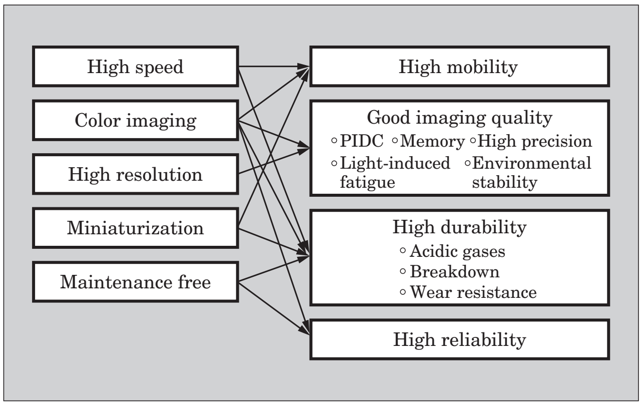
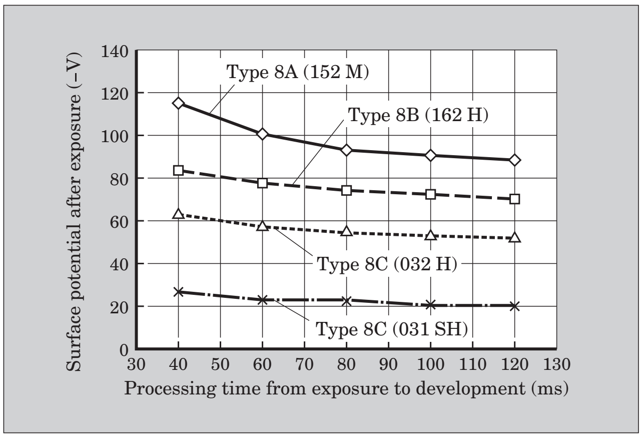



Table 3 Relationship between type 11D characteristics and materials

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

Fig.7 Photo response of negatively charged OPCs




## 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 $2 \times 10^{-5}\,cm^2/V{\cdot}s$. Additionally, to support even high speeds in the future, Fuji is completing development of materials having high mobility of $8 \times 10^{-5}\,cm^2/V{\cdot}s$.

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.

### 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

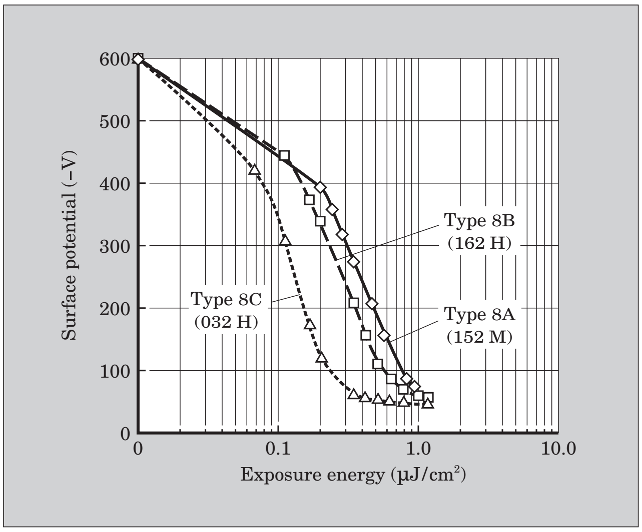
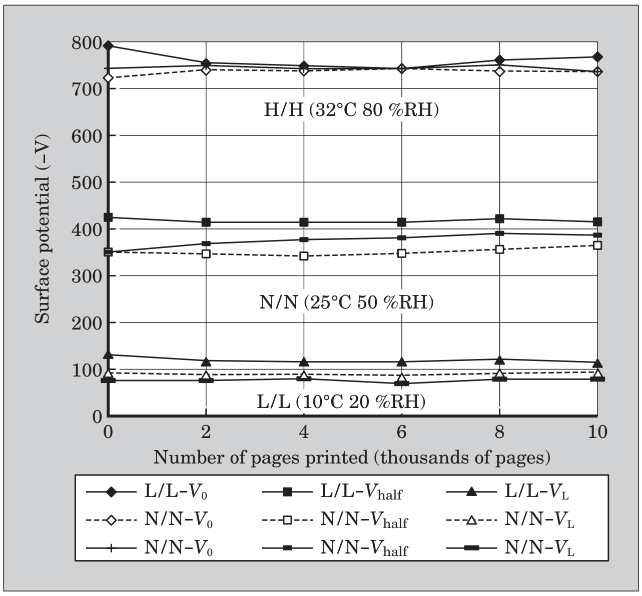



Fig.9 Negatively charged OPC's potential stability during environmental life test




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

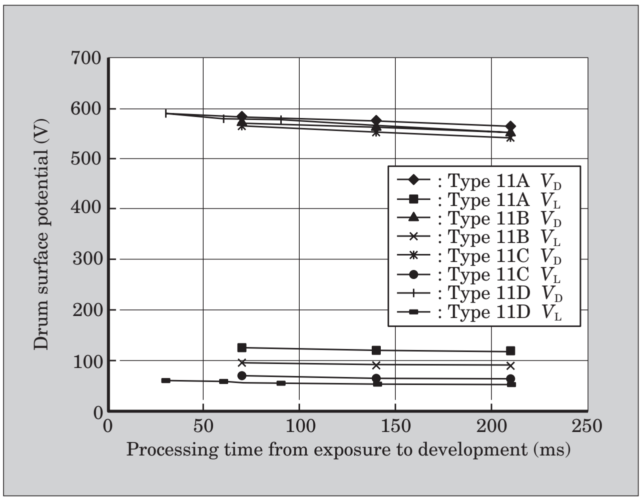



Fig.11 Environmental dependence of positively charged OPC's light area voltage ($V_L$) and dark area voltage ($V_D$)

