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FUJI ELECTRIC REVIEW

3

2002 VOL.48

Magnetic Hard Disks
Photoconductors

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The difference in image quality is due to the difference in photoconductors. Fuji Electric provides a wide range of photoconductors for clearer images.

e-Front runners

Photoconductors for use in printers

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The need for clearer imaging continues to increase for copy machines, facsimile machines, printers and other information devices. Demands are also increasing for the application of advanced technology to photoconductors, the quality of which determines image quality. Fuji Electric has a track record of achieving higher resolutions, faster response speeds and technological innovation. We offer a varied product line of photoconductors for copy machine and facsimile applications and photoconductors for printer applications. From a fully automated integrated production line that incorporates the latest FA technology and 3 global manufacturing bases in Japan, US and China that are under strict quality control, Fuji Electric is able to provide reliable products speedily and with a full range of services.

Fuji Electric Photoconductors

Automated inspection equipment

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Cover photo:

The hard disk drive (HDD) has become an essential component of the modern personal computer. The increasing data storage capacity of HDDs and their utilization in networking and AV (audio-visual) information systems are expected to lead to the development of new markets.

Through the latest technological development, Fuji Electric will continue to provide magnetic hard disks with a leading-edge performance, as critical components in the constantly evolving HDD.

The cover photo depicts the bright future for HDDs and shows the constantly evolving magnetic hard disks in combination with various AV products into which HDDs are expected to be installed in the future.

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Present Status and Future Prospects for Magnetic Hard Disks

Nobuyuki Takahashi
Akihiro Otsuki
Tomonobu Ogasawara

1. Introduction

In the early 1980s, when computer use transitioned from main frame computers used in offices to so-called personal computers for private business and applications, hard disk drives (HDDs) as external storage devices achieved a crucial technological breakthrough. Under these circumstances, Fuji Electric succeeded in commercializing thin film magnetic hard disk processed with a sputtering method, and has been successively introducing new products at appropriate times as the recording density of HDDs has been increasing.

In recent years, recording densities have been increasing at an annual rate of 100 %. As a result, the per-bit cost of hard disk has dropped dramatically and has become lower than that of paper recording media. HDDs, also having a high level of processing capability, are expected to extend their applications to fields other than personal computers.

This paper describes the technological trends that support the future expansion of the market for HDDs, and outlines the present status and future prospects of Fuji Electric's technology for magnetic hard disk.

2. Trends in Market and Technology for HDDs

Due to their drastic reduction in per-bit cost, as well as their high capacity and high access rate, HDDs are expected to dominate such new fields as consumer electronics and IT (information technology) through outperforming other storage systems.

Reflecting the continuously increasing recording densities, Fig. 1 shows the trend of HDDs' recording densities as demonstrated by research institutes throughout the world, one or two years ahead of commercialization.

In 2001, HDDs equipped with 30 Gbits/in^2 (40 Gbytes/platter, 95 mm in size) magnetic hard disk developed by Fuji Electric were commercialized. In addition, Fujitsu Ltd. and Seagate Technology successfully demonstrated 100 Gbits/in^2 magnetic hard disk. In 2002, various companies are promoting their development of commercial 60 Gbits/in^2-class HDDs.

The technological development of magnetic heads and magnetic hard disk is crucial for realizing such sophisticated HDDs as mentioned above. Technological challenges facing the development of magnetic hard disk, in which Fuji Electric specializes, are classified into the following:

○ Magnetic characteristics of thermal stability and reduced media noise
○ HDI (head-disk interface) characteristics of low-flying stability and high reliability (high durability and high environmental resistance)

Figure 2 shows a schematic representation of the

Fig.1 Annual trend in recording densities

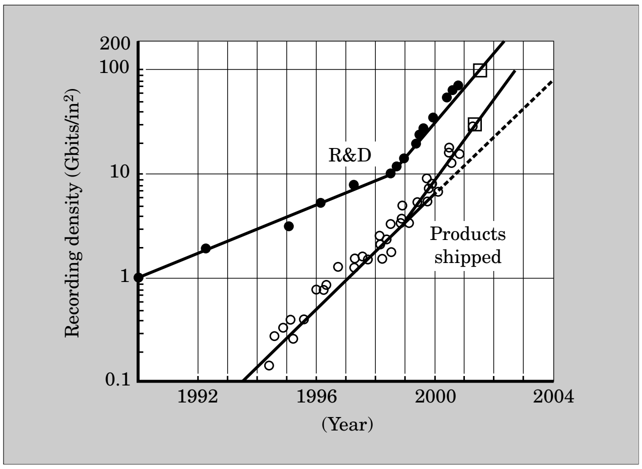
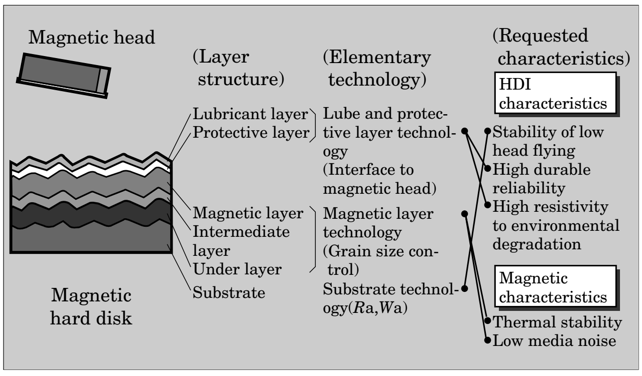


Fig.2 Relationship between elementary technologies and requested characteristics for magnetic hard disk



intricate relationship between elementary technologies and requested characteristics for magnetic hard disk.

The next chapter outlines the progress of these individual elementary technologies.

3. Present Status of Fuji Electric's Technology for Magnetic Hard Disk

3.1 Substrate technology

The performance of currently-used aluminum substrates directly affects the low-flying stability of magnetic heads, which is a primary technology that supports higher recording densities, and plays an important role in reducing physical defects of small recording bits.

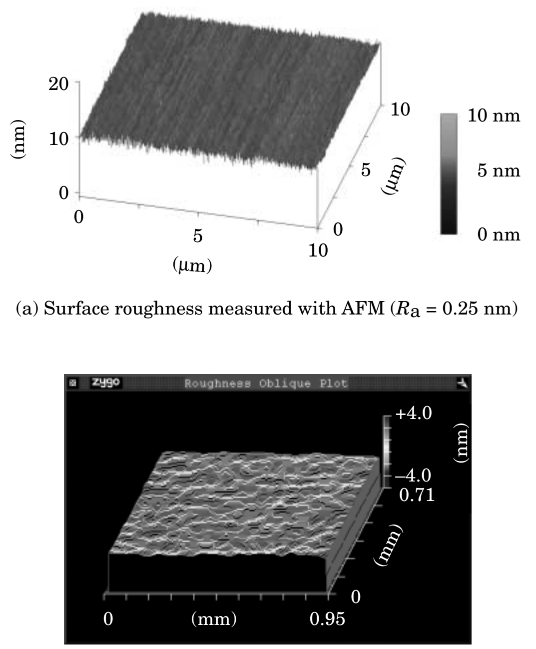
The physical parameters that determine the low-flying stability of magnetic heads are micro-waviness (W_a) and surface roughness (R_a). Reducing W_a requires applying an improved grinding technique to the polished substrates, forming NiP plated film with improved thermal deformation resistance, and applying a highly precise polishing technique. The subsequent texture process greatly affects R_a.

The optimization of processes for the above-mentioned requirements allowed surface properties (R_a = 0.25 nm, W_a = 0.15 nm) as shown in Fig. 3 to be obtained. As a result, the glide avalanche property shown in Fig. 4 was obtained and this almost achieved the low-flying stability required for the 60 Gbits/in^2 magnetic hard disk currently under development.

In order to prevent the depletion of recording bits, tolerance for the size of surface defectives is continuously decreasing. The reduction of defects is essential for higher reliability when magnetic disk media are installed in HDDs, as well as for high yields in the media manufacturing processes. When mass production of 30 Gbits/in^2 recording media started in 2001, Fuji Electric reviewed items to be improved and is promoting the advancement of the following:

○ Reduction of micro pits and scratches during the substrate polishing process
○ Reduction of scratches during texture processing and of micro-contamination during washing

Fig.3 Surface properties of magnetic hard disk



(a) Surface roughness measured with AFM (R_a = 0.25 nm)

(b) Surface micro waviness measured with Zygo (W_a = 0.15 nm)

3.2 Magnetic film technology

To realize high recording density, the extent to which stable recording bits can be made finer is of primary importance. Magnetic films for recording have gone through several changes since the adoption of thin films processed with a sputtering method, and will undergo further change as they are optimized for use in combination with magnetic read/write heads. In the future, it will be important to design magnetic films that correspond with the development of magnetic heads.

This paper introduces a road map for the future development of magnetic films.

The crux of the development of magnetic films for longitudinal recording is to achieve an appropriate balance (tradeoff) between reduced media noise and thermal stability (smaller thermal decay). In addition, the limited writability of magnetic heads keeps the coercivity of magnetic media moderate, particularly in a dynamic range. To be specific, low media noise is realized with magnetically decoupled crystal grains and finer grains in a magnetic recording layer, and through additional measures to secure thermal stability. The importance of thermal stability was recognized during the process of realizing 30 Gbits/in^2 magnetic hard disk, and requires further improvement. This is the reason for interest in the AFC (anti-ferromagnetic coupling) structure[1][2], which was developed in GMR (giant magnetoresistive) elements and is expected to be applied to magnetic disk media. Figure 5 shows the road map for development of magnetic films. As shown in Fig. 5, overlapping the development of conventional-structure 60 Gbits/in^2 longitudinal-recording,

Fig.4 Improvement of glide avalanche properties

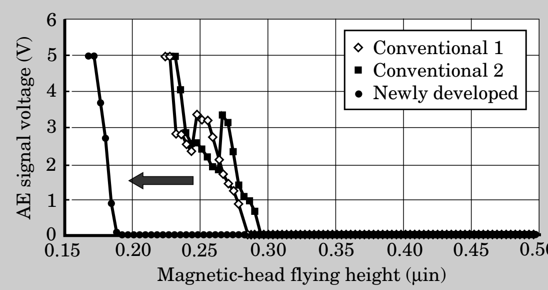


Fig.5 Road map for magnetic film development

Recording density	30 Gbits/in^2	→ 60 Gbits/in^2	→ 120 Gbits/in^2	→ 240 Gbits/in^2
Type of recording layer	<Longitudinal recording> Conventional structure	AFC (anti-ferromagnetic coupling) stucture	<Perpendicular recording> CoCr alloy system	Multi layered film system, hybrid film system
Grain size	8 to 9 nm	→ 7 to 9 nm	→ 5 to 6 nm	→ 4.5 to 5 nm
Coercivity	295 kA/m	→ 334 kA/m	→ 478 kA/m	→ 637 kA/m
Magnetic layer	CCPB system	→ CCPB/AFC	→ CCPB/soft under layer	→ (Co/M)*n*/soft under layer

100 Gbits/in^2 perpendicular-recording is being investigated.

3.3 Lube and protective film technology

In magnetic recording, it is important to minimize clearance between the magnetic recording layer and the magnetic head element, to make the media surface smoother as described in the substrate technology section, and to make the lube and protective film thinner to the extent possible.

Future development, however, faces increasingly difficult challenges for securing flying stability, overcoming interaction between the magnetic head and magnetic disk in an extremely low flying state, for ensuring the required durability in the case that a magnetic head contacts a magnetic disk, and for ensuring corrosion resistance of the magnetic layer, which may be required because the film is very thin.

Figure 6 shows the road map for development of lube and protection films.

Since having established CVD technology for 5nm-thick protective films in 30 Gbits/in^2 magnetic disks, Fuji Electric is developing thinner protective films and expects to be able to realize durable and corrosion resistant 2.5 nm-thick films, through securing further thickness uniformity and higher film hardening. In addition, Fuji Electric is investigating the feasibility of FCA (filtered cathodic arc) films through using a new deposition method, to fabricate extremely thin films in the future.

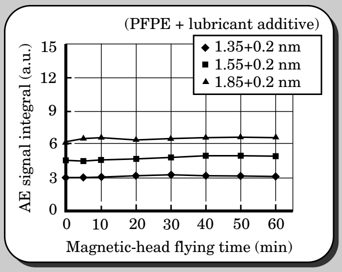
Fuji Electric is promoting the optimization of lubricant films according to individual HDDs designs. The basic concept for achieving flying stability of a magnetic head lies in forming the lubricant film as thinly as possible on the protective film with surface resistivity controlled by a Fuji Electric proprietary treatment. A thin lubricant film can more easily be designed by adopting a lump load system in place of the previous CSS (contact start stop) system.

In high-rpm HDDs for server applications, self-recovering capability of the lubricant essential for durability and prevention of lubricant depletion caused by spin-off must be balanced in the design of a bonding lubricant. On the other hand, lower flying height of a

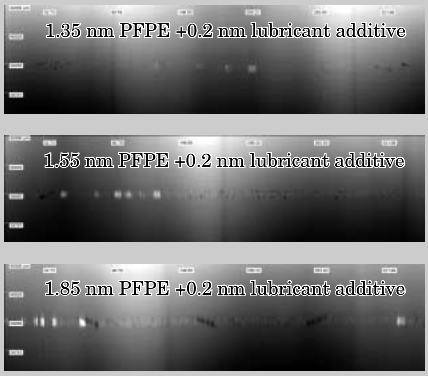
Fig.6 Road map for development of lube and protective film

Recording density	30 Gbits/in^2	→ 60 Gbits/in^2	→ 120 Gbits/in^2	→ 240 Gbits/in^2
Glide avalanche	6 nm	→ 5 nm	→ 4.5 nm	→ < 4 nm (near contact)
Protective film	<CVD> Surface chemical modification 5 nm	→ 2.5 to 3 nm	→ 2 nm	→ < 2 nm (FCA)
Lubricant film	<PFPE> Improvement of molecular weight distribution	→ Mixture system with additive → Design control of molecular weight		→ New lubrication system → Control of molecular structure

Fig.7 Evaluation of magnetic-head flying stability with an AE sensor



(a) Lubricant-thickness-dependence of magnetic-head flying stability



(b) Observation of lubricant thickness change with OSA

magnetic head can lead to increased self vibration (instability) of the head itself. This phenomenon is a key factor for magnetic head reliability because it can increase the risk of accidental trouble in actual severe environments. A Fuji Electric study shows that such trouble is related to various properties on the media surface such as micro–surface-waviness and lubricant thickness. Figure 7 shows an evaluation of magnetic-head flying stability with an AE (acoustic emission) sensor.

According to measurement with an AE sensor, magnetic-head flying stability becomes worse with increasing lubricant thickness. In addition, moguls are formed on the lubricant surface, and in other words the surface becomes bumpy. A key factor in the future development of lubricant is to prevent moguls from being formed.

Based on these conditions, Fuji Electric has developed a proprietary lubricant refining technology SFE (supercritical fluid extraction) to perform detailed molecular weight design according to individual HDD development programs. In addition, based on this technology, Fuji Electric is promoting the study of near-contact-recording and contact-recording systems in their basic research stages.

4. Prospects of Future Technology

As described above, the increase of recording density and cost reduction of recording media are creating new markets for HDDs.

Along this trend, Fuji Electric has been applying its originality to find answers to unsolved issues and to promote developments in new fields for recording media. This paper introduces some new technologies that show potential for success.

4.1 Glass substrate media

With their characteristic advantages of high impact resistance and TMR (track miss registration) resistance, glass substrates are widely used in portable- and server-PCs. Magnetic films formed on glass substrates exhibit, however, isotropic magnetism because of the isotropic surface property of glass substrates. Their magnetic parametric performance is therefore inferior to that of oriented magnetic films formed with Al-substrate media. As a result, future demand will be strong for oriented magnetic films on glass substrates. Although there exists a process to secure oriented magnetism through forming NiP and then performing the same texturing as Al substrates on glass substrates, this process impairs the advantageous characteristics of glass substrates and increases the cost.

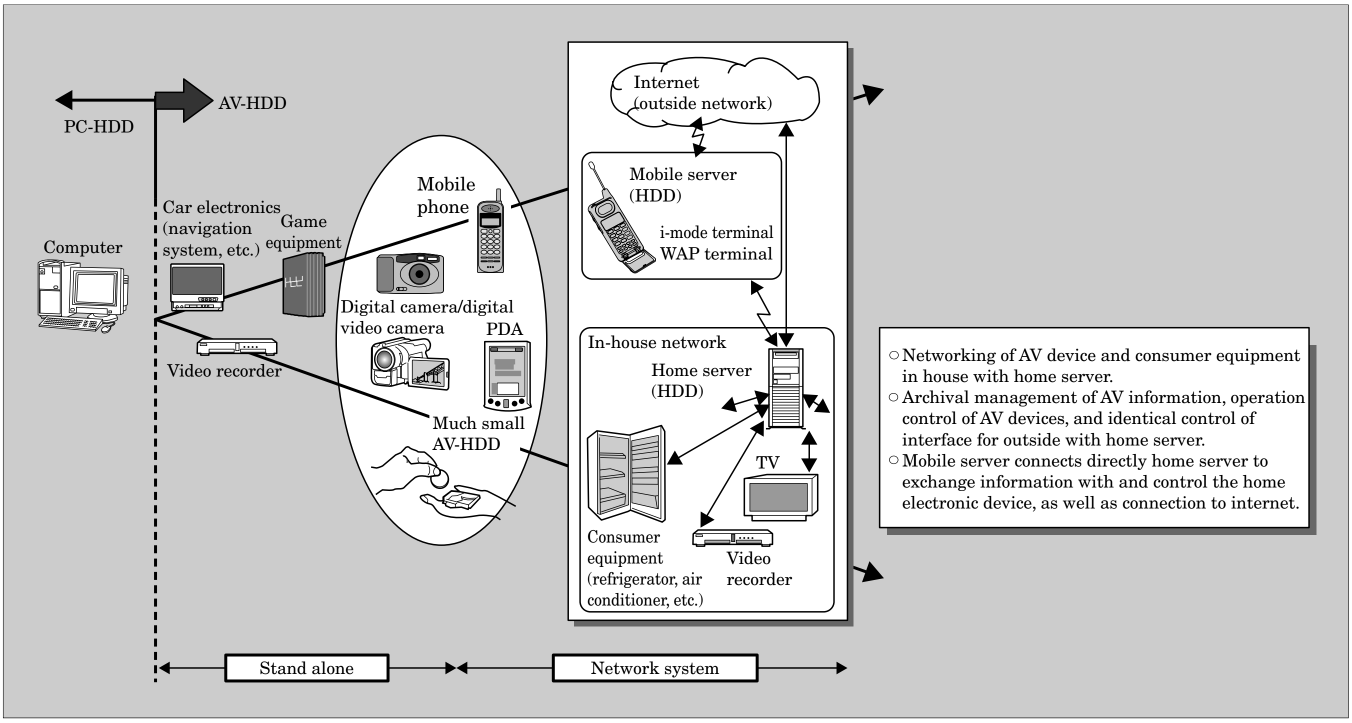
Fuji Electric, having developed a repeatable process to form the same texture lines on glass substrates as on Al-substrates and an original seed layer deposition processes in a vacuum, has optimized the combination of these processes to achieve magnetic-head flying and magnetic parametric performances that compare favorably with Al-substrate magnetic media.

