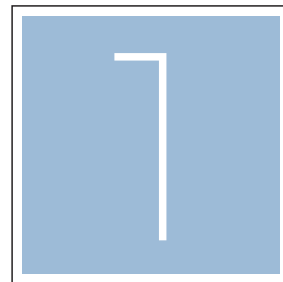
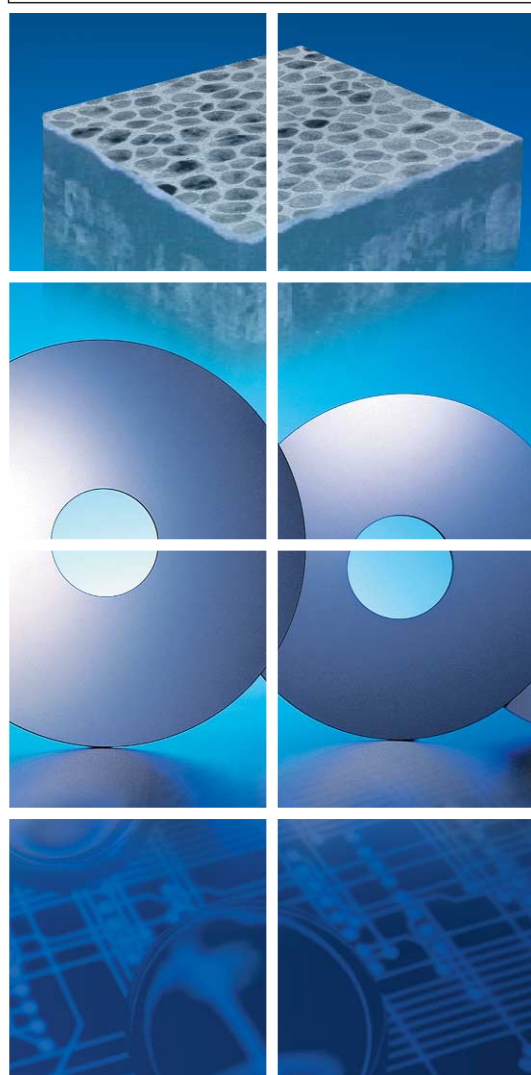


FUJI ELECTRIC REVIEW

Magnetic Recording Media
Photoconductor



2005 VOL.51



Fuji Electric Group

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▲ Photoconductors

For digital copiers, color printers compatible with on-demand printing and the like, Fuji Electric is early to develop new products according to market needs and is also working to reduce ozone emissions and the like in consideration of the environment.

Fuji Electric's Imaging Devices

FUJI ELECTRIC REVIEW

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Cover photo:

As a large capacity memory for the recording, playback and storage of digital data, the hard disk drive (HDD) was first used in personal computers, and now its range of application is expanding to mobile information equipment, cellular phones, and the like.

Fuji Electric has a successful track record in developing, manufacturing and marketing magnetic recording media, a basic component of HDDs. In response to the ongoing HDD trends toward smaller size and larger capacity, Fuji Electric's research and development efforts are focused on combining its proprietary leading-edge technology to advance the goal of realizing dramatically higher densities of magnetic recording media.

The cover photograph shows the outward appearance of magnetic recording media housed in an HDD, and also shows a rendering of the magnetic layer structure of perpendicular recording media for which commercialization is anticipated in the future as an extremely high density magnetic recording media.

Longitudinal Al Substrate Magnetic Recording Media

Shoji Sakaguchi
Kazuo Nimura
Yoshiharu Kashiwakura

1. Introduction

As recording capacities increase and uses for digitally recorded data expand, the recording methods for magnetic recording media and the types and sizes of substrates used in that media are diversifying. At present, most of the magnetic recording media being manufactured by Fuji Electric is longitudinal aluminum substrate media that uses an aluminum substrate on which NiP is plated over an aluminum alloy, and in which magnetization of recorded bits is oriented in a circumferential (longitudinal) direction in the plane of the substrate. This magnetic recording media is used primarily in personal computers and servers. As storage capacities for electronic media have increased, higher recording densities have been developed for longitudinal aluminum substrate magnetic recording media. The recording densities of products released to the market have increased from 30 Gbits/in² in 2001, to more than 60 Gbits/in² in 2002, and to more than 90 Gbits/in² in 2004.

In order to realize these types of higher densities, Fuji Electric is developing elemental technologies and is focusing on texturing technology, magnetic technology and head-disk interface technology. This paper discusses the status of Fuji Electric's technical developments thus far, and also describes technical trends for realizing high densities of more than 100 Gbits/in².

2. Texturing Technology and Cleaning Technology

2.1 The objective of texturing

Magnetic recording media is formed by fabricating multiple layers of metallic and non-metallic thin films on top of a nonmagnetic substrate. The properties of the substrate surface are known to exert a large influence on the characteristics of the magnetic recording media.

At present, the substrate most commonly used for longitudinal recording consists of an aluminum base metal that is plated with a layer of NiP and then processed to a mirror finish. That surface is then textured to form a microroughness in the circumferential direction.

This texturing has the following two objectives:

- (1) To ensure flying stability of the magnetic head over the magnetic recording media
- (2) To orient the direction of magnetization in the circumferential direction of the substrate

The first objective of ensuring flying stability of the magnetic head can be achieved by performing texturing to form a dense roughness in the circumferential direction of the substrate. Fuji Electric aims to reduce the effective surface area further in order to prevent adhesion with the magnetic head.

The second objective depends largely on the electrical characteristics. With magnetic recording media for longitudinal recording, it is preferable that the magnetic orientation (the direction of easy magnetic alignment) is oriented in the circumferential direction of the substrate. Texturing aligns the magnetic orientation in the circumferential direction of the substrate by generating stress in the thin film crystals along the direction of the texture. This orientation is largely determined by the contour of the texture, and therefore, the quality of magnetic recording media products is largely dependent on the texturing.

2.2 Characteristics and dependencies of textured surfaces

One indicator of texturing is the R_a (center line average roughness) value. This R_a value is closely related to two contradictory characteristics of the abovementioned objectives. Figure 1 shows this relationship. When the R_a of a substrate surface is small, the flying performance of the magnetic head is favorable, but on the other hand, the magnetic orientation ratio (OR, the ratio of magnetism in the circumferential direction to magnetism in the radial direction of the substrate) worsens and the signal to noise ratio (SNR) of the magnetic recording media (ratio of the output signal to noise) also worsens. Accordingly, technical development is needed to improve the OR while maintaining good flying performance of the magnetic head.

As an example, Fig. 2 shows the relationship between the tip radius of curvature and OR at the time of texturing. Even at the same R_a value, OR increases when the tip radius of curvature is small, thereby

improving the performance of the media.

The tip radius of curvature is determined according to the processing cloth, slurry (mixture of the coolant and abrasive diamond grains), and the processing conditions.