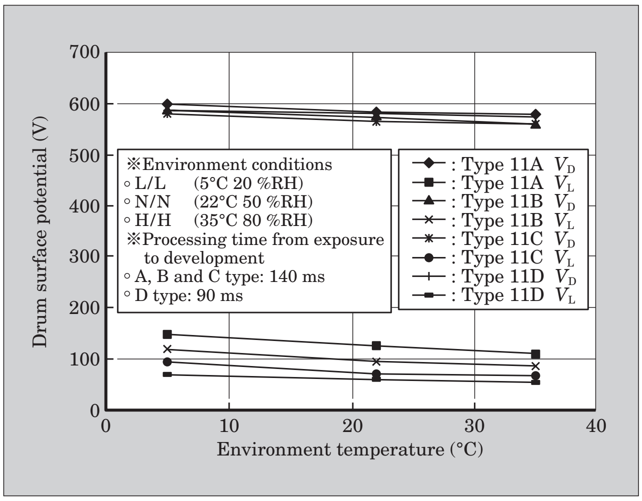


Table 4 Variation in characteristics due to environmental testing of positively charged OPCs

| 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.

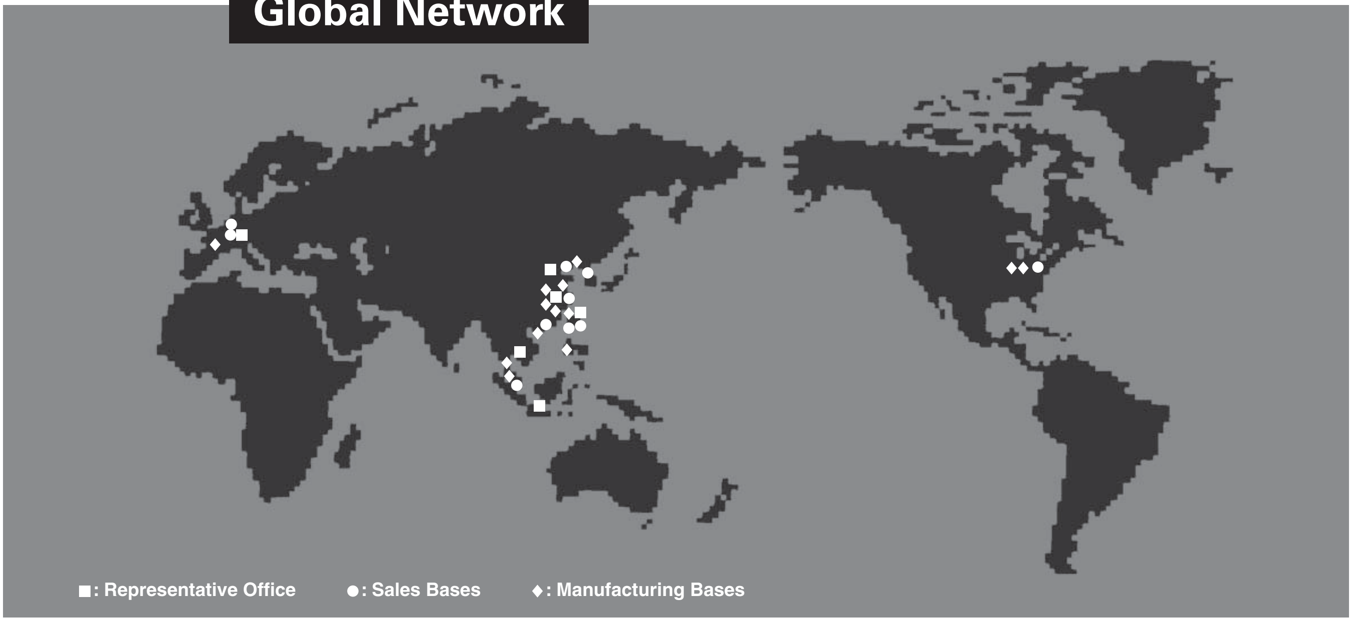
## 5. Conclusion

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.

# Business Outline of the Each Operating Company

| Company | Business Outline |
|---|---|
| Fuji Electric Systems | Fuji Electric Systems strives to inject new value into social infrastructure by offering industry-leading products and services in the industrial, public sector, energy, and transport fields. As a solutions provider in the areas of information, the environment, energy and services, Fuji Electric Systems works hand in hand with customers to make their businesses a success. |
| Fuji Electric FA Components & Systems | Fuji Electric FA Components & Systems supplies a range of components, as well as small and medium-sized systems using these components, to customers in the industrial automation field. The company's extensive array of products, which demonstrate world-leading levels of quality and performance, include electrical distribution control, drive, power electronics, motion, and human-machine interface (HMI) components and devices. Underpinned by this product portfolio and a lineup of related services, the company is working to create new value for customers. |
| Fuji Electric Device Technology | Leveraging its core competence —technological expertise— Fuji Electric Device Technology offers high-quality, high value-added products in the semiconductor, storage and imaging device fields. The company's ultimate goal is to create a range of world-leading products that satisfy customer needs for high-performance, compact and energy-efficient products in the industrial, automobile and information device fields. |
| Fuji Electric Retail Systems | Focusing on three core businesses: vending machines, where Fuji Electric has the leading share in the domestic market, cold-chain equipment, and coin & currency systems, Fuji Electric Retail Systems is working to support society through the creation of innovative and convenient retail spaces. The company also strives for maximum customer satisfaction by offering new solutions and services that enhance vending machine operations and store management efficiency in many areas of the retail sector. |

# Global Network

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