In the future, with its high impact resistance, the newly-developed glass-substrate magnetic media are expected to be used for various mobile HDD applications in addition to PC applications, while smaller size magnetic media are pursued.

4.2 Perpendicular recording media

In recent years, applied research for perpendicular-recording media is increasingly being encouraged because the balance among low media noise, thermal stability and magnetic head writability can be destroyed in higher-density longitudinal recording media. In the future, attention will be given to the feasibility of perpendicular recording media with densities greater than 100 Gbits/in^2. Whether or not any one of the various media layer structures under development is finally chosen depends on technological breakthroughs as well as productivity. Fuji Electric is investigating every possible development and application related to perpendicular recording media. It is also promoting the development of longitudinal and perpendicular recording films simultaneously as shown in the roadmap, through setting the demonstration of 100 Gbits/in^2 magnetic recording films as a first goal. As digital

Fig.8 Usage development of AV-HDD



information technology spreads from PCs to AV (audio-visual) systems, larger-capacity memory will be required, which leads to high hopes for perpendicular recording media and prompts their development and use.

4.3 Magnetic printing media

After magnetic hard disk has been incorporated into an HDD, servo information must be written on the media to control the magnetic head to realize appropriate write and read properties. As recording densities increase, servo writing requires updating of the servo writer and longer times for the servo writing process, resulting in higher cost. With the cooperation of an HDD manufacturer, Fuji Electric has recently established a process for writing pre-servo information through the use of a contact system, and was the first company in the world to realize mass production of 15 Gbits/in^2- and 30 Gbits/in^2-recording media with installed pre-servo information. This technology can be applied to higher-density recording media in the future. It was demonstrated that the servo printing system could effectively be applied to perpendicular recording media. In addition, the servo printing system is expected to be widely applied to HDDs for AV applications as a potential means to write security information to disk media, for which PC development has given little consideration in the past.

Figure 8 shows the development of AV-HDD applications in the future. The technologies described in this chapter will provide specific solutions for issues important to market development, such as low cost, large capacity and security.

5. Conclusion

This paper outlined achievements of Fuji Electric's technological developments and the present status of magnetic hard disk. Technological development to maintain the annual 100 % increase in recording density of recent years is becoming more difficult year after year. Nevertheless, it is expected that 60 Gbits/in^2 hard disk will probably be realized in 2002 through the combined efforts of the concerned parties.

Fuji Electric is determined to lead this technological development and to contribute to the HDD industry in cooperation with other companies as in the case of 30 Gbits/in^2 hard disk. We hope such efforts lead to the expansion of the HDD market.

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Magnetic Layers for Perpendicular Recording Media

Hiroyuki Uwazumi
Yasushi Sakai
Shunji Takenoiri

1. Introduction

Hard disk drives (HDDs) are recently being incorporated into video recorders, car navigation devices, family game machines, etc., as devices (AV-HDDs) to store digital AV (audio-visual) information such as movies and television programs. Because the AV-HDD has the features of large capacity, high speed and low cost, it is suitable for long-time recording, high-speed random access and multi-channel simultaneous recording and playback. The demand for AV-HDDs is anticipated to increase rapidly in the near future. In response to demands from this new market growing at a rate of 100 % per year, it is necessary to further increase the recording density, which is now at a level of 30 Gbits/in^2 in mass production.

Present HDDs utilize a longitudinal magnetic recording system in which the recorded magnetization is aligned in the film plane. If we increase the recording density of this system, the recorded magnetization becomes unstable due to the thermal energy at room temperature, thus creating the problem of thermal agitation of magnetization. Recently, a new recording system suitable for ultra-high density recording, i.e. a perpendicular magnetic recording system[(1)], has been attracting considerable attention, and this new system provides greater stability of the recorded magnetization as the recording density increases.

Figure 1 is a schematic drawing showing the general layer structures and recorded magnetization for perpendicular magnetic recording media. Successive layers are stacked on the substrate in the order of soft magnetic underlayer, non-magnetic interlayer and magnetic recording layer for the storage. Because the recorded magnetization is aligned vertically, as opposed to longitudinally, the film structure and magnetic properties are quite different from those of the longitudinal magnetic recording media. To realize perpendicular magnetic recording media, it is essential to redevelop and redesign the film structure, thin film material and processing techniques.

Of this group, the development of a high performance magnetic recording layer that retains the recorded magnetization is most important. Figure 2 shows several materials that may be used as the thin film material for magnetic recording layer such as CoCrPt alloy film, Co/X multilayer, amorphous film and FePt ordered lattice alloy film, depending on the applicable areal recording density. These materials each have their own characteristic microstructure, physical properties and, particularly, perpendicular magnetic anisotropy energy K_u. The material most suitable for the areal recoding density to be applied must be selected for the development of the magnetic recording layer.

From early on, Fuji Electric started the development of perpendicular magnetic recording media to realize the next generation ultra-high density recording media and also initiated active joint research with

Fig.1 Layer structures and schematic drawing of the recorded magnetization for perpendicular recording media

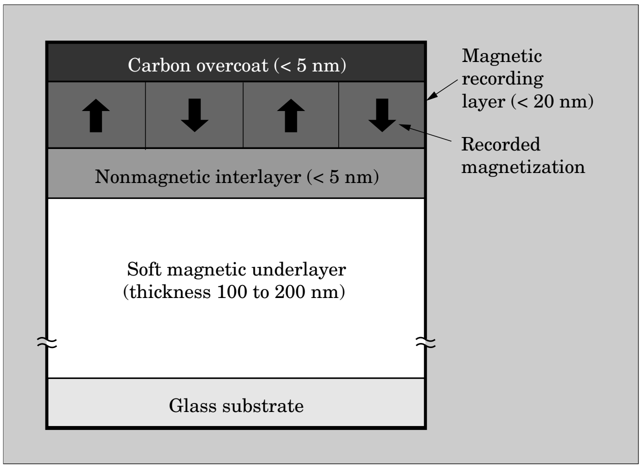
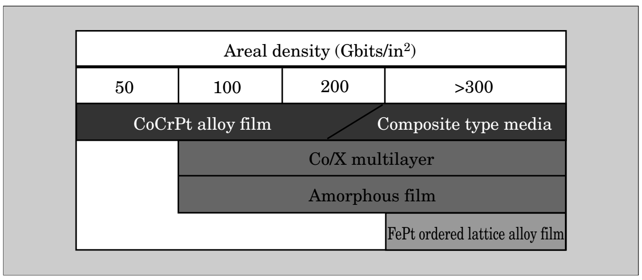


Fig.2 Materials for the perpendicular magnetic recording layer



the Research Institute of Electrical Communication of Tohoku University and the Science & Technical Research Laboratories of NHK.[2][3] In addition to the development of CoCrPt alloy thin film and Co/Pd multilayer with 100 to 200 Gbits/in^2, which are the immediate objectives, we are developing amorphous film which might be applicable to the ultra-high density recording media suitable for densities in excess of 300 Gbits/in^2.

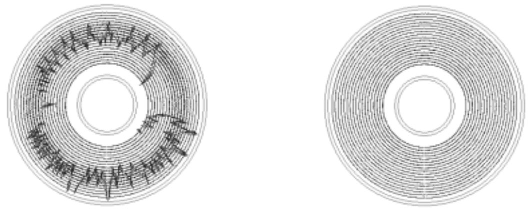
In this paper, we will introduce recent results of the research by Fuji Electric on high recording density technology, magnetic domain control of the soft magnetic underlayer and an evaluation technique for the media, which are essential technologies for the realization of perpendicular magnetic recording media.

2. Magnetic Domain Control of the Soft Magnetic Underlayer

The soft magnetic underlayer functions to raise the strength of the writing field of the recording head and the field gradient applied to the magnetic recording layer, and to improve the recording resolution[4]. However, the soft magnetic film is liable to have a complicated magnetic domain structure in which the direction of the magnetization is grouped in several magnetic domains. Because large stray fields will be generated from the boundaries (domain walls) of the magnetic domains, this will cause high spike noise during the read back of signal. Figure 3 (a) shows a typical observed result of the spike noise measured by a GMR head as generated from a CoZrNb alloy amorphous soft magnetic layer with a thickness of 100 nm sputtered on the glass substrate. Dark color areas correspond to the spike generating locations and such locations are distributed over the whole area of the disk.

Fuji Electric established a layer structure and related process technology so as to reduce the spike noise effectively through adopting magnetic domain control of the soft magnetic underlayer using an antiferromagnetic AF film. In this layer structure developed by Fuji Electric, AF film which consists of MnIr alloy is sputtered onto a seed layer, and then soft magnetic film which consists of CoZrNb is sputtered.

Fig.3 Typical observation results of the spike noise



(a) Without AF film (b) With AF film and magnetic annealing process

Ideally, the magnetization of the AF film will be aligned radially from the center of the disk and a radially biased magnetic field will be applied effectively to the soft magnetic underlayer, and thus formation of a magnetic domain can be prevented.

However, in actuality, the stray field from the target during the sputtering to align the magnetization of AF film is not always uniform, and the direction of the magnetization may change during sputtering of the magnetic recording layer due to heating of the substrate. Recognizing the antiferromagnetic characteristics of MnIr film vanish at temperatures above 280°C, we undertook the challenge of developing a magnetic annealing process to control the direction of magnetization of the AF film itself without degrading productivity. In this process, after sputtering of the magnetic recording layer, the temperature of the substrate will be raised up to about 300°C in the heating chamber of the sputtering machine and then will be cooled down to about 180°C in the cooling chamber where a uniform radial magnetic field will be applied. The magnetic field strength will be about 80 kA/m (1 kOe) and the media will be retained for about 15 seconds in the cooling chamber. Figure 3 (b) shows a typical observation result of the spike noise generated from media subject to the annealing process. The spike noise over the whole area was eliminated and we were able to reduce the spike noise effectively without degrading the productivity.

The layer structure and process described above are also applicable to any soft magnetic materials. We are developing new materials with higher saturation flux densities to realize higher density magnetic recording systems.

3. Technology for High Density Recording Layer

3.1 CoCrPt-SiO$_2$ granular media

To use CoCrPt alloy film as the magnetic recording layer of a perpendicular magnetic recording system, the following conditions must be realized.

① Media noise must be reduced by segregating Cr at the grain boundary of fine Co alloy grains in order to reduce the intergranular magnetic interactions between the grains.

② The c-axis orientation of the Co alloy grain normal to the film plane must be improved and a high K_u value must be induced.

Condition ① can be realized by increasing Cr content, as in the case of the longitudinal magnetic recording system. In addition, it is effective to add Ta or B, etc., however at the same time, the K_u value is liable to deteriorate. Condition ② can be realized by promoting epitaxial growth to optimize the non-magnetic interlayer, however it is known that this is liable to limit Cr segregation at the grain boundary.

Fuji Electric has been developing micro-structure control technology consisting of a CoCrPt alloy granular layer with SiO_2 additive for a longitudinal magnetic recording system. With these materials, a high K_u value can be realized, because SiO_2 can be easily precipitated to the grain boundary of the Co alloy grains and it is not necessary to increase Cr content or add elements for reducing the magnetic interactions between grains. Observing such features, we initiated an investigation of CoCrPt-SiO_2 granular media as the magnetic recording layer for a perpendicular magnetic recording system.

Figure 4 shows a TEM (transmission electron microscope) image of a CoCrPt-SiO_2 granular magnetic layer manufactured by an RF magnetron sputtering process using a CoCrPt/SiO_2 composite target on an Ru interlayer. A granular structure can be seen in which crystal grain boundaries (whitish areas in the image), composed mainly of the oxide, are formed surrounding 6 nm crystal grains. It was verified by X-ray diffraction analysis that the c-axis orientation of Co alloy grains was also excellent. These media have a very high K_u value of 4×10^5 J/m^3 which is more than twice the value of the CoCrPt magnetic recording layer and the loop squareness is almost 1.

Figure 5 shows MFM (magnetic force microscopy) images of magnetization bits recorded by a single pole type head on CoCrPt-SiO_2 granular media with a soft magnetic underlayer. In Fig. 5 (a), (b) and (c) are the bits recorded at linear recording densities of 20, 28 and 31 kfc/mm (500, 700 and 800 kFCI) respectively. Relatively clear magnetization switching is observed even at the linear recording density of (b) which corresponds to a recording density of 82 Gbits/in^2. These media have excellent thermal stability and the read back signal decay is almost zero at any recording density.

As mentioned above, the CoCrPt granular magnetic layer with SiO_2 additive is a promising material for magnetic recoding layers with recording densities of 100 to 200 Gbits/in^2. We are making further efforts to optimize the layer structure and composition of the material.

Fig.4 TEM image of CoCrPt-SiO_2 granular magnetic layer

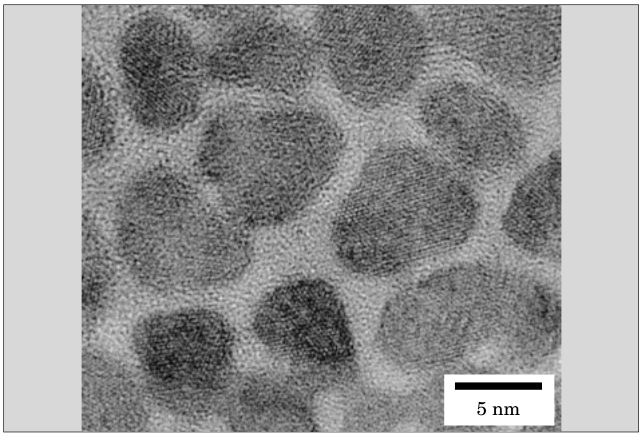
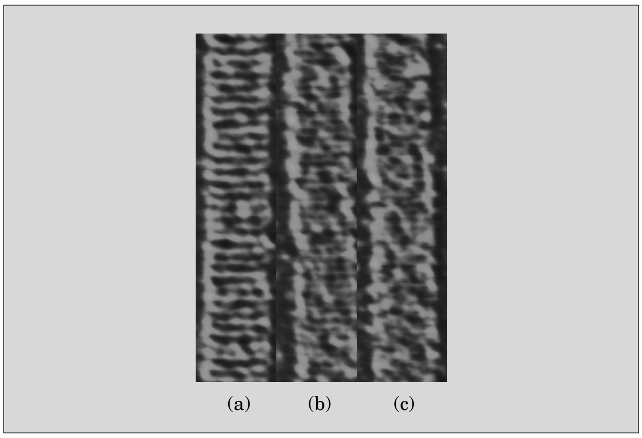


Fig.5 MFM images of CoCrPt-SiO_2 granular media



3.2 CoTb amorphous composite-type media

As mentioned before, amorphous film, consisting of a rare-earth metal such as Tb and a 3d transition metal such as Co or Fe, is a material that holds potential for realizing the high recording density beyond 300 Gbits/in^2. Because of the extremely strong exchange interaction in the film plane direction, the magnetization is widely coupled. Therefore, it is difficult to implement microscopic magnetization switching on the order of nanometers.

We investigated a process for realizing the microscopic magnetization switching of amorphous film and discovered that a composite type media layered with CoCrPtB film, for which the magnetization switching unit is small, is compatible with both thermal stability and media noise characteristics.

Fig.6 SNR and time decay of the read back signal as a function of CoTb layer thickness

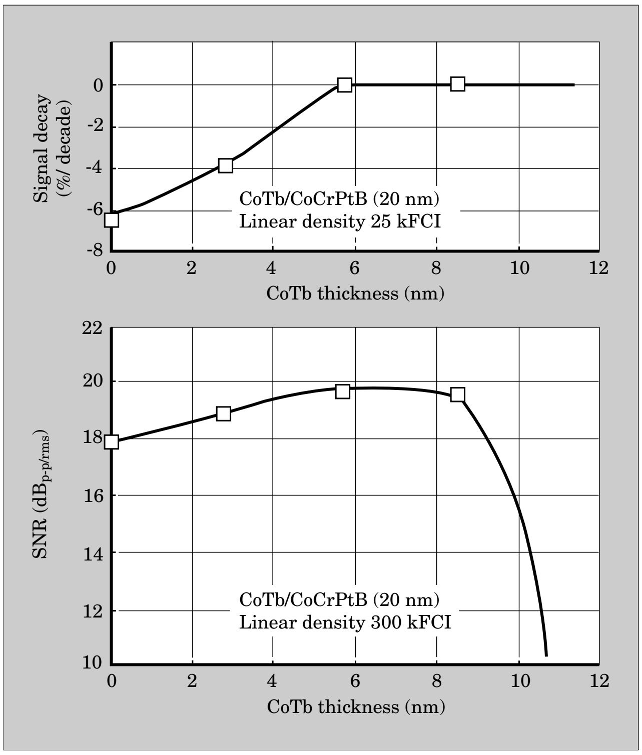


Figure 6 shows the signal-to-media-noise ratio (SNR) of the composite type media formed from CoTb amorphous film layered on a CoCrPtB alloy film, having a thickness of 20 nm at the linear recording density of 12 kfc/mm (300 kFCI), and the time decay of the read back signal measured at 1 kfc/mm (25 kFCI) for the evaluation of thermal stability, as a function of the CoTb layer thickness.

At a CoTb thickness of 6 nm, SNR is at its maximum value and SNR is improved by 2 dB compared with its value in the case without CoTb. With the increase of CoTb thickness, the time decay of the read back signal is improved. The time decay is almost zero when CoTb thickness is greater than 6 nm. Excellent SNR and thermal stability characteristics were obtained from composite type media having a layer structure of CoTb (6 nm) and CoCyPtB (20 nm).