There are five basic control parameters, and these are listed below:

- (1) Workability of the coolant in the slurry
- (2) Shape of the abrasive diamond grain in the slurry
- (3) Number of rotations of the substrate during texturing
- (4) Processing force during texturing
- (5) Material and diameter of the fibers in the processing cloth

These parameters can be combined appropriately to produce a surface condition that provides a magnetic flying head performance and OR that are both satisfactory.

2.3 Cleaning quality

The OR described above is largely influenced by the quality of substrate cleaning after the texturing

Fig.1 R_a dependence on OR and head flying height

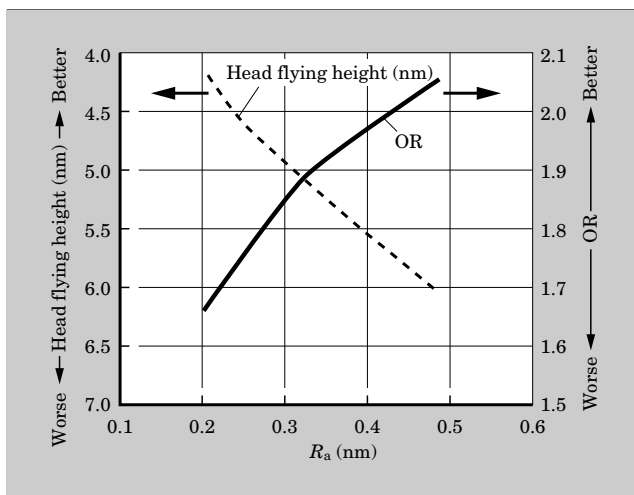
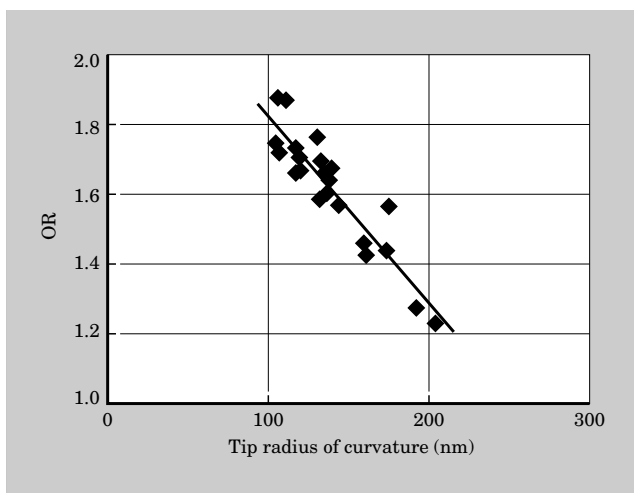


Fig.2 Tip radius of curvature dependence on OR



process. It is important that the coolant used in texturing is thoroughly removed in order to obtain a clean surface condition with low residue. Fuji Electric presently maintains media performance by monitoring, at the nanogram-level, the amount of surface residue per disk at the stage prior to magnetic film deposition.

2.4 Residue reducing methods

Listed below are the three main ways to reduce the amount of substrate surface residue prior to magnetic film deposition:

- (1) Use of a coolant with good cleaning performance
- (2) Use of a cleaning agent having good cleaning performance and rinsability
- (3) Reduction of the occurrence of drying spots

To implement item (1) above, it is necessary to improve the cleaning performance without degrading the texturing performance. Item (2) requires the use of a cleaning agent based on consideration of its permeability (removal of solid matter), emulsification and dispersability (removal of oil content) with regard to the coolant, and also its absorption into the NiP surface. The reduction of drying spots in item (3) is extremely difficult to achieve in magnetic recording media formed with an interior hole.

In the types of media currently being mass-produced, the occurrence of drying spots is controlled by reducing the surface residue. To achieve an even cleaner substrate surface, an advanced hot deionized water pull-up drying method is utilized. A substrate free from drying stains can be produced by immersing the substrate in a tank of heated ultra-pure water, slowly lifting out the substrate to disperse residue components on the substrate into the ultra-pure water and obtain a clean condition, and then to spray a gas such as nitrogen gas or isopropyl alcohol (IPA) having higher volatility than the water onto the substrate at the top of the water tank.

2.5 Next generation-compatible texturing and cleaning technology

For the next generation of magnetic recording media having recording capacities of greater than 120 Gbytes/disk, the space between the flying head and the magnetic disk is expected to become smaller than in the past (less than 5 nm), and technologies capable of texturing more precise roughnesses and providing higher degrees of cleanliness will be required. Rather than extend previous technologies, technical development that incorporates new methodologies will be necessary.

Figures 3 and 4 show the surface contours of an image obtained by an atomic force microscope (AFM) and a comparison of the magnetic head flying performance (glide avalanche) for the textured media used in an existing 80 Gbytes/disk product and for the latest textured media. By reducing the tip radius of curvature, Fuji Electric has developed texturing technology

that decreases the R_a value (0.2 nm), maintains the OR, and enhances the magnetic head flying performance. This technology will be used for the first time in next generation products.

With the miniaturization of the size of recording bits, cleaning technology requires lower levels of adherents than in the past and the capability to identify adherent properties. There is also an urgent need to development a new cleaning method that

Fig.3 AFM image of substrate surface

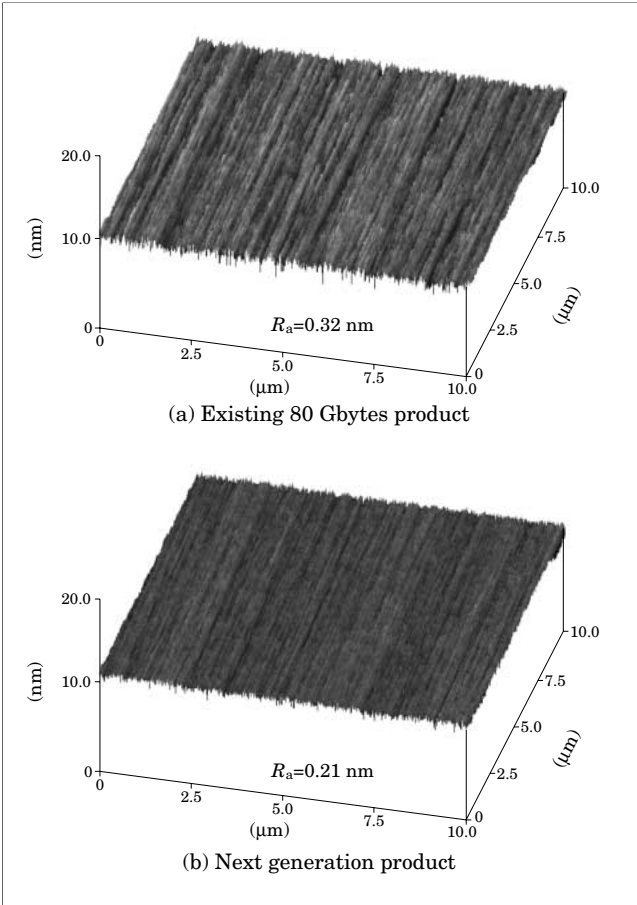
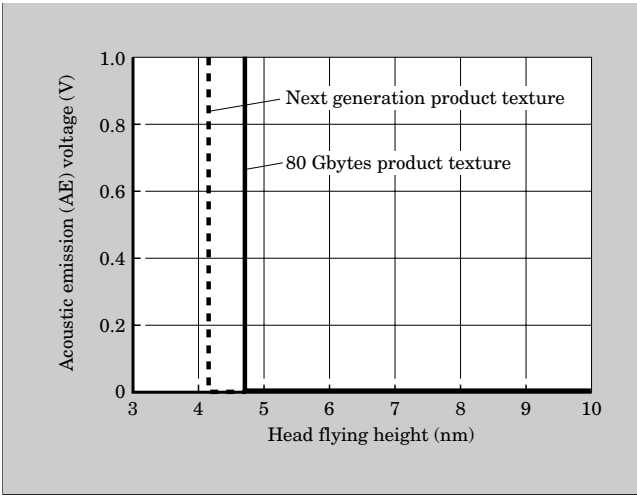