By observation using an MFM, it was verified that 70 Gbits/in^2 could be realized with this media. We hope to be able to achieve even higher recording densities through combination with granular media.

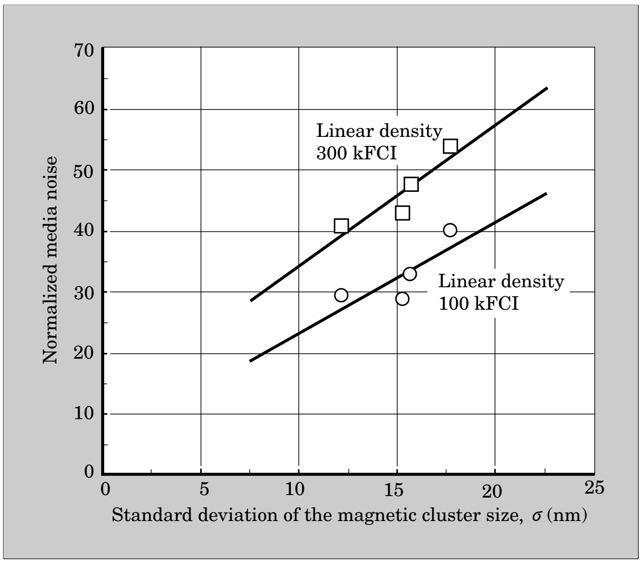
4. Evaluation and Analysis Technique for Perpendicular Recording Media

In the development of excellent magnetic recording media, evaluation and analysis techniques are indispensable. Especially, for quantitative discussions of the noise characteristics of high-density recording media, the micro recording bits have to be observed and evaluated directly, and then the causes of noise generation must be investigated. For this purpose, we are developing an evaluation and analysis technique for the magnetized patterns of perpendicular magnetic recording media using an MFM and are working jointly with the Science & Technical Research Laboratories of NHK.[3] In this paper, we would like to introduce a technique for evaluating and analyzing magnetic cluster size in an ac erased state, which is considered to have a strong correlation with media noise.

The number of magnetic clusters in the oriented magnetization can be viewed by observing ac erased media with an MFM. After image processing of the observed image, we approximated each cluster with a circle and obtained its diameter D and standard deviation σ. Figure 7 shows the relationship between standard deviation σ of the magnetic cluster and normalized media noise of the perpendicular magnetic recording media for several magnetic recording materials and layer structures. The standard deviation σ shows a strong correlation with the media noise and the media noise decreases with the decrease of σ. It is also clear that the size of the cluster has a strong correlation with the recording resolution.

Such analysis is very effective for quantifying the target magnetic cluster size necessary for higher recording density and lower noise. Therefore, this analysis technique is useful for the design of media. Now, we are investigating procedures for achieving better resolution of the MFM image, so that an even more precise evaluation can be obtained.

Fig.7 Relation between normalized media noise and standard deviation of the magnetic cluster size



5. Conclusion

Fuji Electric is performing comprehensive research and development of perpendicular magnetic recording media for ultra-high-density recording, including the magnetic domain control and the evaluating analysis technique. In addition to the development of the CoCrPt-SiO_2 granular film magnetic recording layer for 100 to 200 Gbits/in^2, we are developing amorphous film which has the potential to realize ultra-high recording densities of more than 300 Gbits/in^2. We are working toward realization of the high capacity AV-HDD which is expected to become a major sales item on the market. Lastly, we extend our thanks to Prof. Yoshihisa Nakamura and Prof. Hiroaki Muraoka of the Research Institute of Electrical Communication, Tohoku University, and to Dr. Takahiro Tamaki, Senior research engineer of the Science & Technical Research Laboratories, NHK for their helpful advice.

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Magnetic Printing Technology

Kiminori Sato
Kazuo Nimura
Akira Saito

1. Introduction

Hard disk drives (HDDs) are equipped in most personal computers as peripheral storage equipment and the worldwide annual production of HDDs is expected to reach 200 million units (in 2001). In recent years, HDDs also have come to be installed in so-called network household appliances such as information appliances and digital home electronic equipment (the latest of which includes car navigation devices, digital TVs, and VCRs with built-in HDDs). This trend is creating another new market equal to or greater than the personal computer market. Aiming at these markets, Fuji Electric has been promoting the research and development project of magnetic disks for HDDs since 1999. Fuji Electric's projects cover such diverse topics as the development of new material substrate alternatives to aluminum, perpendicular recording media for high-density recording, and technology to lower the cost of embedding information into magnetic disks. The above-mentioned last technology aims to embed into magnetic disks such information as servo patterns used in HDDs and security data indispensable to network household appliances.

As part of the above-mentioned technologies, this paper will present our servo pattern and the magnetic printing technology, which is a new technique for embedding patterns into magnetic disks, and describe the major practical results achieved by the development thus far. This magnetic printing technology has been developed for the mass production of magnetic disks, based on research by Matsushita Electric Industrial Co., Ltd., and in cooperation with Fuji Electric's customer HDD manufacturers.

2. Magnetic Head Positioning Mechanism and Servo Pattern

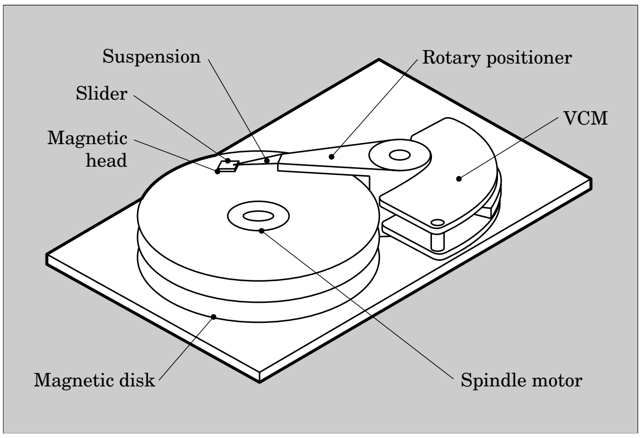
2.1 Magnetic head positioning mechanism in HDD

Figure 1 shows a schematic illustration of the structure of a magnetic head positioning mechanism in the HDD. The magnetic disk as a recording medium rotates at a high-speed of several thousand r/min by a spindle motor. When reading or writing data, the magnetic head flies about 10 nm above the rotating magnetic disk with a surfacing mechanism referred to as a slider. The slider is fixed to a rotary positioner via a suspension and the magnetic head can be moved to and positioned at an arbitrary track on the magnetic disk by a rotating action of the rotary positioner.

2.2 Servo pattern

In an HDD, the position information (which is referred to as the servo pattern) for detecting the position of the magnetic head relative to the target track on magnetic disk is written in advance onto the magnetic disk. As shown in Fig. 2 (a), servo zones written with servo patterns and data zones for reading/writing data are alternately aligned at fixed intervals in the circumferential direction. Thus, the magnetic head can detect its own position at every fixed time while reading/writing data (this method is referred to as the sector servo method and is utilized widely in HDDs.). Figure 2 (b) shows an example servo pattern written in a servo zone. The servo zone contains a servo clock, an address pattern, and a position detection pattern. The position detection pattern in the figure is a checker pattern utilized in many HDDs, and detects the position based on the difference in amplitude of a read signal waveform.

Fig.1 Magnetic head positioning mechanism in HDD



3. Servo Writing

3.1 Conventional servo writing method by STW

In conventional HDDs, an equipment referred to as the servo track writer (STW) writes servo patterns (see Fig. 3). After building in the magnetic disk in the HDD, a pushpin is inserted into the HDD case in order to mechanically hold the rotary positioner in the drive. Based on an encoder in the STW, the STW's fine rotary mechanism is moved to cause slight movement of the above-mentioned pushpin and rotary positioner, and to successively write the servo pattern corresponding to each track. A 20 Gbyte-per-plate class magnetic disk requires about ten minutes or more for servo writing.

Fig.2 Servo pattern

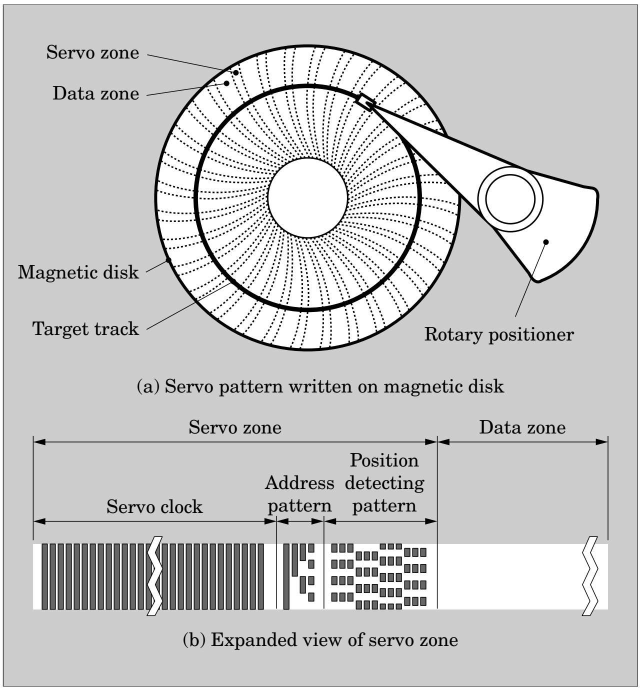
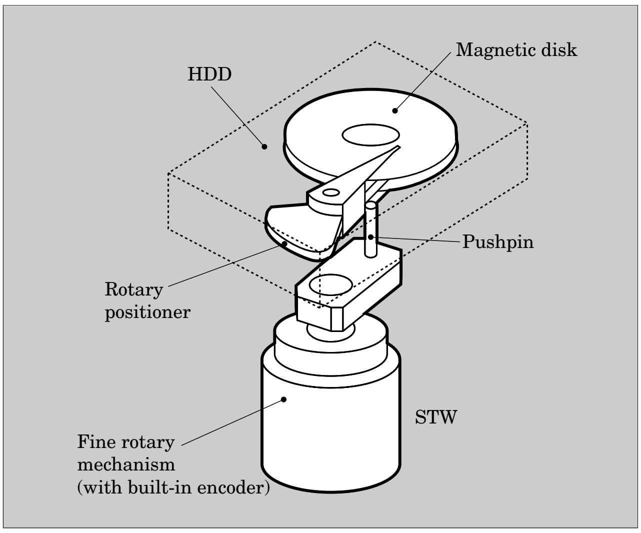


Fig.3 Servo writing by STW



As the track recording density increases, the number of the tracks increases, and accordingly, the servo writing time also increases. In addition, a higher accuracy is required for the STW mechanism, since the track pitch becomes narrower. Parallel servo writing with multiple expensive STWs provided in a clean room may provide a temporary solution, but imposes a heavy financial burden.

3.2 Servo writing by magnetic printing

As a low-cost and speedy servo writing measure alternative to the above-mentioned STW, Fuji Electric focused attention on the magnetic printing technology that copies magnetic patterns from an original recording disk (referred to as the master disk) to another magnetic disk in block.[(1) to (3)] In this magnetic printing technology, a reference servo pattern is written in advance to a magnetic disk, then based on the reference servo pattern, the HDD writes a finer servo pattern on itself (this is referred to as self servo writing). The time required for magnetic printing of one magnetic disk is less than six seconds and is much less than the STW's executing time. Since self servo writing can be implemented outside of a clean room, it has the effect of extensively reducing the investment in clean rooms.

Figure 4 shows the principle of the magnetic printing process. First, an external magnetic field is brought close to the magnetic disk to magnetize the recording layers of the magnetic disk in one direction (DC erasing). Next, a magnetic field is applied from above the master disk in the direction opposite to the DC erasing, while bringing the master disk into close contact with the magnetic disk. The master disk is a silicon substrate, in which slots of several hundred nm in width are formed corresponding to the servo pattern, and soft magnetic material (Co) is embedded in the slots. In the gaps between the soft magnetic material, magnetic flux leaks in the direction opposite to the DC erasing magnetic field. On the magnetic disk, areas that have been in contact with parts of the master disk part containing no soft magnetic material are magnetized in the direction opposite to the DC erasing magnetic field, and the DC erased condition is retained at areas that have been in contact with the parts containing soft magnetic material. Thus, the servo pattern data of the master disk is printed on the magnetic disk. Lastly, contact between the master disk and the magnetic disk is released. Figure 5 shows an external view of the master disk.

In mass production, the keys to achieving uniform printing of signals over the entire disk surface are the technologies to ensure good contact between the master disk and the magnetic disk and to maintain the cleanliness of both disks while in close contact. The former technology is achieved by configuring the master disk to have alternating land parts that form the servo patterns and groove parts that function as

Fig.4 Magnetic printing process (longitudinal recording)

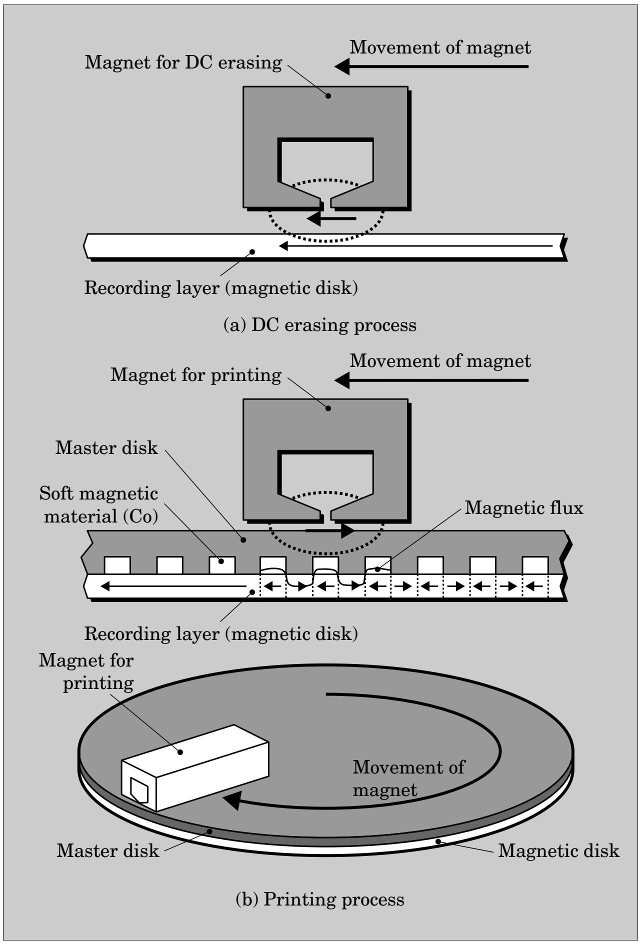
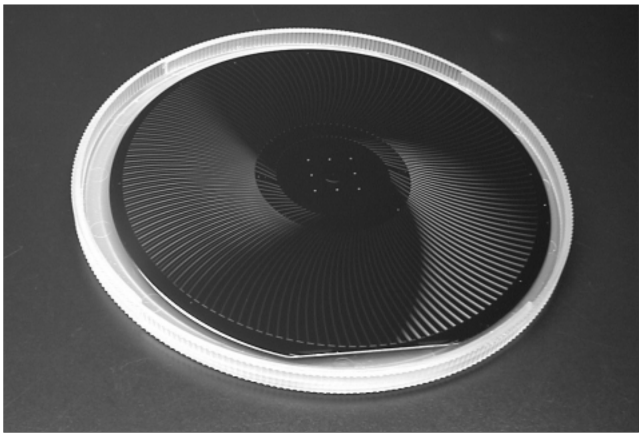


Fig.5 Outer view of master disk

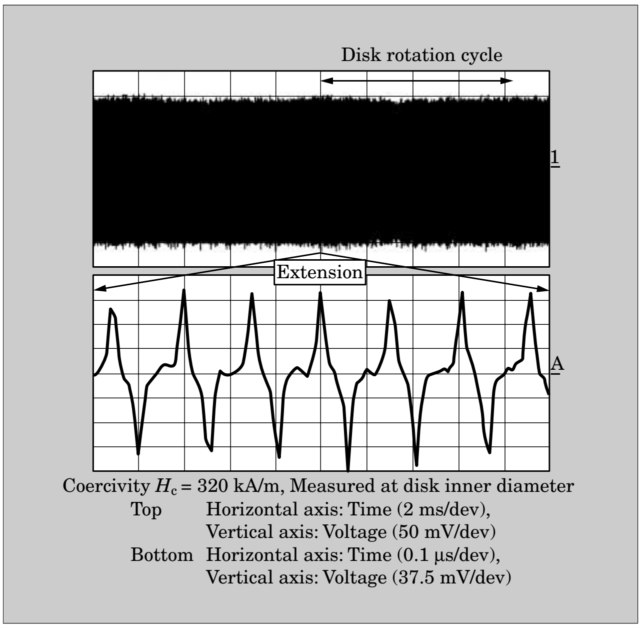


air flow channels, for controlling the pressure of the air flow through the grooves. Measures for achieving the latter technology are as follows:

(1) Perform a magnetic disk surface inspection just before the magnetic printing process.
(2) Provide a continuous downward flow of air to maintain cleanliness in the vicinity of the magnetic printing process to below Class 1.
(3) Periodically clean the master disk.

Figure 6 shows an example of a servo signal

Fig.6 Servo signal waveform from magnetic printing disk (longitudinal recording)



waveform read from a magnetic-printed servo pattern. It is evident from the figure that a uniform envelope is achieved around the circumference of a track.

4. Practical Results of Development

4.1 Mass production of magnetic printing disk

In July 2001, Fuji Electric started to mass-produce magnetic disks with servo patterns recorded by magnetic-printing (hereafter referred to as magnetic printing disks). At present, magnetic printing disks with recording capacity of 40 Gbyte-per-plate class are being shipped to HDD manufacturers. These disks are for use in personal computers and the number of disks shipped in 2001 is expected to reach 2.5 million units. Before shipping, quality checks associated with the cleanliness of the magnetic disks (including the tests for amplitude stability, ion contamination, corrosion, and organic contamination) are implemented. The results have verified that application of the cleaning technology described above enables magnetic printing to be performed without causing any damage or contamination on the magnetic disk surface.