Fig.4 Results of glide avalanche test



includes analytical techniques.

3. Magnetic Technology

3.1 Basic layer structure of magnetic recording media

Various magnetic recording technologies are incorporated into magnetic recording media in order to achieve optimal magnetic characteristics.

Figure 5 shows an example of the layer structure of longitudinal aluminum substrate media. Multiple layers of thin metal films are formed on top of a NiP-plated substrate, and on top of those multiple layers, a carbon overcoat layer is formed to protect the magnetic recording media from the sliding contact generated between the media and the magnetic head. Then, a liquid lubricating film is coated on top of the carbon overcoat and the abovementioned texturing of the substrate surface is performed.

The multiple thin metal films are designed to have extremely fine film thicknesses, ranging from about 0.8 nm to about 15 nm for a relatively thick film. These thin metal films each have their own individual function. An underlayer, consisting of Cr and a Cr alloy, is provided so as to align the crystalline orientation of the above magnetic layer in the plane of the substrate. An intermediate layer, formed from a Co alloy thin film, is provided to increase the crystal conformation between the underlayer and the magnetic recording layer, and to reduce crystal defects in the magnetic recording layer. The magnetic recording layer is the film onto which magnetic signals are actually written, and is formed from a Co alloy,

Fig.5 Layer structure of magnetic recording media

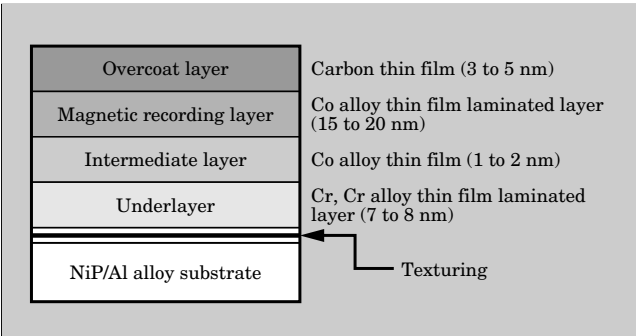
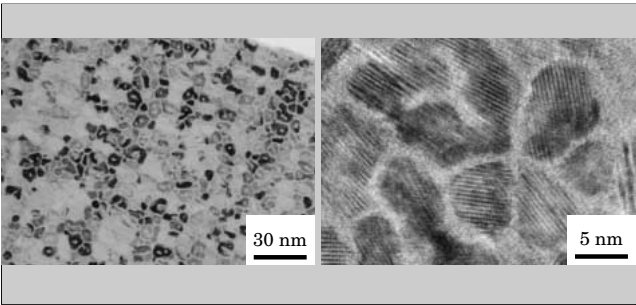


Fig.6 TEM plane image of magnetic recording media

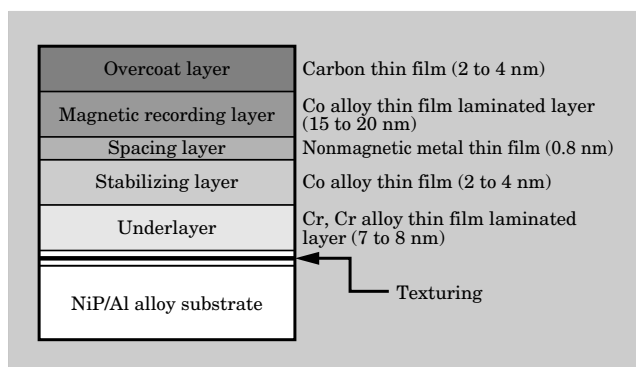


typically consisting of Co with additional elements of Cr and, according to the purpose and function of this layer, Pt, Ta, B, and the like. Figure 6 shows a plane view of a magnetic recording layer imaged using a transmission electron microscope (TEM). The magnetic recording layer is an aggregate of multiple Co alloy grains. At present, the average grain size is approximately 7 nm, and this grain size has been shrinking year after year as recording densities increase. At recording densities greater than 100 Gbits/in², the length of a single recording bit will shrink to approximately 30 nm and the size of the Co crystal grains will have to be reduced to about 6 nm. However, when the size of the Co crystal grains is reduced, the problem of thermal decay becomes noticeable. Thermal decay is a phenomenon in which the magnetically recorded signal decays and is eventually erased due to the influence of ambient temperature. As a small magnet will lose its magnetism, smaller sized Co crystal grains more easily lose their magnetism. The Co crystal grain size must be designed based on an understanding of the relationship between recording density and thermal decay.

3.2 Layer structure of AFC media

In order to suppress the problem of thermal decay, Fuji Electric has been using AFC media since 2003 in its magnetic recording media of 60 Gbits/in² and above. AFC media is a type of magnetic recording media that relaxes the problem of thermal decay by utilizing anti-ferromagnetic coupling. The layer structure of AFC media is shown in Fig. 7. In this AFC structure, the intermediate layer of Fig. 5 has been replaced by a stabilizing layer and a nonmagnetic spacing layer. By controlling the thickness of the spacing layer and the magnetic characteristics of the stabilizing layer within certain ranges, the magnetic orientation of the stabilizing layer can be aligned in a direction opposite to the magnetization of the magnetic recording layer. In this manner, resistance to thermal decay can be enhanced by increasing the thickness of the total magnetic layer (magnetic recording layer + stabilizing layer) without increasing the magnetic signal which is a source of media noise.