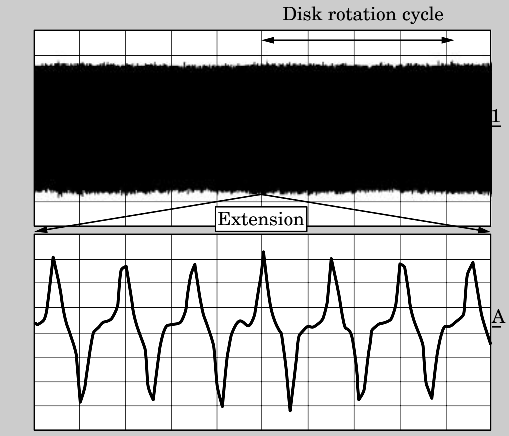
4.2 Application to next generation disks

An experimental trial of magnetic printing for high-coercivity magnetic disks and perpendicular recording disks has been implemented ahead of time. The results of the basic experiment confirmed that the magnetic printing technology could be applied to both disks.

4.2.1 High-coercivity disk

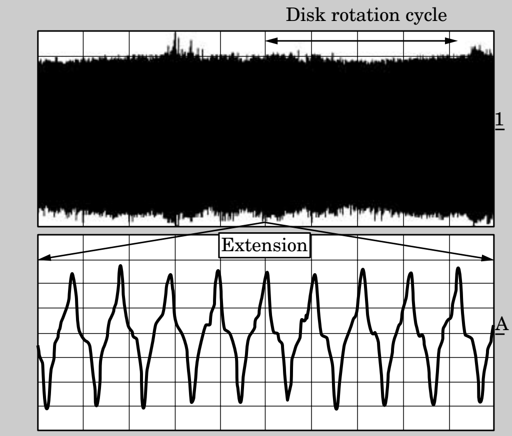
The recording layer coercivity, H_c, of magnetic disks is increasing year after year and is expected to reach 480 kA/m (6,000 Oe) in 2003. As a result of the

Fig.7 Servo signal waveform from high-coercivity magnetic printed disk (longitudinal recording)



Coercivity H_c = 480 kA/m, Measured at disk inner diameter
Top Horizontal axis: Time (2 ms/dev), Vertical axis: Voltage (50 mV/dev)
Bottom Horizontal axis: Time (0.1 µs/dev), Vertical axis: Voltage (37.5 mV/dev)

Fig.8 Servo signal waveform from perpendicular magnetic printing disk



Coercivity H_c = 240 kA/m, Measured at disk inner diameter
Top Horizontal axis: Time (2 ms/dev), Vertical axis: Voltage (70 mV/dev)
Bottom Horizontal axis: Time (0.2 µs/dev), Vertical axis: Voltage (70 mV/dev)

magnetic printing basic experiment for magnetic disks with recording layer coercivity H_c of over 480 kA/m, it could be verified that a signal output level equal to that of current media with $H_c \approx$ 320 kA/m (4,000 Oe) can be achieved. Figure 7 shows an example of a servo signal waveform.[(4)]

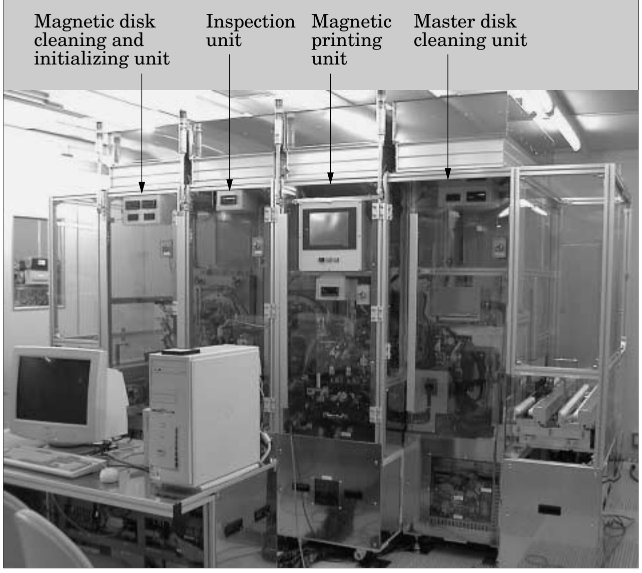
4.2.2 Perpendicular recording disk

For areal densities greater than 100 Gbits/in^2, the recording method is expected to shift from the current longitudinal recording method to the perpendicular recording method. The basic experiment of magnetic printing was implemented for the perpendicular recording disk. Using an external magnet and a master disk equivalent to those used for longitudinal recording, the perpendicular components of magnetic leakage flux from the edge of the soft magnetic material on the master disk perform the perpendicular recording. Figure 8 shows an example of a servo signal waveform. It was verified that a signal output level equal to that of a longitudinal disk can be achieved.[(5)]

4.3 Development of next generation magnetic printing equipment

Figure 9 shows an external view of the next generation magnetic printing equipment developed by Fuji Electric. This equipment has newly been developed to support magnetic printing to not only conventional aluminum-substrate longitudinal recording magnetic disks but also to disks for which demand is expected to increase such as glass-substrate magnetic disks, perpendicular magnetic printed disks, and magnetic disks with high-coercivity recording layers. This next generation magnetic printing equipment contains a magnetic disk cleaning and initializing unit with

Fig.9 External view of next generation magnetic printing equipment



tape burnishing function for removing particles attached to the disks using a burnishing (polishing) tape and a DC erasing function for magnetic disks, a surface inspection unit for detecting attached particles smaller than 1 µm in size, a magnetic printing unit for implementing the magnetic printing while limiting the eccentricity between the master disk and the magnetic disk to less than 10 µm, and a master disk cleaning unit for removing particles attached to the master disks with the tape burnishing function. The equipment has been designed for ease of maintenance and each unit can operate independently. By placing the magnetic disk cleaning/initializing unit and the surface inspection unit just in front of the magnetic printing unit, the cleanliness of the magnetic disk to be inserted into the magnetic printing unit can be strictly controlled. Additionally, the magnetic printing unit ensures a cleanliness level of Class 1 by placing the magnetic printing mechanism at the top of the disk handling mechanism to constantly maintain a downward flow of clean air. The main specifications are listed in Table 1.

4.4 Development of servo tester

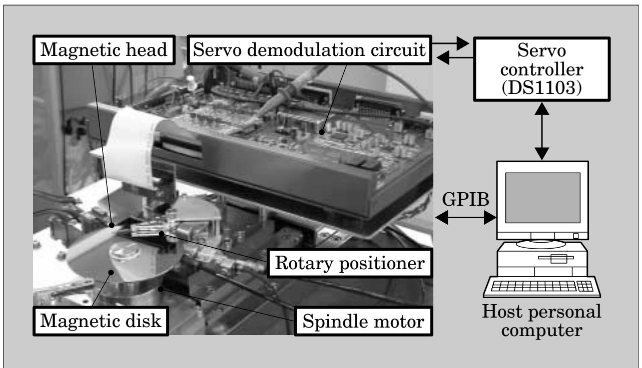
A servo tester has been developed, incorporating a servo signal test function that automatically measures the servo signal quality of the magnetic printing disk, and a track following test function that, based on the servo signal, performs positioning control of the magnetic head on an arbitrary track and measures the positioning accuracy. The former function is helpful as a measure for evaluating details of the signal quality, and the latter function is effective as a measure for comprehensive evaluating the servo signal.

Figure 10 illustrates the structure of the track following test function system, which is based on a commercially available spinstand (a specific tester for magnetic disks and heads consisting of a spindle motor for rotating a magnetic disk and a stage mechanism for moving and positioning a magnetic head). The system includes a rotary positioner for positioning a magnetic head on a target track rapidly, a servo demodulation circuit for acquiring a position error signal from a servo track, a servo controller (DS1103 made by dSPACE) for controlling the rotary positioner's positioning based on a position error signal, and a host personal computer. This allows the track following test to be performed on the spinstand, for a magnetic printing disk on which a servo pattern has been recorded. The VCM (voice coil motor) type rotary positioner commonly equipped with the HDD is used here. Figure 11 shows an example of the magnetic head positioning accuracy measured on a magnetic printing disk. It is evident that the accuracy is within ±0.1 µm, which is nearly equal to 1/10 of the track width.

Table 1 Specifications of next generation magnetic printing equipment

Item	Specification
Printing throughput	600 plates/hour
Eccentricity	< 10 µm
Magnetic disk size	2.5/3.5 inch
Substrate	Aluminum/Glass
Coercivity H_c	< 640 kA/m
Recording method	Longitudinal/Perpendicular
Setup time	< 4 hours
Cleanliness	Class 1 (below 0.1 µm)
Master disk cleaning	Yes (tape burnishing method and purpose-built cleaning disk method)
Magnetic disk cleaning	Yes (tape burnishing method)
Availability factor	> 96 %
Size	3,300 width×1,400 depth ×2,000 height (mm)

Fig.10 Structure of track following test function



5. Future Plans

Because the HDDs equipped in network household appliances are expected to be used daily for recording or replaying movies, greater recording density per magnetic disk will be required as in the case of personal computer use. Figure 12 shows a yearly trend forecast of the track recording density (TPI: Track per inch).

To further enhance magnetic printing technology, Fuji Electric plans to achieve a track recording density of 150 kTPI (equal to twice the current value) within the year of 2002 by promoting the formation of finer servo patterns on the master disk, optimization of the magnet for an external magnetic field using magnetic simulations, and improvement of the servo pattern.

The magnetic printing technology can be applied not only to the servo pattern, but also to data or

Fig.11 Measured positioning accuracy of magnetic head when track-following

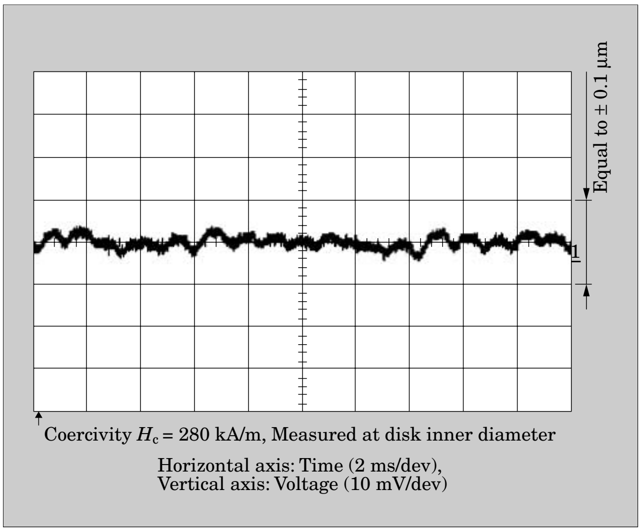
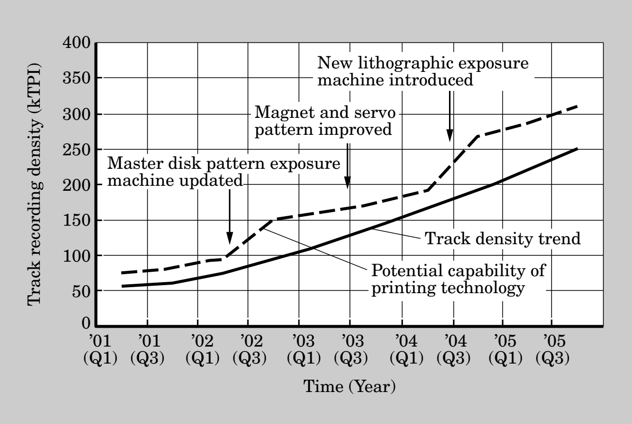


Fig.12 Trend forecast of HDD track recording density



software embedding. Another study is planned into the feasibility of new applications such as a security magnetic disk with security data embedded, which will become a key technology in network household appliances.

6. Conclusion

This paper has presented a servo pattern for positioning the HDD magnetic head, its new writing method, and magnetic printing technology, and has reported Fuji Electric's principal developmental results and future plans. The magnetic printing technology is receiving attention from HDD-related manufacturers as a potential technology for extensively reducing the cost of the servo writing process in HDD production. Fuji Electric expects that the number of manufacturers adopting this technology increases and that the technology becomes the de facto standard for servo writing in the future.

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Present Status and Future Prospects for Photoconductors

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Mitsuru Narita
Tatsuo Tanaka

1. Introduction

The improvement in performance of personal computers and peripherals and their rapid popularization has recently been remarkable. The influence that development of these information devices brings into our lives can be expressed with three keywords: digitalization, colorization and networking. For example, imaging devices, including cameras and videos, are advancing at a rapid pace and the transmission of color images via internet is already a daily occurrence. It is significant that these phenomena are seen not only in offices but also widely in homes.

Under these circumstances, the importance of the role of printers and PPCs, which display and record the information and images, is increasing more and more, and their expected level of performance is becoming higher.

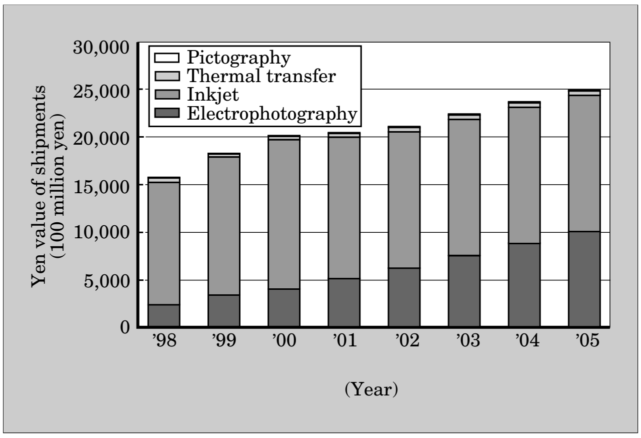
In this paper we are going to explain the market trends for printers and PPCs, discuss the trends of printers using electrophotographhc technology and of PPCs, and present an overview of corresponding Fuji Electric photoconductors and their peripheral devices.

2. Market Trend of Printers and PPCs

Despite the progress of thin model displays as typified by liquid crystal displays, the consumption of paper as an information medium continues to grow steadily. The main reason for the increasing consumption of paper is thought to be attributable to the fact that, above all, paper combines multiple functions such as the displaying, writing, storing and transmitting of data, and also is a lightweight and very serviceable medium.

On the other hand, new technologies, including electronic books and electronic paper, are being developed as media alternatives to paper. In the mid- and long-term horizons, the percentage of these electronic media relative to paper is estimated to increase continuously. For the moment, the increase in information quantity itself is thought to be due to the synergistic effect of both media, resulting in the continued growth of both media[1].

Fig.1 Forecast of shipment amount for color hard copying devices



In computer image output devices, the inkjet method is used mainly for personal-use devices and the electrophotographic method is mainly for office-use devices. The inkjet method has features of low device price, color printing and good printing quality for coated papers, and the electrophotographic method has features low running cost, high printing speed and good printing quality for plain papers. Figure 1 shows a market forecast for color hard copy devices. Although electrophotographic color printers and color PPCs are only at the beginning of their real popularization, future large-scale growth is expected. The inkjet method and electrophotographic method are expected to compete with each other and yet to continue growing together, benefiting from their respective advantages. At present, the ratio of printed sheets by the inkjet method compared to the electrophotography method (including monochrome images) is said to be approximately 1 : 3 (inkjet: electrophotography).

3. Trend of Electrophotographic Devices

The shipped quantities of electrophotographic printers and PPCs have in the last several years exhibited a trend of saturation, showing only a small increase of several percent. But with the progress of technologies and change in device composition, a new market is now opening up corresponding to the change in business environment represented by the abovementioned three keywords.

3.1 Electrophotographic printer

The introduction of color printing in electrophotographic printers lagged the development of colorization in other information devices. Figure 2 and Fig. 3 show the trends in shipment quantities for monochrome electrophotographic printers and color electrophotographic printers respectively. In the estimates for 2001, the shipment of monochrome printers is about 10 million units, while the shipment of color printers is only 700 thousand units. However, in the last several years shipments of color printers have grown by about 30 % per year, suggesting rapid growth of the market in coming years.

As seen in Fig. 3, at present most of the shipped color printers are low-speed machines having printing speeds not higher than 6 pages per minute (ppm). However, owing to the rapid progress of technological development and the ongoing application of that technology into products, medium- and high-speed machines having printing speeds in excess of 15 ppm are expected to become the major products. In this scenario, the one-drum rotary system which prints 4 colors sequentially with a single drum, will be utilized in low-speed machines, while the four-drum system which prints each of 4 colors with 4 individual photoconductor drums, will be chiefly adopted for medium- and high-speed machines. The potential for expanding the market for electrophotographic devices depends upon the extent to which products can be provided at lower prices.

The requested improvements in properties of photoconductor drums for color printers are enhanced printing quality, especially higher resolution, and the stable photo-responsibility necessary for color reproduction. Of the abovementioned processes, especially in a 4-drum system, high dimensional accuracy is required of substrates for the purpose of controlling discrepancy in colors.

Another new trend is the popularization of on-demand printers with the advance of networking of information. Of the total quantity of printing on paper media, 70 % is occupied by newspapers, books, magazines and catalogs. Offset printing and photogravure printing are applied at present as the printing method for these paper media, of which the on-demand-printer targets small-lot printing or on-site printing. Their market image is not clear in some aspects, but the on-demand printer is a new application that leverages the features of electrophotographic printers, i.e. high-speed and flexibility.

For photoconductor drums used in these applications, high sensibility and high photo response for supporting the printing speed, durability for achieving a long useful life of the photoconductors, and high resolution approaching the level of offset printing are required. Some trials are reported to have achieved improved resolution by using liquid toner instead of the conventional dry toner, and photoconductors corresponding to this method are also being developed[2].