Fig.7 Layer structure of AFC media



3.3 Improvement of recording density

The direction in which magnetic technology development is being advanced to increase the recording density of magnetic recording media is nearly the same regardless of the size of the recording density. Specifically, the following items are important for development:

- (1) Miniaturizing the Co grains
- (2) Weakening the magnetic interactions among Co grains
- (3) Controlling the crystalline orientation
- (4) Increasing the thermal stability of the recorded signal

Although the direction of development does not change, higher recording densities require a higher level of performance. To satisfy those requirements, the alloy design, layer structure design and process design are continuously being optimized.

3.4 Alloy design

Many types of alloys are used in the thin metal films of magnetic recording media according to the desired function.

The underlayer is formed from pure Cr having a favorable crystalline orientation, a Cr alloy containing additional elements of V, Mo, W, Ti or the like in order to regulate the spacing of the crystal lattice and to increase crystal conformation with the Co magnetic thin film, or a Cr alloy containing an additional element of B or the like in order to reduce the size of the crystal grains. Recent magnetic media that exceeds 60 Gbits/in² is typically designed with a laminated structure that combines multiple functions in two to three layers of these metal alloy thin films.

The magnetic recording layer is based on the conventionally-used CoCrPt alloy and contains a B additional element in order to reduce the size of the crystals and to promote a segregated structure and additional elements of Ta, Cu and the like to regulate the crystal structure. The types of additional chemical elements and their quantities are important factors in the design of the magnetic layer composition. Increasing the quantities of Cr and B, which are effective in shrinking the size of Co grains and in reducing the magnetic interactions among grains, also effectively reduces the media noise. However, because the magnetism of the Co grains is weakened, the thermal stability of the recorded signal deteriorates. Conversely, if the quantities of Cr and B additional elements are limited to small amounts, the thermal stability improves but media noise increases. Recently, two or more magnetic recording layers having different compositional ratios of Cr and B are being used to maintain a balance between low noise and thermal stability.

3.5 Design of the layer structure

When designing the layer structure, the designer

must take care of the thickness of each film and the ratio of film thicknesses. From prior experience it is known that when the film thickness of the Cr and Cr alloy underlayer increases, the size of Co grains also increase in the magnetic recording layer formed above. This phenomenon also applies to the stabilizing layer that is formed between the underlayer and the magnetic recording layer. Figure 8 shows the relationship between Co grain size in the magnetic recording layer and thickness of the stabilizing layer. By simply increasing the designed thickness of the stabilizing layer from its usual value of about 3 nm to a thickness of 5 nm, the Co grain size in the above-laminated magnetic layer will increase by 8 % or more. An increase in crystal grain size invites an increase in media noise and is one cause of SNR degradation as shown in Fig. 9. (A higher SNR value enables recording density to be increased.) As in this example, it is important that the layers of magnetic recording media be designed such that each layer is as thin as possible.

Recent magnetic recording media is typically de-

Fig.8 Co grain size dependence on stabilizing layer thickness

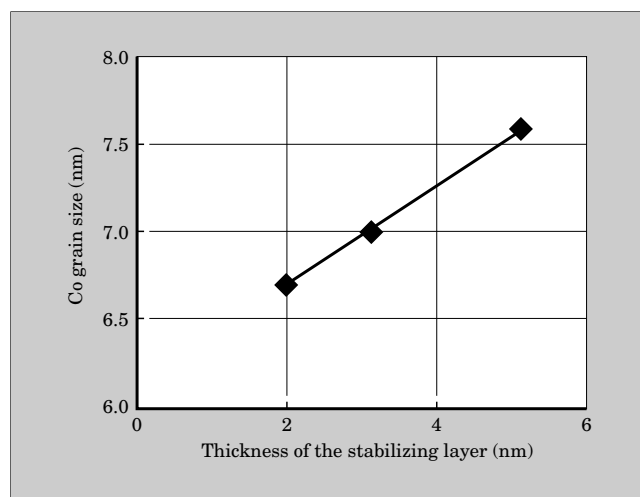
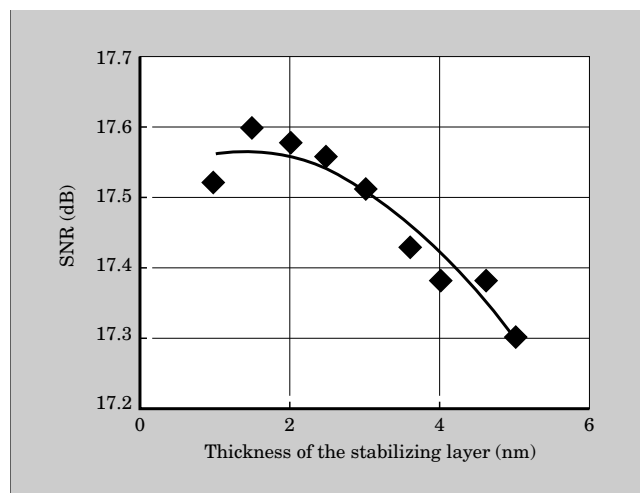
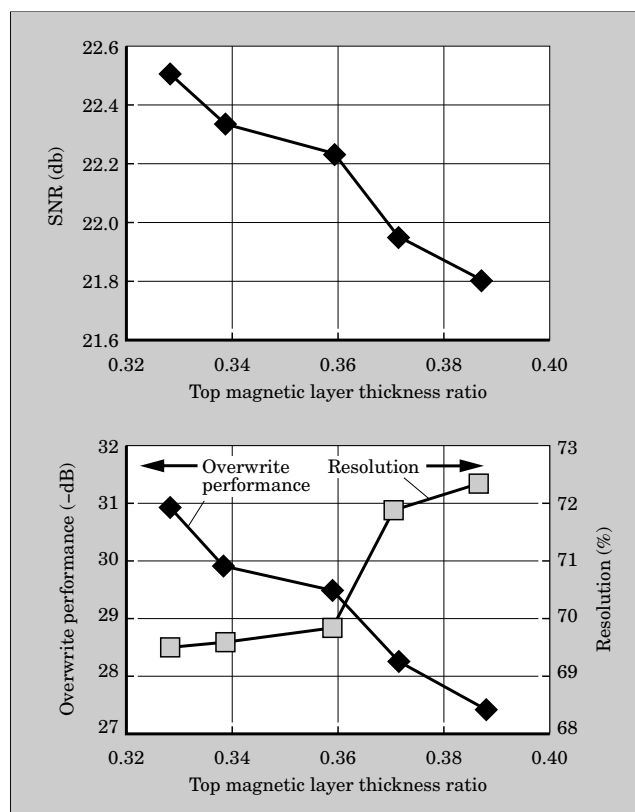


Fig.9 SNR dependence on stabilizing layer thickness



signed with a laminated layer structure of two or more magnetic thin films, and the ratio of those film thicknesses is an important design consideration. Figure 10 shows the relationship between read and write (R/W) properties and the top magnetic layer thickness ratio in the case where two magnetic layers have been laminated together. The R/W properties have a large dependency on the magnetic layer thickness ratio. The optimal film thickness ratio depends on the combination of magnetic layer compositions and the capability of the magnetic head that reads and writes signals. However, the optimal R/W properties are obtained in a narrow range of magnetic layer thickness ratios, and film deposition technology capable of controlling the thickness ratio within this narrow range is required. Fuji Electric has optimized its film deposition equipment, processes and film thickness control methods in order to achieve a high level of film thickness control and to produce magnetic recording media stably without fluctuation of the magnetic layer thickness ratio. Moreover, by enhancing TEM analysis technology and introducing synchrotron radiation analysis (using the SPring-8 facility) to enable the analysis of crystalline structures having film thicknesses of 1 nm or less, Fuji Electric is strengthening its thin film analysis technology and establishing guidelines for the design of layer structures.