Fig.2 Transition of shipment units for monochrome electrophotographic printers

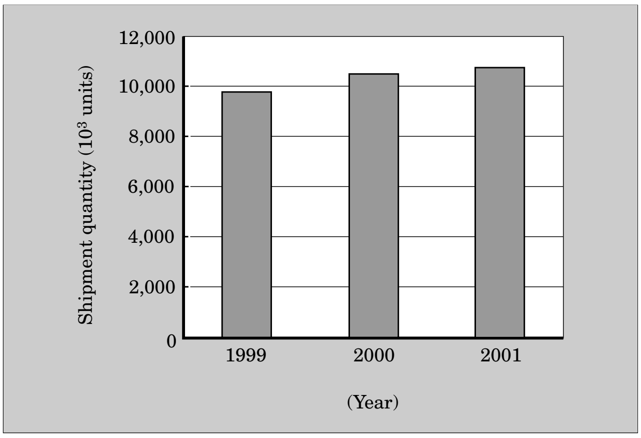
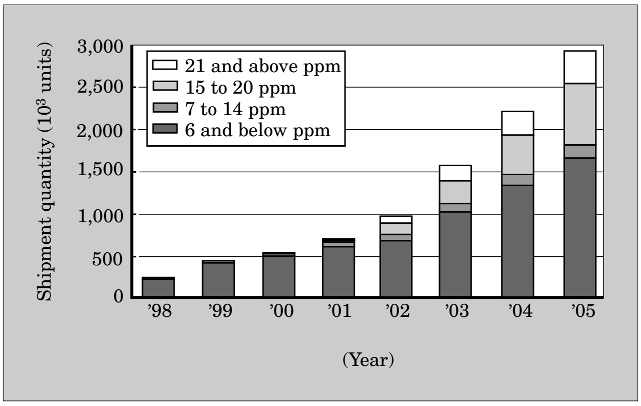


Fig.3 Forecast of shipment units for color electrophotographic printers



3.2 PPCs

Figure 4 shows the trend of shipments of PPCs. Although the total number of shipments has nearly leveled off, shipments of digital PPCs show a rapid growth of 20 % per year, overtaking the lead from analog PPCs. Especially multifunction peripherals, which combine the functions of printers, PPCs and facsimile machines, show a steady increase with medium- and high-speed types as their main products. On the other hand, it is also estimated that low-speed machines having an image output speed of lower than 10 ppm will gradually be replaced by printers.

The characteristics requested of photoconductors for digital PPCs, in addition to high-speed photo response and durability, are the realization of photo-responsibility adapted to the printer process including tonal characteristics for reproduction of half tones.

Fig.4 Transition of shipment units for PPCs

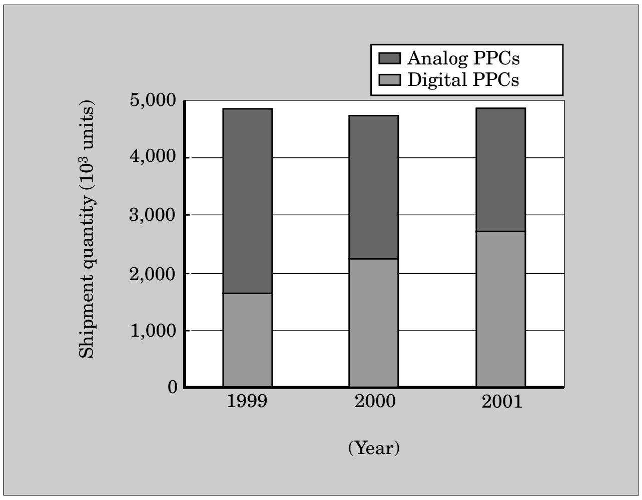
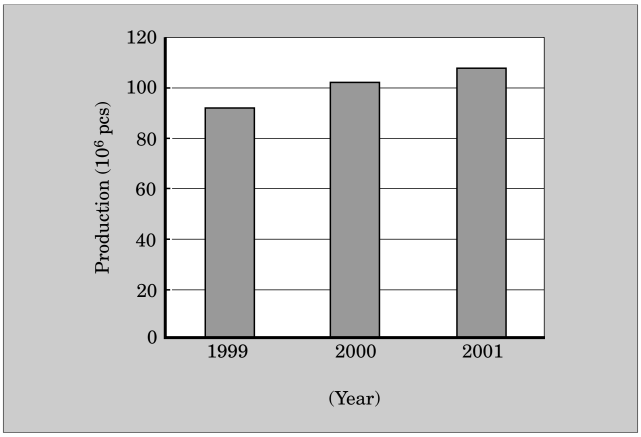


Fig.5 Transition of production for photoconductors



3.3 Photoconductors

Organic photoconductors (OPCs), selenium photoconductors and amorphous silicon conductors are used as the photoconductors for electrophotographic printers and PPCs. Figure 5 shows the trend of total production of these photoconductors, exhibiting steady annual increase rates of 6 to 10 %. As was already mentioned, the formation of new markets in the future is expected, including the popularization of color printers and on-demand printers, for which further growth is forecast.

The required characteristics for coping with these new developments are summarized as follows:

(1) For color printers: high-resolution, color reproducibility and material tube precision

(2) For on-demand printers: high-sensitivity, high-speed response and durability

(3) For digital PPCs: high-speed response, durability and tone

In addition, improvement of various components, including developers, rollers and blades, and improvement in process conditions (low temperature fixing, advanced image-transfer conditions) are being advanced, and application of these improvements to existing processes is an important task.

Table 1 Outline of Fuji Electric's OPCs

Type	Feature		Application
	Charging polarity	Layer structure	
8	Negative	Multilayer	Printer, Facsimile, Multifunction peripheral
9	Negative	Multilayer	Analog PPC
10	Negative	Multilayer	Digital PPC, Multifunction peripheral
11	Positive	Monolayer	Printer, Facsimile, Multifunction peripheral

4. Overview of Fuji Products

Fuji Electric has established an independent company, Fuji Electric Image Devices Co. Ltd., uniting the businesses of electrophotographic photo conductor and related areas, and has built up a system to cope speedily with drastic environmental changes. As production bases for photoconductors, in addition to the domestic Fuji Electric factory in the Matsumoto area, Fuji has subsidiary companies, i.e. U. S. Fuji Electric in USA and Hong Kong Fujidenki in Hong Kong, and is able to meet worldwide demand effectively. Also in the Shenzhen area of China, Fuji has Fusui Electric, a subsidiary company of Hong Kong Fujidenki, as a production base for various peripheral devices including process cartridges and toner cartridges. At present, many printer suppliers assemble printers in the Asian region including China, and we believe that the production of photoconductors in Hong Kong and of peripherals in Shenzhen will provide great convenience.

4.1 OPC

Fuji Electric has the 4 types of OPCs shown in Table 1 as a product series.

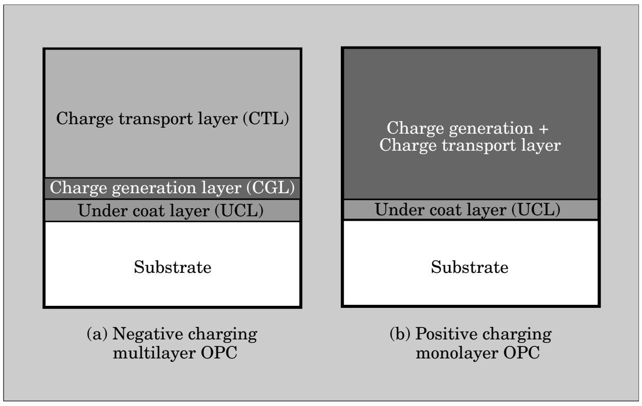
(1) OPC for printers

As OPCs for printers (Type 8), Fuji Electric has various products which correspond to a wide sensitivity range from low-speed machines to high-speed machines. Especially for the series of organic material products we provide many kinds of materials (charge generation material, charge transport material, etc.) and can satisfy diverse customer requirements. The color reproducibility can also be controlled for a wide range as required by color printers. In addition, the dimensional precision of drums is also enhanced by improving the finishing method.

(2) OPC for PPCs

We have 2 product series of photoconductors, type 9 for analog PPCs and type 10 for digital PPCs. We

Fig.6 Layer structure of OPC



offer a full range of products to satisfy requirements for high-speed response, high durability and tone as requested especially for PPCs, and we are improving the characteristics further by developing and designing new materials.

(3) Positive monolayer OPCs

The realization of positive charging monolayer OPCs, which have low ozone generation, excellent resolution, response and environmental stability, has long been expected. The layer structure thereof is shown in Fig. 6. As is known well, positive charging OPCs have the advantage of low ozone generation even when using a charging process with corona charging, and additionally are able to achieve intrinsically high resolution because photo absorption and charging occurs on the surface of the photoconductors. They have higher response and environmental characteristics than multilayer types and, in addition, require only a simple dipping process resulting in a high productivity. Based upon these advantages, positive charging monolayer OPCs are being applied to medium-speed page printers and on-demand printers, and improvements in sensitivity are further extending their application range.

4.2 Selenium photoconductors

The product series of selenium photoconductors is shown in Table 2. We have 2 types of products, Se–Te and Se–As. Fuji Electric always leads this product area based upon its abundant experience which includes selenium material technology, selenium purification technology and vacuum evaporation technology, and Fuji Electric's proven track record in meeting customer requirements.

Table 2 Outline of Fuji Electric's Se photoconductors

Type	Material	Application
4	Se-Te	Medium- and low-speed PPC, Laser diode printers
5	Se-As	High-speed PPC, Laser diode printers

4.3 Peripheral products

On the basis of electrophotographic process technology cultivated over many years, Fuji Electric develops, designs and manufactures integrated process units, each of which contains a core photoconductor, and charging, development and cleaning components. Furthermore, we are endeavoring to develop a Fuji Electric original unit that realizes small-size and high image-quality. Many of these products are manufactured at the above-mentioned Fusui Electric facility.

5. Conclusion

With the advent of a highly information-oriented society, the performance expected of photoconductors is becoming higher and higher, including clearer image quality and higher durability. To meet these requirements, Fuji Electric endeavors to develop the most attractive products in the world, and to develop the most advanced materials, products and production technology. We are firmly determined to further build up our technology through concentrated effort by the entire company and all of its groups, and to supply products having high performance and reliability corresponding to customers' needs.

References

(1) Kipphan, H. Final Program and Proceedings of IS&T's NIP17. International Conference on Digital Printing Technology. 2001, p.2.

(2) Yagi, H., et al. Final Program and Proceedings of IS&T's NIP16. International Conference on Digital Printing Technology. 2000, p.246.

Organic Photoconductors for Printers

Seishi Terasaki
Koji Fukushima
Masahiro Morimoto

1. Introduction

With changes in the printer business such as the growth of inkjet printers as personal-use low-speed printers and the arrival of the network age, the market for high-speed, MFP (multifunction peripheral) and full color electro-photographic printers is expected to expand, and in contrast, the market for low-speed printers with simple functions will contract as shown in Fig. 1.

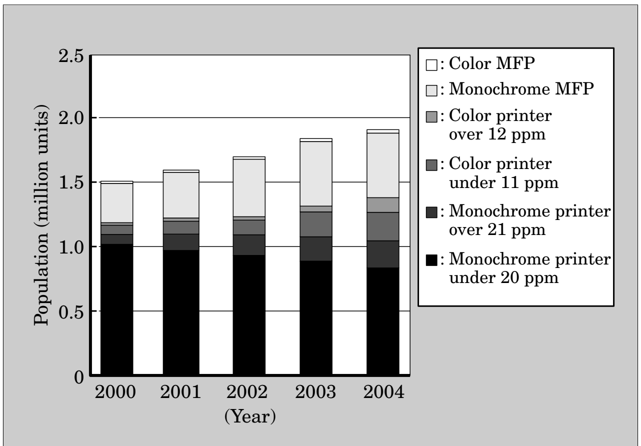
In keeping with this market trend, requirements of functionality and quality for photoconductors as major printers components are increasing year by year. Fuji Electric has developed and manufactured negative-charging and positive-charging OPCs (organic photoconductors) to meet these various needs.

This paper presents a general overview and describes the performance of negatively-charged OPC products including facsimile machines, plotters and MFPs.

2. Overview of Negatively-charged OPC

Figure 2 shows the layer structure of a negatively-charged OPC composed of aluminum conductive substrate, a resin UCL (under coat layer) to block positive charge and to prevent exposure interference, a CGL (charge generation layer) and a CTL (charge transport layer) layered in turn one above the other.

Fig.1 Market trend



The CGL is composed of CGM (charge generation material) and binder resin, and provides a charge generation function when exposed to light from a laser or LED (light emitting diode). The CTL is composed of CTM (charge transport material) and binder resin, and functions to transport charges generated in the CGL to the CTL surface.

Fuji Electric provides a series of three products, having low-, medium- and high-sensitivities, corresponding to the CGM's characteristics. This enables correspondence to the various exposure quantities shown in Table 1.

Half decay exposure can be adjusted within the range of 0.08 to 0.60 μJ/cm², in addition to strict control of the CGL layer thickness as shown in Table 1.

Figure 3 shows the respective spectral sensitivities of the low-, medium- and high- sensitivity types. Every type provides flat panchromatic characteristics in the wavelength range of 600 to 800 nm and is suitable for generic lasers or LED light sources. By

Fig.2 Layer structure

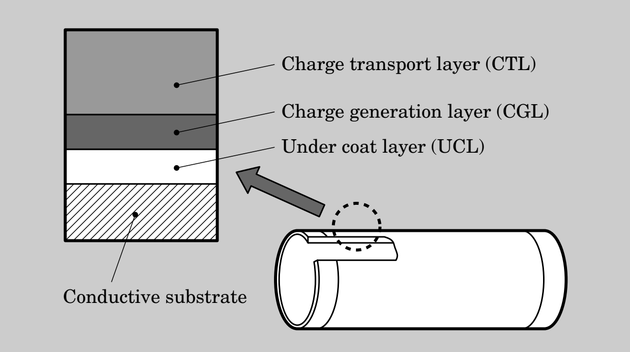


Table 1 Product outline

Type	Sensitivity (Half decay exposure)	Print speed
8A (Low sensitive)	0.20 to 0.60 μJ/cm²	Up to 20 ppm
8B (Mid. sensitive)	0.13 to 0.20 μJ/cm²	Up to 40 ppm
8C (High sensitive)	0.08 to 0.13 μJ/cm²	40 ppm≦

Fig.3 Spectral sensitivity

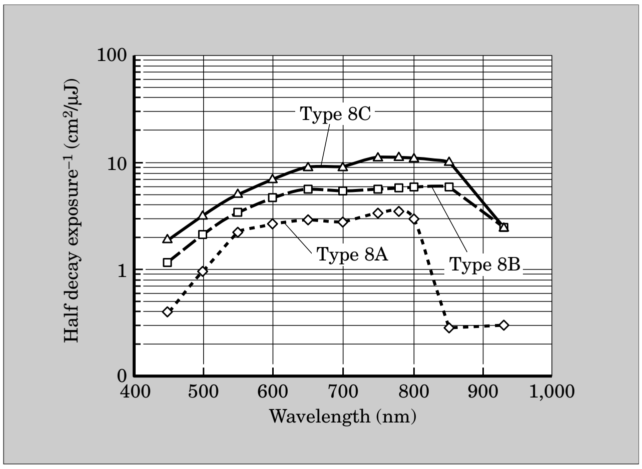


Fig.4 Performance and quality required by OPC

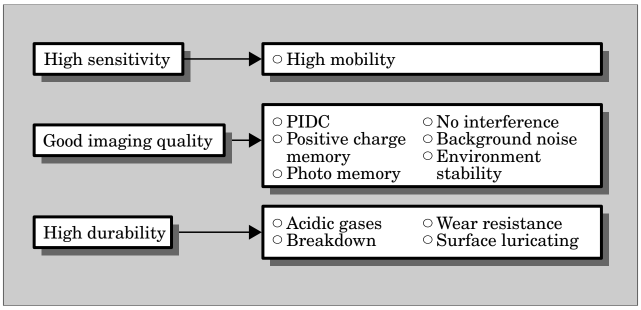


Fig.5 Photo response

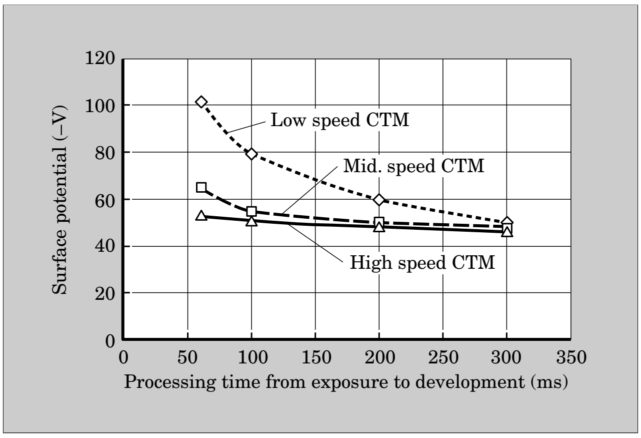
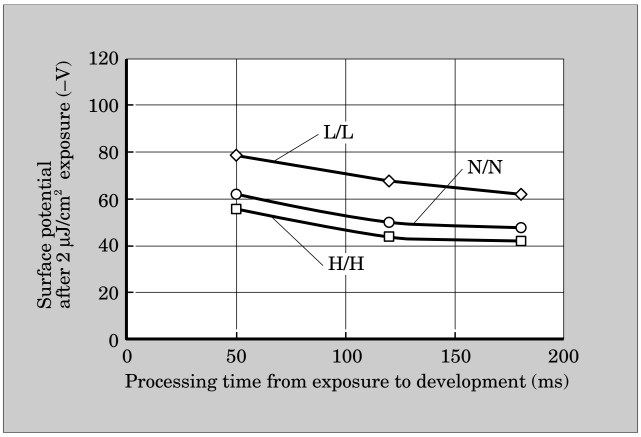


Fig.6 Environmental stability of photo response



combining these CGL and CTL, OPCs can be provided that are suitable for printers having a wide range of speeds, from 20 pages per minute (ppm) or less to 40 ppm or more.

Since OPCs can be provided with outer diameter ranging from 24 mm to 262 mm and length ranging from 246 mm to 1,000 mm, a wide range of products from A4 size page-printers to A1 size plotters has been developed.

3. Performance of Negatively-charged OPCs

In order to supply OPCs that satisfy the three major requirements of the printer market, namely high-speed, multifunction and full-color, Fuji Electric has classified the OPC requirements as shown in Fig. 4, and has undertaken the challenge of solving the respective technical problems. The respective performance of each characteristic is described below.

3.1 Technology for high sensitivity

In order to satisfy the requirements for A4 size laterally-fed high-speed printers having speeds of 40 ppm or more, although there is a dependence on the process layout, the optical sensitivity must be flat during a processing time of 80 ms or less, from exposure to development. To fulfill this requirement, Fuji Electric has developed CTMs with 5×10^{-5} cm^2/V·s that are suitable for high-speed printers.

Figure 5 shows the dependency of exposed surface potential versus the processing time from exposure to development. For a high-speed type CTM, the exposed surface potential is almost flat down to a 60 ms processing time from exposure to development, and therefore this CTM provides performance that is suitable with the above process. In addition, as shown in Fig. 6, environmental fluctuation of the exposed surface potential of this OPC is excellent since it is not more than 20 V.

3.2 Technology for good imaging quality

3.2.1 Photo-induced decay characteristics

For MFPs having a copying function, tone reproducibility is required similarly as for the OPCs for digital PPCs.

Printers are advancing toward higher resolutions, from 600 dpi (dots per inch) to 1,200 dpi or more, and together with advances in peripheral processes such as the fabrication of finer toner or implementation of the fine control of laser beam emission, improvements in graphical imaging quality are being sought more and more. Fuji Electric has developed and manufactured OPCs whose photo-induced decay characteristics are optimized to various machine processes so that high imaging quality, and in particular high resolution, is achieved.

Figure 7 shows an example of the photo-induced decay characteristics for each type of OPC made by Fuji Electric. Because this characteristic highly depends on carrier injection efficiency from the CGL to CTL, the characteristic may be adjusted by combining CGL and CTL.

3.2.2 Resistance to opposite polarity charge

Negatively-charged OPCs are charged with a positive charge on a drum at the transfer section. Depending on the process conditions, a positive charge-induced memory condition may occur in which half-tone images are shaded due to the effect of the positive charge. As the imaging quality of printers advances, the shading of printed letters has come to be easily reproduced by small potential differences, and thus the requirements for resistance to positive charge have increased more than before.

Fuji Electric has endeavored to reduce the affect of positive charge by optimizing the materials utilized in each layer of ULC, CGL and CTL based on the knowledge accumulated thus far.

Table 2 lists the positive charge characteristics of the improved and conventional type products. The surface potential difference at on/off of positive charge is improved to less than 1/3 of the conventional type, and therefore the positive charge-induced memory does not occur even for half-tone images at the 600 dpi MFP copy mode.

Fig.7 Photo induced decay

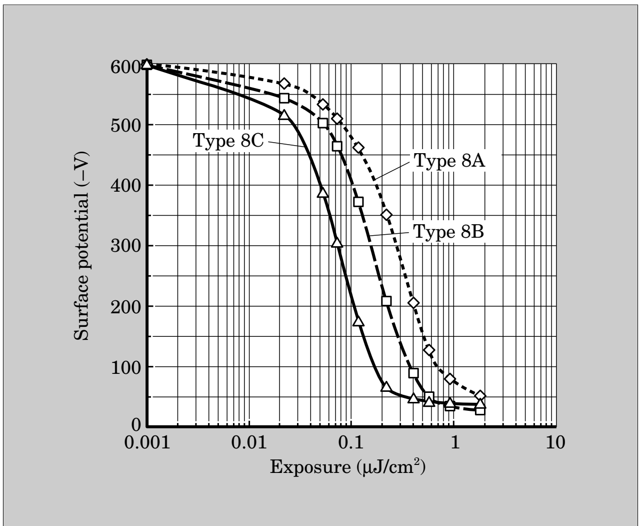


Table 2 Positive charge-induced memory characteristics

Type	Surface potential at non positive charge	Surface potential at positive charge add	Δ	Print quality
Old type	–610 V	–575 V	35 V	Poor
New type	–615 V	–605 V	10 V	Good

3.2.3 Control of fatigue characteristics after strong exposure

Even minute differences of potential may disturb the image of a photo-induced memory due to the same reason as a positive charge induced memory, and therefore OPCs having low exposure-fatigue characteristics are required. Figure 8 shows a comparison of strong exposure fatigue characteristics of OPCs made by Fuji Electric and other manufacturers. In both the cases of strong exposure at 1,000 lx and long-term weak exposure at 200 lx, excellent characteristics of almost no potential drop are observed.

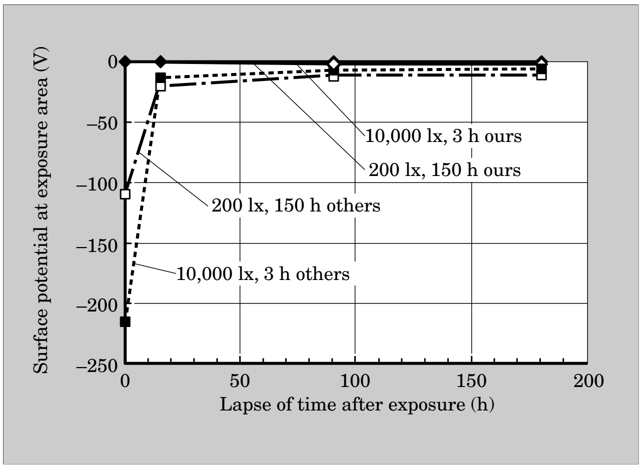
3.2.4 Control of interference for exposure light

In the case of a laser light source, there will be interference in the incident light if the reflectivity of the conductive substrate surface is high. Because this interference causes shading to appear on half-tone images, a function to control the interference of exposure light is necessary to for OPCs used in printers. In general, interference control is implemented by fine machining of the substrate surface, but Fuji Electric realizes a light interference countermeasure by providing sufficient interference control function in the UCL, without machining the surface of the raw tube. On the other hand, Fuji Electric possesses unique technology for finely machining the substrate surface in order to support processes of modern color printers in which even minute interference is imaged.

3.2.5 Control of background noise

Requirements are increasing for better control of background noise than in conventional printers. This trend is especially noticeable for OPCs used in full-color printers that employ a color superimposing process. Background noise is a phenomenon in which toner adheres to an area of white paper and is caused by the charge potential drop on a drum surface due to the injection of charge at a small area from the substrate side. Fuji Electric is striving to control background noise by reducing the minute defects that cause charge injection from the substrate side. These defects can be prevented by selecting the optimum

Fig.8 Fatigue characteristics after strong exposure



substrate material and by unrestrained use of substrate cleaning technology, UCL material technology and painting technology.

3.2.6 Environment stability and durability of printing

OPCs are required to be unaffected by the environment during their prescribed life in order to maintain the initial imaging quality.

Figures 9 to 11 show measured data of the surface potential of commercially available MFPs equipped with an OPC having a diameter of 30 mm. These measurements were performed for 25,000 A4 size vertically-fed prints in the 2-print intermittent mode under conditions of normal temperature and normal humidity environment (N/N), low temperature and low humidity environment (L/L), and high temperature and high humidity environment (H/H) respectively, and the potential was measured every 5,000 prints. The measured results show excellent characteristics in every environment with no large potential fluctuation.

Fig.9 Surface potential stability by printing (N/N)

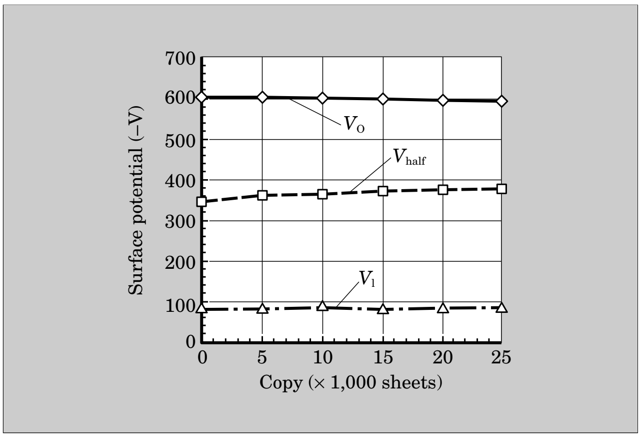


Fig.10 Surface potential stability by printing (L/L)

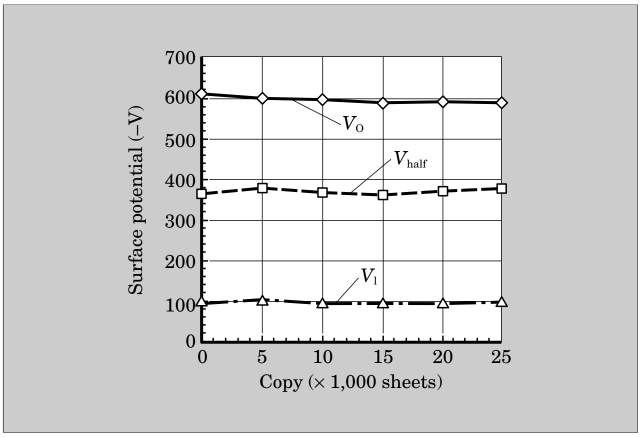
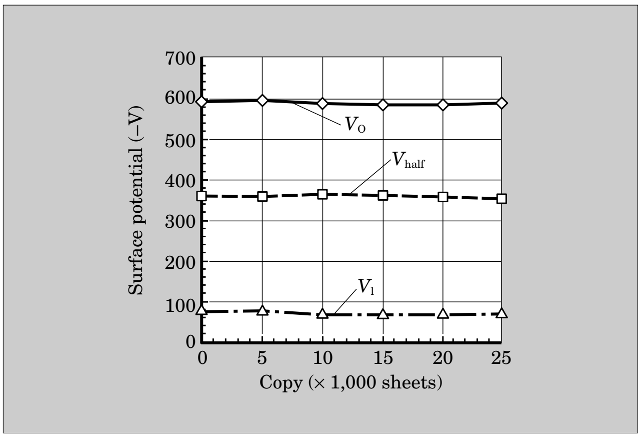


Fig.11 Surface potential stability by printing (H/H)



3.3 Technologies for high durability

3.3.1 Resistance to acidic gases

The contact charging method with rollers and brushes is the leading technology for page printers or personal-use MFPs, on the other hand, the corona charging method is still popular in large size printers or plotters and resistance to acidic gases such as ozone is required.

Various anti-oxide agents are used in OPCs, however, although increasing the quantity of agent improves the resistance to acidic gases, it leads to adverse electrical characteristics such as residual potential rise. Fuji Electric ensures sufficient resistance to acidic gases by utilizing material with deep ionization potential in the CTM, and also by combining appropriate anti-oxide agents. Specifically, appropriate anti-oxide agents having various actions are combined in the CTM for the purpose achieving maximum effect with least quantity.

3.3.2 Resistance to dielectric breakdown

The contact charging method is the leading technology for medium speed printers or MFPs as mentioned in section 3.3.1, and resistance to dielectric breakdown is required strongly compared with the corona charging method. Fuji Electric has developed and manufactured a UCL that provides resistance to dielectric breakdown which is equivalent to that of an anodized layer membrane (ALM). Table 3 shows the evaluated results of resistance to dielectric breakdown measured by fixing a charging component connected to an external power source on the drum surface. It is clear that resistance to dielectric breakdown of the

Table 3 Resistance to dielectric breakdown

Type	Supplied voltage to contact film (–kV)				
	6.0	6.5	7.0	7.5	8.0
ALM-Sample 1	Good	Good	Good	Good	Poor (breakdown)
ALM-Sample 2	Good	Good	Good	Poor (breakdown)	Poor (breakdown)
ALM-Sample 3	Good	Good	Good	Good	Good
UCL-Sample 1	Good	Good	Good	Poor (breakdown)	Poor (breakdown)
UCL-Sample 2	Good	Good	Good	Good	Poor (breakdown)
UCL-Sample 3	Good	Good	Good	Good	Good

UCL, similar to the case of the ALM, is provided up to 7 kV or higher.

3.3.3 High wear resistance

Life of the OPC is affected by the imaging system, through wear due to contact components such as the cleaning blade and paper, scratches that cause printing trouble and adhesion of toner or paper powder to the surface of the OPC (filming). Although the extent of these factors differs widely according to the respective component of the OPC or process design, high wear resistance, high hardness and low filming characteristics are required for OPCs.

Fuji Electric has also developed a resin having high wear resistance and lubricity through novel structural design of the OPC for digital PPC, and has endeavored to incorporate this resin into various process by adjusting its composition.

4. Conclusion

The characteristics required of photoconductors will advance much more in the future as electrophotographic printers evolve toward multi-functionality and high quality, and the functional classification between printers and PPCs will disappear. Fuji Electric will endeavor to provide excellent products that are friendly to the environment by pioneering development and manufacture of OPC products to meet market needs, together with promoting consistent development and manufacturing that includes cartridges.

Organic Photoconductors for Digital Plain Paper Copiers

Micho Shinozaki
Masahiko Kasahara
Shuichi Hamada

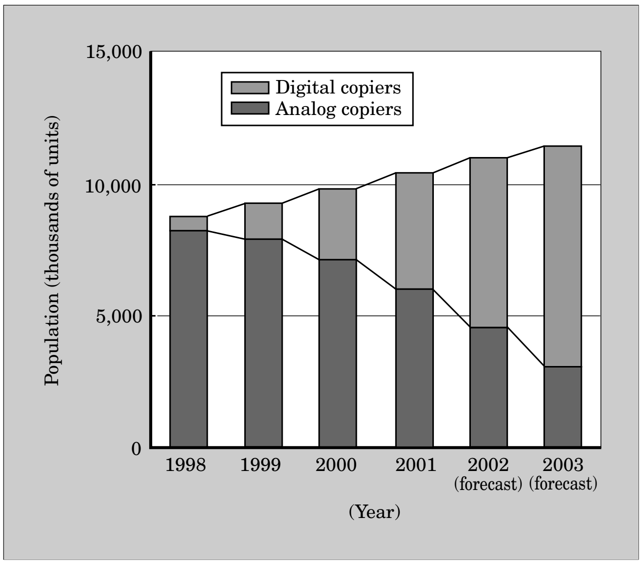
1. Introduction

Following the technical trends of the copier market each manufacturer has sought to realize higher speed, less maintenance and lower cost. In order to satisfy these requests, they have improved the sensitivity characteristics, stability and durability of photoconductors. Organic photoconductors (OPC) have developed especially rapidly because they are suitable for miniaturizing (diameter), can be manufactured at low cost, and furthermore they can be easily disposed of.

With the recent digital boom, digitalization has been progressing in the copier market too. Figure 1 shows the change in population of digital and analog copiers in USA market. The percentage of digital copiers was just under 30 % in 2000, but is estimated to grow to about 75 % in 2003.

Fuji Electric provides the type 9 series OPC for analog copiers and the type 10 series OPC for digital copiers. In this paper, we shall introduce an outline of the type 10 series OPC for digital copiers.

Fig.1 Population of digital copiers and analog copiers



2. Outline of the Product

Copiers that employ OPCs are classified as low-speed copiers (3 to 12 prints/min), medium-speed copiers (13 to 39 prints/min) and high-speed copiers (more than 40 prints/min) according to their copying speed. Fuji Electric has developed 3 types of OPCs that can be utilized in these copiers and applies them roughly in accordance with Fig. 2. Typical characteristics of these OPCs are shown in Table 1. Their applied ranges of sensitivity are different for each type but can be selected freely according to the customer's request.

The general structure of an OPC is shown in Fig. 3. The OPC shown in Fig. 3 is a layer-type OPC having separated function layers, and is formed from a

Fig.2 Applied range of copying speed, outer diameter of OPC and each type

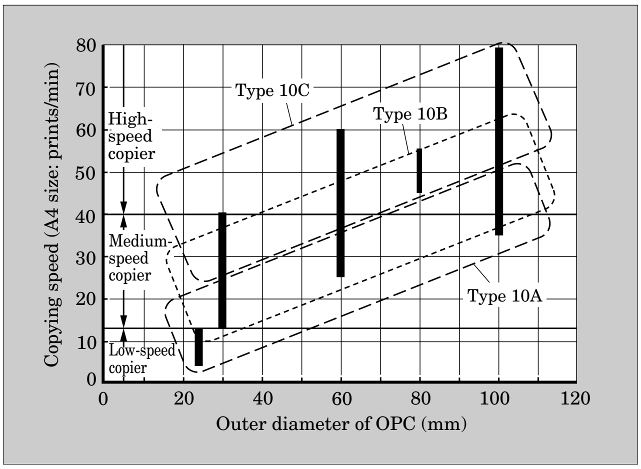


Table 1 Electrical characteristics

Item / Class	Half decay exposure in adopted sensitivity band ($\mu J/cm^2$)	Charging potential V_0 (V)	Retentivity (After 5 s) (%)	Half decay exposure ($\mu J/cm^2$)	Residual potential V_r (V)
Type 10A	0.30 to 0.50	–605	97.1	0.41	–35
Type 10B	0.15 to 0.30	–603	97.5	0.20	–21
Type 10C	0.07 to 0.15	–603	97.2	0.08	–9

Fig.3 OPC structure for digital copiers

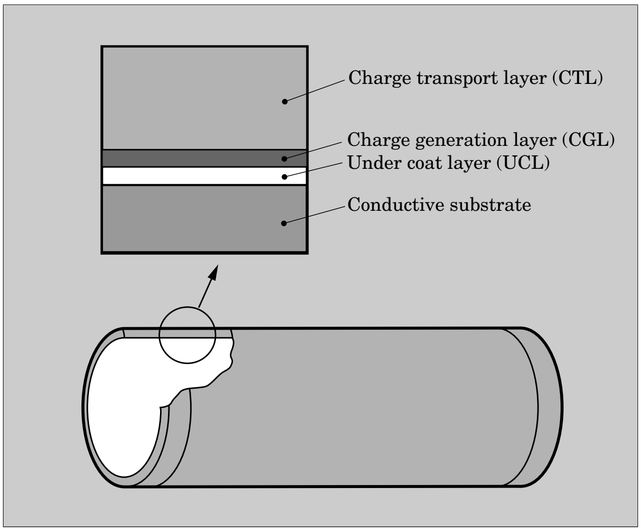


Fig.4 Spectrum sensitivity of OPC

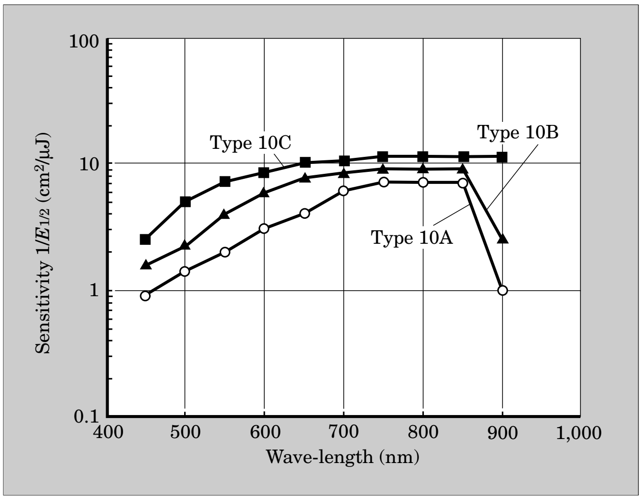
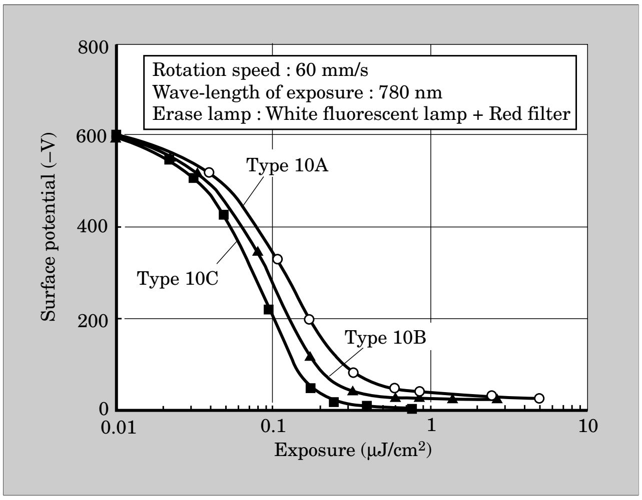


Fig.5 Photo-induced discharge characteristics of OPC



cylindrical conductive substrate coated, in succession, with a first under coat layer (UCL), a charge generation layer (CGL), and then a charge transport layer (CTL) which is the outermost surface.