Fig.10 R/W properties dependence on top magnetic layer thickness ratio



3.6 Film deposition process

The magnetic characteristics and R/W properties of magnetic recording media depend on film deposition process conditions including heating temperature of substrate, film deposition pressure, the rate of film deposition, and the substrate bias. As an example, Fig. 11 shows the change in SNR characteristics when a substrate bias is applied during deposition of the magnetic layer. The magnetic recording layer used in this case had a laminated structure consisting of two magnetic layers, and the application of a substrate bias to the bottom magnetic layer (layer closer to the substrate) caused the SNR characteristics to improve, but the application of a substrate bias to the top magnetic layer (layer further from the substrate) resulted in no noticeable improvement in the SNR characteristics. The application of a substrate bias has the effect of increasing the energy of the sputtered grains, thereby forming a dense film with few defects. The application of a substrate bias also has the effect of changing the lattice spacing of the crystals and increasing the substrate temperature. Because these effects interfere with one another, a film can be classified as exhibiting a good effect, no effect or an adverse effect in response to the application of an applied substrate bias.

Fuji Electric optimizes the deposition process to attain the greatest performance for improving its layer and alloy design accompanied by the progress of generation.

Fig.11 SNR dependence on bias

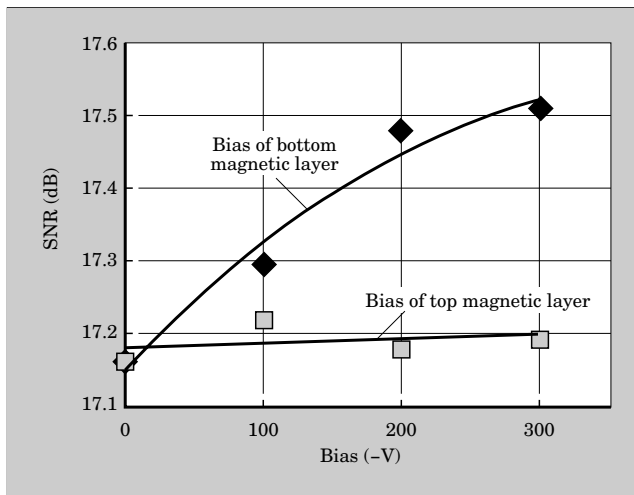


Table 1 Comparison between new media and old media

	End of 2002	February 2004
SNR	15.98 dB	17.15 dB
Overwrite performance	-28.7 dB	-30.4 dB
Resolution	59.1 %	63.1 %
Signal decay rate	-0.35 %	-0.26 %

3.7 Next generation-compatible magnetic technology

Table 1 compares the R/W properties of the 60 Gbits/in² class of magnetic recording media that was first produced at the end of 2002 and the magnetic recording media that was mass-produced in February 2004. The magnetic recording media of 2004 employs an AFC structure, has a multilayered underlayer, and a redesigned magnetic layer composition. Moreover, the biasing and heating processes were optimized for the layer structure and composition. As a result, the magnetic recording media of 2004 has better R/W properties than the magnetic recording media of 2002. The signal decay rate, which is a measure of thermal stability, has also been improved (smaller absolute value) through the use of an AFC structure and the redesign of the magnetic layer composition. At present, Fuji Electric is again reviewing the composition of the magnetic layer, is developing magnetic recording media that provides even higher-level performance, and is making final adjustments for application of that media to a 90 Gbits/in² product.

Additional performance improvements are necessary in order to realize recording densities in excess of 100 Gbits/in² in the future. As described above, a major objective of magnetic technology is to reduce the crystal grain size while maintaining thermal stability. Presently, Fuji Electric is considering reducing the crystal size by redesigning the compositions of the underlayer and magnetic recording layer, and maintaining the thermal stability by redesigning the AFC structure and the magnetic layer structure. For the film deposition process, Fuji Electric is investigating a method for uniformly distributing magnetic characteristics in the plane of the magnetic recording media and is aiming for a comprehensive improvement to media characteristics. Fuji Electric is also investigating methods for maintaining a higher level of cleanliness in the vacuum atmosphere during film deposition in order to reduce crystal lattice defects in the thin metal film and to improve media characteristics.

4. Head-disk Interface (HDI)

4.1 Overcoat layer

An effective way to increase the recording density in a magnetic disk device is to decrease the distance (magnetic spacing) between the magnetic head and the magnetic layer of the recording media. As an example, Fig. 12 shows the relationship between thickness of the carbon overcoat layer and the SNR. When the carbon overcoat layer is made thinner, the magnetic spacing becomes narrower, thereby improving the SNR. In order to decrease the magnetic spacing, it is necessary to lower the flying height of the magnetic head and to reduce the thickness of the overcoat layer. Accordingly, in addition to the texturing technology for creating surfacing conditions that support low flying

Fig.12 Relationship between SNR and overcoat layer thickness

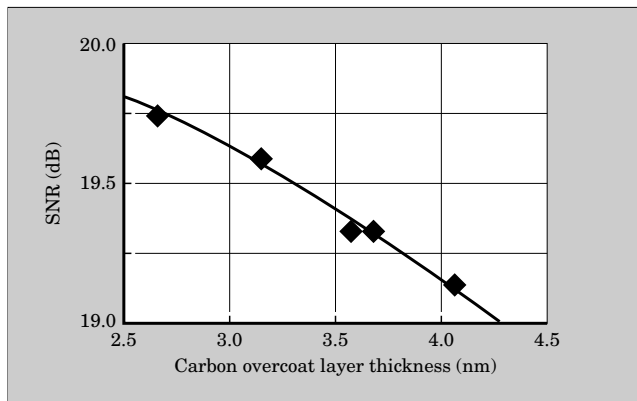
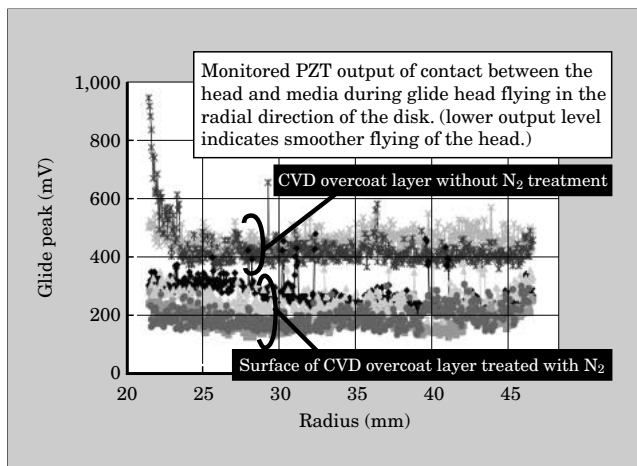


Fig.13 Flying stability improvement by applying N₂ treatment to carbon overcoat



heights of a magnetic head, the overcoat layer and lubricating film must provide sufficient corrosion resistance and durability even as a thin film.