The OPC for digital copier-use can utilize materials (type 8 series) that are also used in the OPC for printer-use. Therefore the technology accumulated for the type 8 series can be adapted to the type 10 series.

3. Special Features of the Product

By shifting from analog to digital copiers, the copier market is progressing toward multi-functionality, higher speeds and higher reliability. With these trends, the required characteristics for copiers are many and diverse. Therefore, we are advancing the development of materials in order to satisfy the required characteristics.

Fuji Electric's OPCs for digital copiers are suitable for all copiers, from low-/medium-speed copiers to high-speed copiers, and have the following features.

(1) High sensitivity
(2) High responsiveness
(3) High durability
(4) High reliability

3.1 High sensitivity

As a result of using a laser or LED (light emitting diode) as the exposure source, the digital copier requires sensitivity in the 600 to 800 nm of wavelength band. Fuji Electric utilizes a sensitive phthalocyanine pigment in this wavelength band. Figure 4 shows the spectrum sensitivities of types 10A, 10B and high sensitive type 10C. In the case of a digital copier, the wavelength of the exposure source is monochromatic light, and consequently we can design the OPC without consideration for color reproduction, as would be manifest in an OPC for an analog copier.

Figure 5 shows the photo-induced discharge characteristics observed in an actual copier. Comparison to types 10A, 10B, and to high sensitive type 10C shows about 50 % and 30 % higher sensitivity, respectively. Further, each type exhibits a sharp reduction in the region of residual potential, and therefore is favorable for the process design of copiers.

3.2 High responsiveness

There is a wide range of digital copiers, from low-speed to high-speed copiers. Among them, the high-speed copier, having printing speeds above 100 prints/min, which targets the on-demand copying market and POP (point of purchase) advertisement field, requires higher responsiveness in OPCs.

In order to improve the responsiveness, coordination of mobility and ionized potential between materials and their purities is very important. For improving the responsiveness, Fuji Electric has undertaken the challenge of developing charge transport materials (CTM) and has developed and produced a high mobility CTM that has a mobility of 5×10^{-5} cm^2/V·s and that has about 10-times higher performance characteristics

Fig.6 Developing characteristics

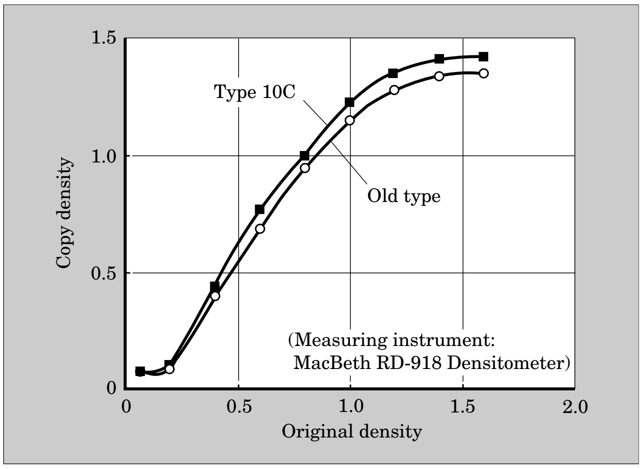
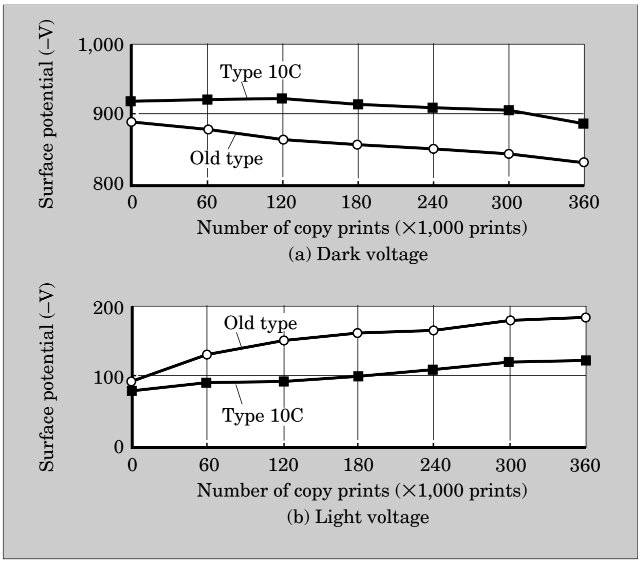


Fig.7 Running characteristics



than the old type. Figure 6 shows an example of an actual copier with enhanced developing. As a result of the improved responsiveness, print density (black density) was able to be improved compared to the old type.

3.3 High durability

The general modes of OPC's life-decreasing factors are classified in the following two categories:

(1) Life-decrease by electrical stress
  (a) Decrease of charge acceptance (Background)
  (b) Rise of residual potential (Decrease of copy density)
(2) Life-decrease by mechanical stress
  (a) Cut (Black line, white line)
  (b) Abrasion of photoconductive layer (Decrease of copy density, background)

3.3.1 Improvement of electrical characteristics

Functional material in the OPC undergoes a chemical change due to repeated exposure from corona discharge in the charging-exposure process, from ozone

Fig.8 Mechanical characteristics of OPC

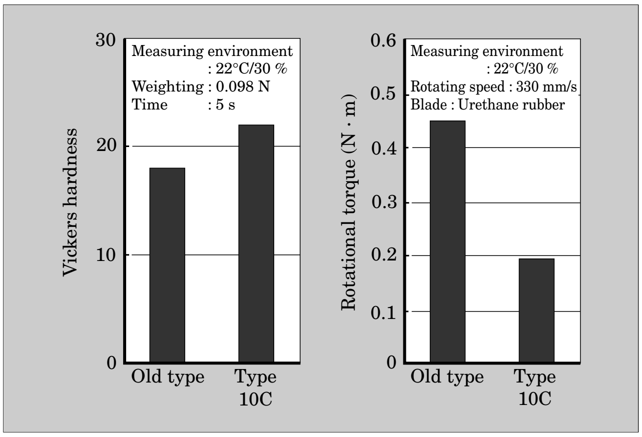
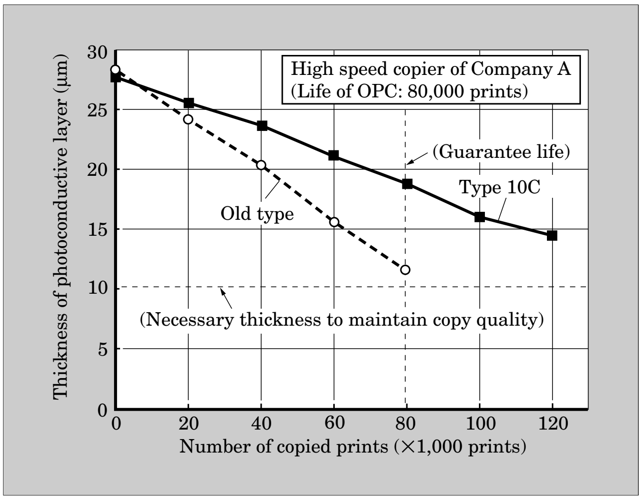


Fig.9 Abrasion of OPC



generated by the corona discharge process and from light. Consequently, characteristics become degraded, such as a decrease in charge acceptance or rise in residual potential, and these phenomena cause a decrease in print density and the background.

In order to control the degradation of charge acceptance and of print density, Fuji Electric has developed an original charge control agent for suppressing the generation of electrical defects in CGL and CTL, and has supplied OPCs that operate stably in several processes.

The change in surface potential of our typical digital copier is shown in Fig. 7. Compared to prior types, this new type exhibits only small changes in potential and print quality, and realizes an excellent OPC having stable operation.

3.3.2 Improvement of mechanical characteristics

In OPCs, life-decreasing physical and mechanical characteristics may occur due to contact with the cleaning-blade, charging roller, transfer roller, paper and toner, and consequently result in wear or cuts in the exposing layer and substance adhesion of toner or paper dust. The potential for each of these phenomena to occur differs according to the machine process, but

Table 2 Environmental test

Item	Condition
Ozone exposure test	100 ppm, 2 h
Light-induced fatigue test	1,000 lx, 5 min
Exposure test under high temperature	45°C, 1,000 h
Exposure test under high humidity	40°C, 90 % RH, 1,000 h
Exposure test under low temperature	–20°C, 1,000 h
Cycle test of temperature and humidity (5 cycles)	–20°C, 1 h → N/N, 0.5 h → 45°C, 1 h → N/N, 0.5 h → –20°C, 1 h (N/N: Normal temperature and normal humidity)

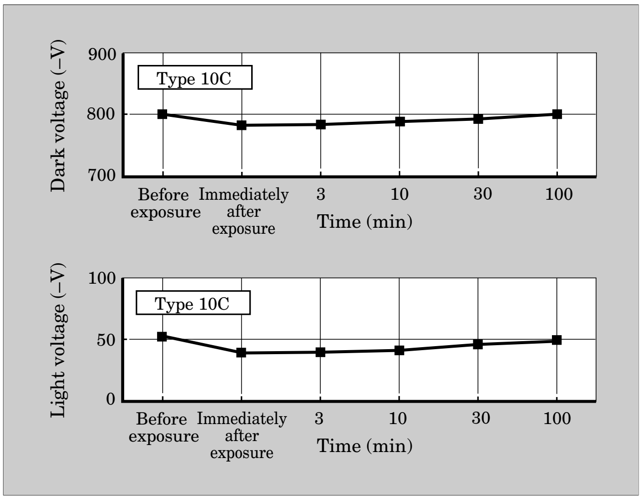
Table 3 Ozone-resistance characteristics of OPC

Class \ Item		Charging potential V_0 (V)	Retentivity (After 5 s) (%)	Half decay exposure (μJ/cm^2)	Residual potential V_r (V)
Type 10A	Before exposure	–603	97.4	0.42	–34
	After exposure	–602	94.8	0.43	–38
Type 10B	Before exposure	–601	97.1	0.18	–22
	After exposure	–603	95.1	0.18	–23
Type 10C	Before exposure	–601	97.3	0.08	–8
	After exposure	–603	95.6	0.09	–12

depends greatly on the performance of binder, which is a component of CTL. The binder performance is a big factor in determining the life of the OPC. Therefore the development of binder is important. Fuji Electric has introduced durability test equipment which is able to quickly estimate the binder performance, has promoted acceleration evaluation, and consequently has succeeded in achieving large improvement in the binder's performance.

Figure 8 shows mechanical characteristics (Vickers hardness, rotational torque of OPC) and Fig. 9 shows an example of improved wear and abrasion performance on exposed layers in a specific copier. By decreasing the friction with other contact parts, wear or abrasion of exposed layers are improved, and can lead to an approximate 50 % extension of OPC life. Fuji Electric tries to cut down the quantity of OPC waste by improving the life of the OPC.

Fig.10 Light-induced fatigue of OPC



3.4 High reliability

To quantify OPC reliability, the environmental tests shown in Table 2 have been carried out. The ozone-resistance test assumes an ozone atmosphere generated by corona discharge in the copier, and test data are shown in Table 3. Each characteristic is little affected even after 2 hours of exposure in a 100 ppm ozone atmosphere. The light-induced fatigue test assumes that the OPC is exposed to light during maintenance. Test data is shown in Fig. 10. The OPC was little affected after 5 minutes exposure to 1,000 lx of fluorescent light.

4. Conclusion

We have introduced Fuji Electric's OPCs for digital copiers, and described the high sensitivity OPC (Type 10C) in detail.

In the copier market, digital copying is becoming mainstream, so it is estimated that almost all copiers will be replaced by digital copiers after several years. Further, in the replacement by digital copiers, the trend toward multi-functionality requires printer, copy and facsimile functions to be integrated within the same machine, and consequently the boundary between printers and copiers will disappear gradually. Fuji Electric will continue to develop superior OPCs that provide required characteristics and precisely conform to the needs of market.

Process Units for Electrophotographic Machines

Seizo Kitagawa
Tadashi Asakawa
Yoshihiko Tanaka

1. Introduction

Electrophotographic machines, which are represented by copy machine (PPCs), fax equipment and printers, are expected to continue to develop into the future as important image output equipment that provides high image quality, high speed and low noise operation. Recent trends of electrophotographic machines include miniaturization, lowering of price, and shifts from analog to digital, from single function to complex function, and from monochromatic to color machines. The processing parts of these machines, the heart of the machines, will become standardized in order to enhance users' convenience and to facilitate the exchange of wear-and-tear parts.

Fuji Electric, as a manufacturer of photoconductors, has developed and manufactured selenium photoconductors and organic photoconductors (OPC), and recently is promoting the development and manufacture of process peripheral equipment aiming to add value to the products and to offer proposals for processes to our customers.

In this paper, an overview of our activities concerning process units is introduced.

2. Overview of Products

2.1 Composition of process unit

As shown in Fig. 1, in an electrophotographic machine, a process unit contains a photoconductor and integrates some or all electrophotographic processes, such as electrostatic charging, development and cleaning. This kind of process unit facilitates miniaturization of the equipment and stabilization of image quality and further eliminates the necessity of maintenance by service personal.

Fig.1 A schematic of printer
(Source: basic and application of electrophotographic technology, corona, 1988)

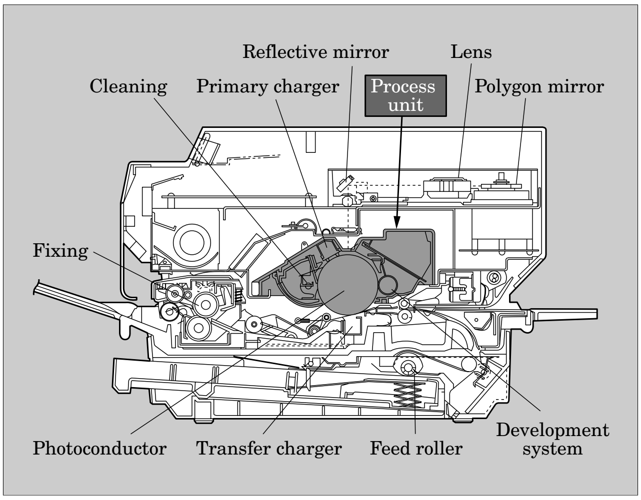
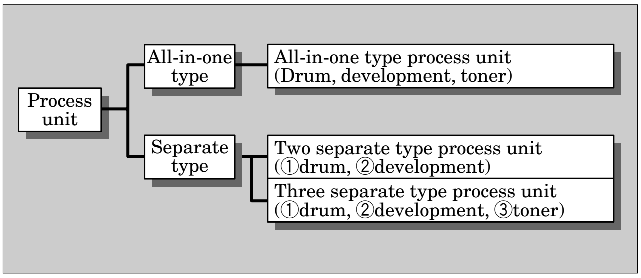


Fig.2 A system of process unit



2.2 Types and characteristics of process units

There are several types of process units as shown in Fig. 2, and each of which is utilized in accordance with the characteristics of the type of electrophotographic machine.

The all-in-one unit integrates all processes including the photoconductor, electrostatic charger, developer, toner, etc. This type of unit is supplied filled with toner. So, when the toner is used up, the entire unit, that is, all of the process should be exchanged. Accordingly, although handling is very easy, printing costs generally tend to be high because the life of the unit is determined by the amount of toner filled in the unit.

The separate unit has two types, the two-block separate type and the three-block separate type. The former contains a photoconductor, charger and cleaner in one unit (drum unit) and developer and toner in another unit. For this type of unit, when toner is used up, the entire unit can be refreshed simply by exchanging the development unit, while the drum unit having a longer life can remain unchanged. Accordingly, this type has an advantage of lower running cost compared to the all-in-one type.

In the latter type, the toner container is separated from the development unit. This type of machine has an advantage in that each component unit can be exchanged according to the life of each individual process, but also has a disadvantage of less easy handling compared to the other two types. This type of unit is the least wasteful and has the lowest running cost.

3. Market Trends

The North American and European markets for electrophotographic machines such as PPCs, facsimile machines and printers occupy about 80 % of the global market. Figures 3 and 4 show the predicted changes in market scale for process units for electrophotographic machines in these two regions. Although electrophotographic machines compete with ink jet printers in the field of low-speed machines, they are expected to grow steadily in the fields of medium- and high-speed machines because of their advantages of high-speed and high resolution.

Further, the predicted market scale for each type of process unit in Japan is shown in Figs. 5 and 6. Also, the same steady growth is expected in Japan as in foreign markets. For 2001, all-in-one units occupy about 80 % of the market in terms of monetary amount and about 70 % in terms of quantity. However, the percentage occupied by the separate units, with separate drum unit and development unit, is estimated to increase in the future.

For this enlarging market, countermeasures for the global environment are required. All the manufacturers are requested to contribute to strengthening recycling measures and to conserve the earth's resources. In the past, used units were treated and disposed of as industrial waste. However in recent years, each manufacturer is starting to collect used units and to recycle some of them. In the future, collection and recycling will increase and a unit design suitable for recycling will become required.

4. Activities of Fuji Electric

4.1 History of process unit business

As a manufacturer of photoconductors, Fuji Electric has developed various types of selenium photoconductors and OPCs for many years. Our research

Fig.3 The market scale prediction of process units (quantity)

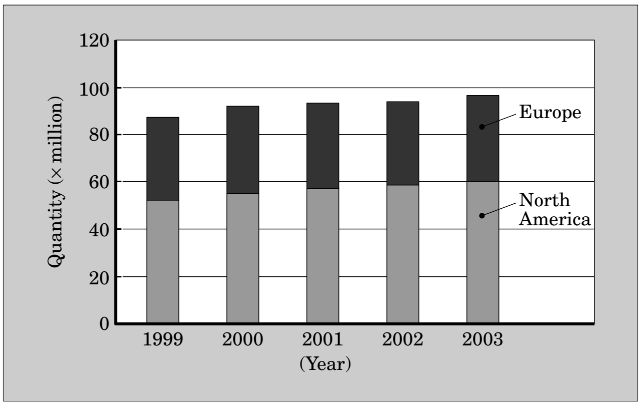


Fig.4 The market scale prediction of process units (the sales)

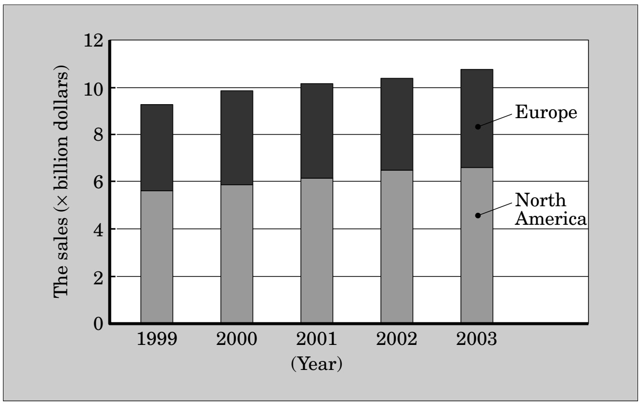


Fig.5 Japanese market scale prediction of process unit (quantity)
(Source: reproducts sweeping over Japanese cartridge market, data supply, 2001)

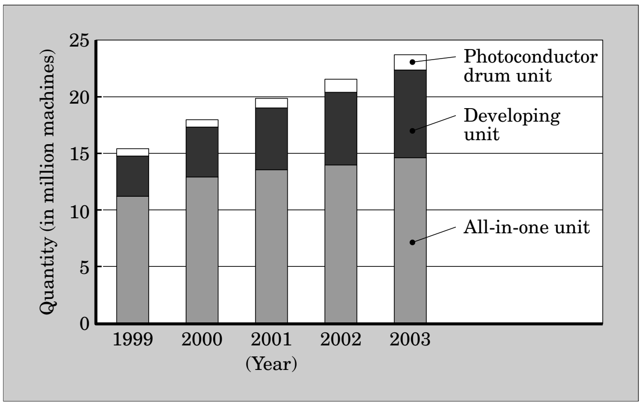
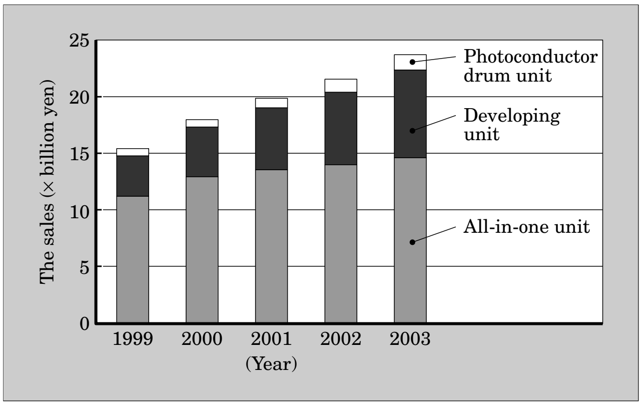


Fig.6 The market scale prediction of process units (the sales)



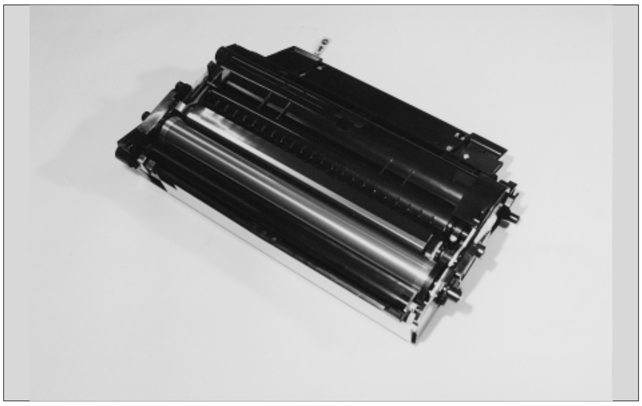
efforts have sought to discover the optimal photoconductor that functions most suitably for each type of electrophotographic process in various types of ma-

Table 1 History of process unit product development

Year	Status
1986	Starting up production of drum unit for PPC at Fuji Electric, Matsumoto factory (using Selenium photoconductor drum for copy machine)
1987	Starting up production of drum unit for PPC at Hong Kong Fujidenki Co., Ltd. (using Selenium photoconductor drum for copy machine)
1990	Starting up production of drum unit for PPC at Hong Kong Fujidenki Co., Ltd. (using positive charging type OPC drum for copy machine)
1995	For processing unit production, Fusui Electric Co. Ltd. was founded in Guangzhou, China. (Fig. 7)
1996	Starting up production of three divided type process unit for A4 size printer at Fusui Electric Co. Ltd. (using negative charging type OPC drum for printer)
1997	Starting up production of three divided type process unit for A3 size printer at Fusui Electric Co. Ltd. (using negative charging type OPC drum for printer)
1998	Starting up production of two divided type process unit for A4 size printer at Fusui Electric Co. Ltd. (using negative charging type OPC drum for printer) Starting up production of toner unit for copy machine
1999	Starting up production of toner unit for color printer

Fig.7 Fusui Electric Co. Ltd. in Guangzhou, China (process unit production center)

Fig.8 An example of mass-produced process unit



chines. We have also endeavored to develop the most stable process. As a result, our products have been adopted by many machine manufacturers. Our technology to match our products to customers' processes is highly appreciated by our customers. And at present, we produce not only photoconductors but also process units equipped with photoconductors as well as toner units.

Further, in order to increase our production of process units, we are working to develop and commercialize the process units. Fuji Electric's activities concerning electrophotographic process units up to now are shown in Table 1.

Fuji Electric continues to develop products under a fully integrated system in which development design is performed at our Matsumoto Factory and production is performed at Fusui Electric Co. Ltd. in Guangzhou, China. Figure 8 shows an example of our products.

4.2 Development of positive charging type process unit

Nowadays manufacturers of electrophotographic machines are competing with one another in trying to reduce the price of their products (that is, the reduction of initial costs and running costs for users) and to improve printing speed and image quality. Realization of these goals such as low price, long life and high performance are also required for photoconductors. Accordingly, Fuji Electric started to develop positive charging type OPCs upon realizing that they are more advantageous in principle compared to conventional negative charging type OPCs. Fuji Electric fully leveraged its own capabilities to develop organic materials, made full use of product development capabilities (application development capabilities) that had been cultivated through development of selenium photoconductors, and applied its OPC mass production technology. As a result, we have succeeded in developing and commercializing a positive charging type OPC capable of providing higher speed and higher resolution than a conventional negative charging type OPC and in reducing the price of the machine.

However, the positive charging type OPC had a

Fig.9 An example of Fuji developing process unit (positive charging type)

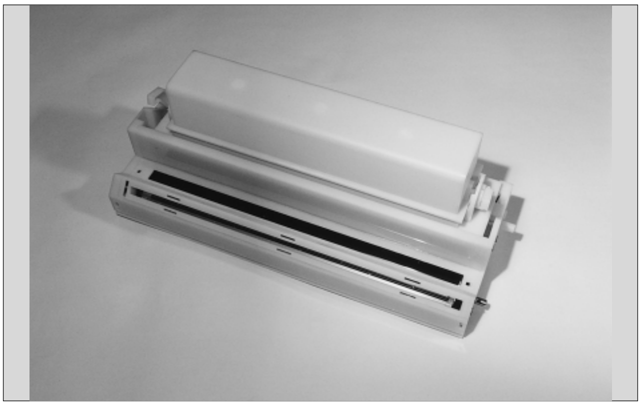


Fig.10 A transition of drum surface potential in negative charging process

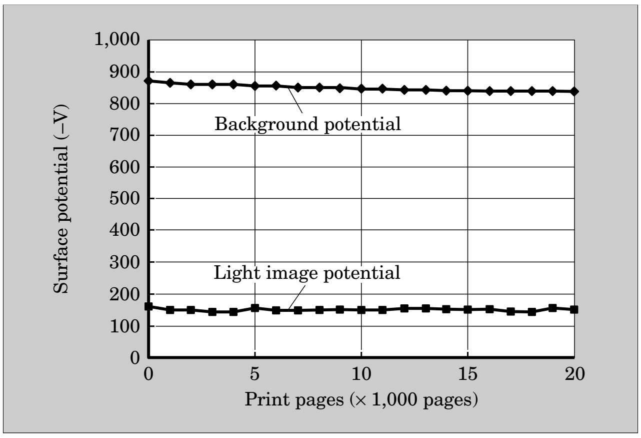


Fig.11 A transition of drum surface potential in positive charging process

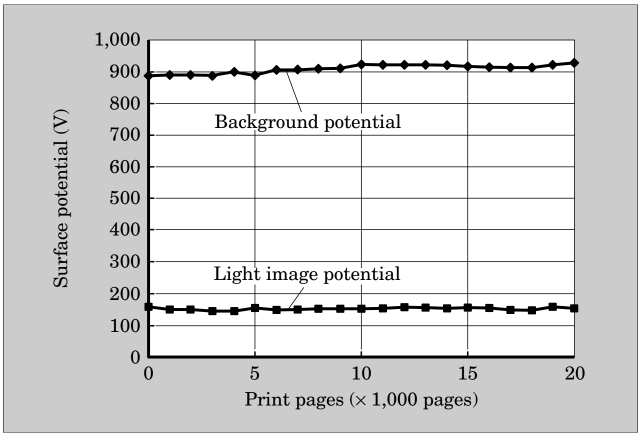


Fig.12 A transition of image density in negative charging process

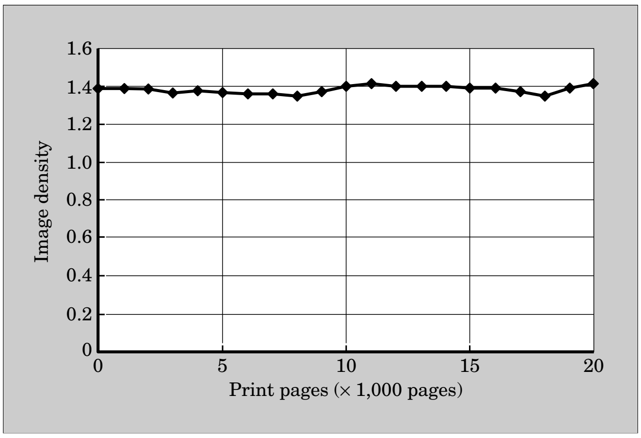


Fig.13 A transition of image density in positive charging process

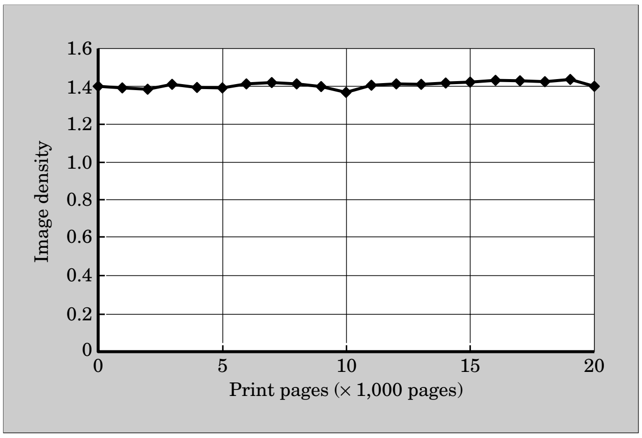


Fig.14 Tone property in negative charging process

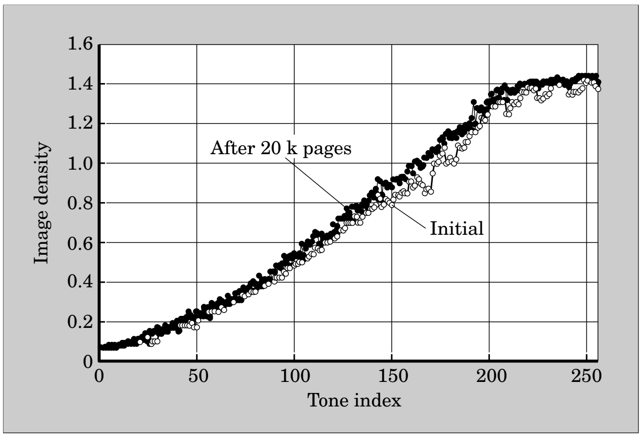
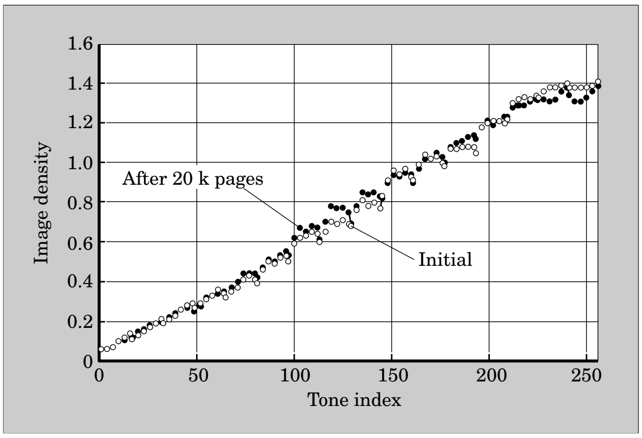


Fig.15 Tone property in positive charging process



problem in that it required a process different from that of the traditional negative charging type OPC, and adoption of the positive charging type process (positive charging type OPC) was difficult even though its superiority to the negative charging type OPC had been recognized. Fuji Electric considered it necessary to overcome this limitation in order to enlarge the application range of this advantageous photoconductor and we therefore developed a positive charging type process unit as shown in Fig. 9. Through the process development for this photoconductor, we aim to be able to propose optimum processes to our customers and ultimately to develop, design and produce process units that include photoconductors.

4.3 Results of comparative experiment of positive charging type and conventional type units

Characteristics of the original negative charging type process applied to a commercial printer and those of the positive charging process unit of Fuji Electric applied to a commercial printer which was modified to the positive charge process were researched, and the results are given in Figs. 10 to 15. Figures 10 and 11 show the change of drum surface potential for negative and positive charging processes while running under the environmental conditions of normal temperature and humidity, respectively. Also the positive charging process exhibits stable potential characteristics, the same as those of the negative charging process.

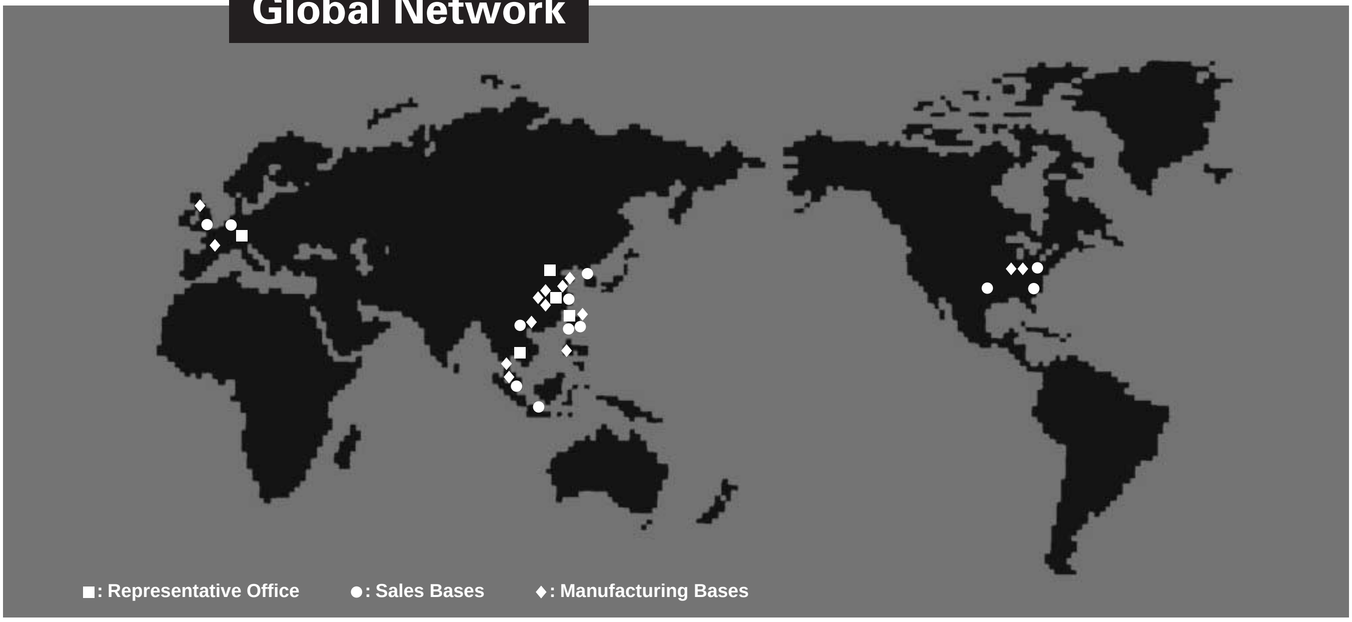
Figures 12 and 13 show the change of image density for negative and positive charging processes while running under the environmental conditions of normal temperature and humidity, respectively. Moreover, the positive charging process exhibits stable image density, the same as that of the negative charging process.

Figures 14 and 15 show the tone property of negative and positive charging processes while running under the environmental conditions of normal temperature and humidity, respectively. Tone property of the positive charging process is better and more stable than that of the negative charging process. Thus, the positive charging type process is recognized as having higher resolution and better stability. This suggests that this process will exhibit superiority not only in monochromatic high-resolution machines but also in color machines.

5. Conclusion

Regarding the electrophotographic machine, it is forecast that the trends toward digital, complex and color machines will continue to progress, accompanied with lower prices. Corresponding to such trends, lower price, longer life and higher performance are also required of the process unit, which is the heart of the machine. Further, easiness of recycling is also required for the sake of environmental protection. Fuji Electric intends to continue to develop process units corresponding to these requirements, centered about the positive charging type OPC, and further intends to promote actively the unit recycling business.

Global Network



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