Fuji Electric uses hollow cathode chemical vapor deposition (CVD) to deposit the overcoat layer and to ensure greater corrosion resistance and durability than can be achieved with a sputtered carbon layer. The amount of oxygen and nitrogen contained in the overcoat layer affect properties such as the film density, and can be changed to influence the wear characteristics. It has been learned that the surface potential and interactions with the lubricating film, to be described layer, also influence the flying performance of the magnetic head. Figure 13 shows the glide noise when a glide head flies over a disk in which the nitrogen content on the surface of the overcoat layer has been changed. It has been confirmed that the addition of nitrogen causes the glide noise to decrease. By optimizing the amounts of oxygen and nitrogen in the film based on consideration of flying performance of the head, wear resistance and durability, and by achieving uniform characteristics throughout the plane of the disk, the prospects are favorable for achieving reliability in a film thickness of 2.5 nm. As an overcoat layer capable of providing

Fig.14 Lubricant roughness

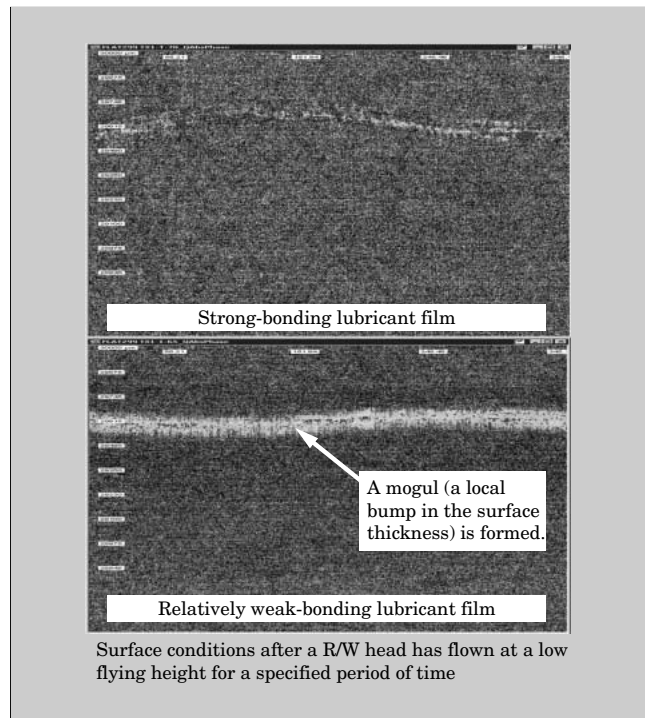
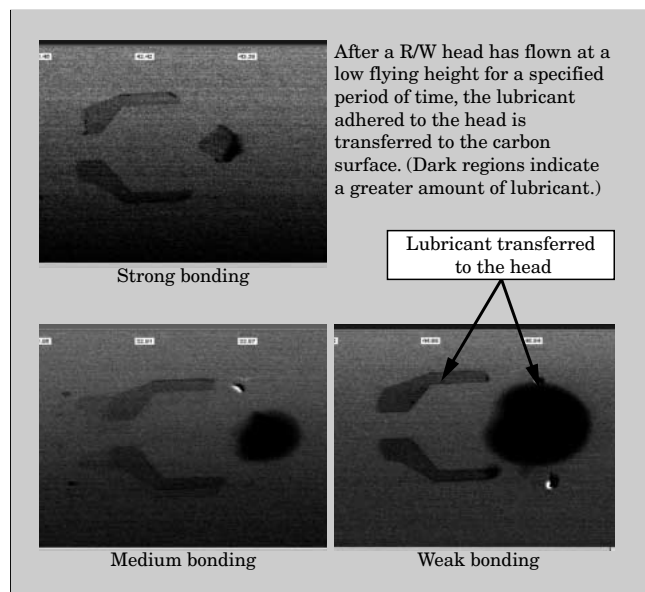


Fig.15 Lubricant-carbon overcoat bonding and head pick-up



satisfactory levels of durability and corrosion resistance at thicknesses of 2 nm or less, Fuji Electric has focused its attention on dense tetrahedral amorphous carbon (ta-C) which is rich in sp³-bonded carbon, and is currently evaluating such a carbon overcoat layer fabricated using a filtered cathodic arc (FCA).

4.2 Lubricating film

At present, HDI reliability of the magnetic disk is ensured by the synergistic function of a fluorine lubricating film of perfluoropolyether (PFPE) that is coated on top of the overcoat layer at a thickness of 1 to

Table 2 Lubricant diffusion coefficients

Lubricant material	Diffusion coefficient of lubricant film ($\mu\text{m}^2/\text{s}$)
Lubricant A	0.53
Lubricant B	1.19
Lubricant C	0.02

Diffusion coefficients were calculated based on the speed at which lubricant moguls formed during head gliding are restored.

2 nm. Fuji Electric is also investigating functional thin film materials for the lubricating film in order to support the lower head flying height clearances and thinner overcoat layers that accompany higher recording densities.

Lowering the flying height of the magnetic head results in a stronger influence on the lubricating layer of air vibrations under the head slider, and brings an increased opportunity for sporadic surface contact to occur. Accordingly, the lubricating film may, in some cases, form a local roughness (mogul) or be transferred to the head slider. This impairs the flying stability of the magnetic head and causes the output of the R/W signal to fluctuate. Figures 14 and 15 show examples of the results of an investigation for the bonding between the lubricant film material and the overcoat layer. A strong-bonding lubricant film resists forming a roughness even when the head flies at a lower height than the design value. Moreover, the transfer of lubricant film to the slider surface can be reduced by

treating the surface after it has been coated with the lubricant film.

To reduce frictional wear, it is important that the lubricant film continuously covers the surface of the overcoat layer. The lubricant film must not dissipate during high-speed rotations or when subject to an environment of stressful heat and humidity, additionally, the loss of lubricant film due to contact between the head and disk during contact start-stop (CSS) operation must be suppressed and diffusibility must be sufficient in order to replenish any lost amounts. Fuji Electric has established a technique for quickly evaluating the diffusibility of a lubricant film and is moving ahead with the optimization of lubricant films suited for designed drive characteristics (Table 2).

Fuji Electric has also developed proprietary refining technology for lubricant materials and aims to enhance the quality and functionality of the lubricant film.

5. Conclusion

Applications for longitudinal aluminum substrate media are limited because of its poorer shock resistance than glass substrate media. For this reason, no large increase in demand is expected, but the market is predicted to continue at its present size. The theoretical limit of longitudinally recording density has long been debated, but it is only a matter of time before the density of mass-produced longitudinal recording media exceeds 100 Gbits/in², and development toward the target of 200 Gbits/in² is ongoing. In terms of manufacturing costs, longitudinal magnetic recording media continues to maintain its advantage over other types of media. The elemental technologies acquired herein may also be applied to glass substrate media and to perpendicular magnetic recording media, for which practical applications are imminent as the next-generation recording method. It can be said that the technical development of longitudinal aluminum substrate media is becoming even more important. Fuji Electric intends to continue to develop technology to challenge the limits of longitudinal aluminum substrate media and to support our information-based society.

Glass Substrate Magnetic Recording Media

Souta Matsuo
Katsuya Masuda
Shinji Shirai

1. Introduction

The hard disk drive (HDD) market is expanding from conventional applications in personal computers (PCs) to full-fledged non-PC applications. Annual HDD shipments reached 230 million units in 2003 and are predicted to climb to 400 million units by 2007. These HDDs can be categorized as having substrates of either glass or aluminum media. Aluminum media is mainly used in HDDs for desktop PCs and servers, while glass substrate magnetic recording media (glass media) is used in HDDs for notebook PCs and non-PC applications. In particular, large growth is forecast for the glass media market, and it is predicted that approximately half of all HDDs will use glass media by 2007 (see Fig. 1).

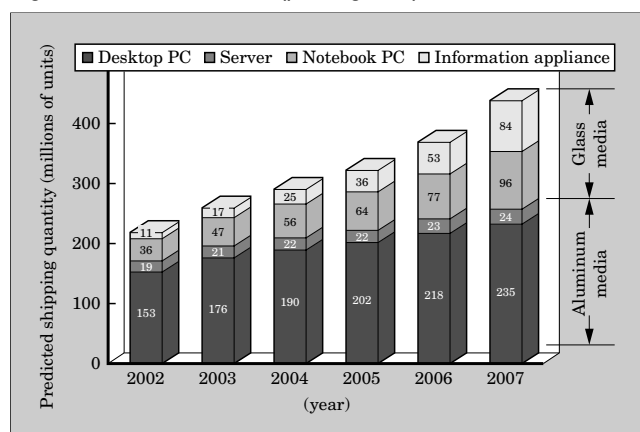
Fuji Electric is planning to expand its production of glass media in addition to its existing production of aluminum media products:

Glass media has the following characteristics.

- (1) Small TMR (track miss-registration: positional misalignment of the magnetic head)
- (2) High shock resistance

The 2.5-inch HDD which leverages the above characteristics is installed in most notebook PCs. A rapid increase in smaller diameter HDDs for use in such mobile devices as cell phones, USB storage, MP3 players and the like is predicted for the future.

Fig.1 HDD market trends (per segment)



HDDs for use in mobile devices, typically cell phones, are required to exhibit stable quality under conditions that are more severe than those in a notebook PC. Three characteristics presently required in the marketplace are listed below:

- (1) Environmental durability (-20 to $+70^{\circ}\text{C}$)
- (2) Shock resistance (1,000 G)
- (3) Small-sized (thickness of 3.3 mm which is comparable to a memory card)

Fuji Electric initially began developing technology for 2.5-inch glass media and these efforts are leading to the development of technology for even smaller diameter glass media.

This paper describes Fuji Electric's development of glass media technology.

2. Typical Customer Requirements of Glass Media

Table 1 lists typical customer requirements of glass media and conditions necessary to achieve those requirements in glass media currently being developed for mass production.

The most important technical development items to realize these requirements are the development of parametrics performance and the development of head-

Table 1 Typical customer requirements of glass media

HDD requirements		40 Gbytes model
Rotational speed		5,400 r/min
Number of bits per inch		660 kbits (size $0.038\ \mu\text{m}$)
Number of tracks per inch		100,000 tracks (size $0.254\ \mu\text{m}$)
Recording density		66 Gbits/in ²
Head floating height limit		4 nm
Thermal decay		< 1.20 % decay
Error rate		Less than 10^{-7}
LUL test	55°C, 5 % RH	300,000 times
	5°C, 15 % RH	300,000 times
Corrosion test		60°C, 80 % RH, 21 days
Environmental durability test		5 to 55°C, 5 to 80 % RH, 5 days
Shock resistance		700 G (while not operating)

disk interface (HDI) technology.

By using glass media that is anisotropic, Fuji Electric has developed technology that satisfies the customer requirements.

3. Anisotropic Glass Media

In the past, glass media was produced mainly without texturing the media surface, and the media produced by this method is known as isotropic media.

On the other hand, in the case of aluminum media, an NiP film is plated on an aluminum alloy and then textured. By orienting the magnetic recording layer in the direction of the texturing, the $M_r t$ (residual magnetization) in the circumferential direction will be large, and this has the advantage of providing a larger output signal for the same thickness of the magnetic layer.

Consequently, aluminum media has good signal-to-noise ratio (SNR) characteristics and less media noise than glass media.

The SNR characteristics directly influence the error rate of an HDD, and therefore an effective way to increase recording density is to make the glass media anisotropic, as in the case of aluminum media.

3.1 Development of direct texturing technology for glass

Glass media was initially developed at individual companies using the same process as with aluminum media, whereby an NiP film was plated on a glass substrate and then textured. By performing texturing after plating of the NiP film, the requirements for anisotropic media are satisfied, however as shown in Fig. 2, because this method requires the addition of a washing process and an NiP plating process (in addition to the processes for conventional aluminum media), there is a disadvantage in that cost increases.

In order to fabricate glass media with the same process used in the fabrication of aluminum media, it is necessary to directly texture the glass substrate. However, if the glass substrate is textured and then plated, the media will not simply become anisotropic.

Fuji Electric solved this problem by developing

technology for texturing the glass substrate and by optimizing the seed layer.

3.1.1 Development of texturing technology

When texturing a glass substrate, it is fundamentally necessary to realize both the required texture and the items required for improving the anisotropy.

Typically technical requirements include the following:

- (1) Reduction of surface roughness
- (2) Scratch and ridge tree
- (3) Optimization of texture line density
- (4) Optimization of texture peak curvature

The reduction of surface roughness affects the flying characteristics of the magnetic head. By reducing the surface roughness, the space between the head and media is secured.

The improved uniformity of scratch and ridge contributes to a reduction in signal faults and in damage to the head device. If the surface has a deep scratch, the space at that location will increase and the output amplitude will decrease. If the surface has a ridge, the ridge will come into contact with the head, or will cause an abrupt change in the flying condition, resulting in amplitude fluctuation.

Optimization of the texture line density and texture peak curvature contribute to improvement of the $M_r t$ -OR (orientation ratio of the cumulative residual magnetic film thickness) characteristic. By texturing an NiP layer on the aluminum media, the magnetic layer becomes easier to orient due to the large amount of distortion caused by thermal expansion of the NiP. In the case where the glass substrate is textured directly, because the surface has a high degree of hardness and the geometric distortion due to thermal expansion is small, texturing must be performed densely in order to ensure the anisotropic characteristics, and a high density of texture lines per unit length is required. At this time, if the line density is large, the peak curvature will become smaller. This effect enables the achievement of a large $M_r t$ -OR characteristic as shown in Fig. 3.

In order to satisfy the above requirements, a special-purpose polishing agent, polishing tape and the processing conditions for glass media have been opti-

Fig.2 Process comparison

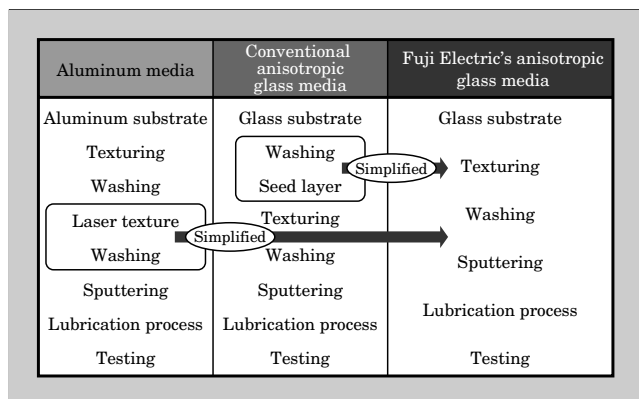
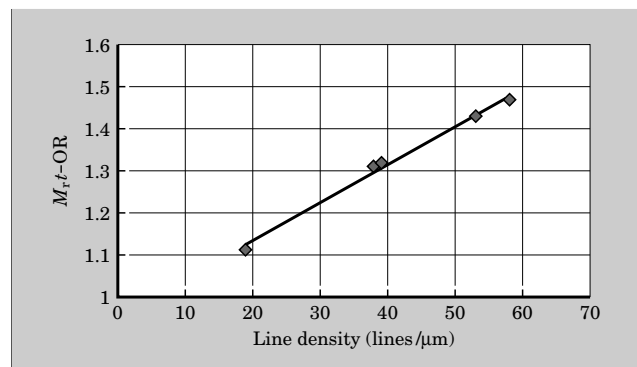


Fig.3 Correlation between line density and $M_r t$ -OR



mized, and a surface profile that satisfies customer requirements is presently being achieved as shown in Fig. 4. The same profile can be fabricated even in cases where the properties of the glass substrate material are different.

3.1.2 Development of the seed layer

The effect of textured anisotropic media has been discussed above, but an $M_r t$ -OR characteristic that satisfies customer requirements cannot be guaranteed with only texturing. The combination of a seed layer and texturing is crucially important.

Noticing that the use of an NiP amorphous film with aluminum media was correlated to the $M_r t$ -OR characteristic, Fuji Electric investigated the amorphization of the seed layer.

Important factors are listed below:

- (1) Seed layer materials
- (2) Thickness ratio of the seed layer
- (3) Control of reactive gas

With regard to the seed layer material, it is important to select a material that adheres well to the glass substrate and has an easy-to-orient texture. Moreover, it is important to select a material whose underlayer is aligned in-plane in a (200) orientation along the direction of the texturing.

The seed layer thickness ratio is set to a condition that provides a high degree of orientation when the

Fig.4 Typical surface profile of glass media obtained by AFM (atomic force microscope)

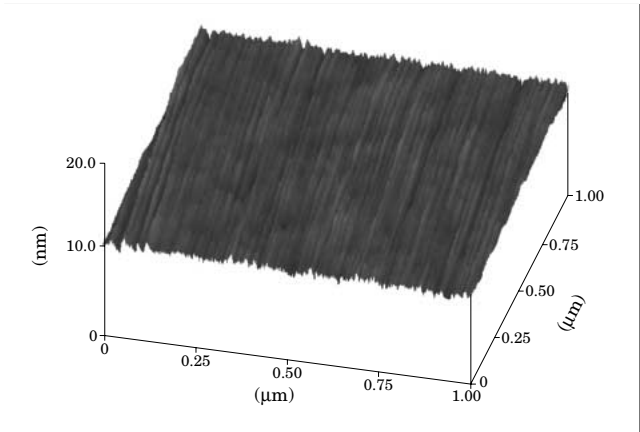
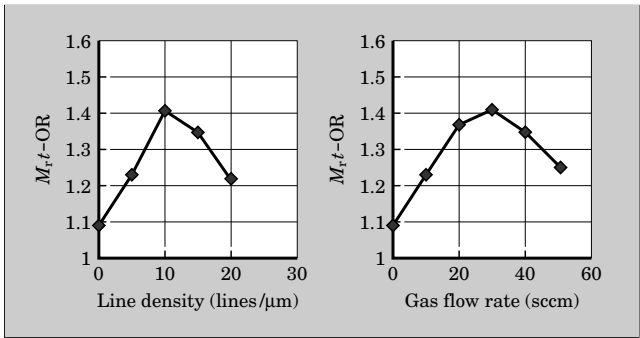


Fig.5 Correlation between seed layer process conditions and $M_r t$ -OR



thickness of the seed layer is optimized.

In order to control reactive gas, it is necessary to control the types of gas that induce amorphization and to optimize the quantity of gas that is input.

By optimizing the combination of these three factors, the large $M_r t$ -OR characteristic shown in Fig. 5 can be achieved. In the future, as recording densities increase and the roughness formed by texturing becomes smaller and more difficult to orient, it is important to promote optimization of the seed layer and to achieve a collectively large $M_r t$ -OR characteristic.

3.2 Magnetic layer having an AFC structure

Glass media has the same antiferromagnetic-coupled (AFC) structure formed on a seed layer (see Fig. 6) as the above-described aluminum media. This AFC structure consists of an underlayer, a stabilizing layer, a Ru layer and a magnetic layer. In particular, according to typical customer requirements for HDDs, the glass media must have a magnetic layer that is thin and has low resolving power and low noise.

Fig.6 AFC-structure magnetic layer

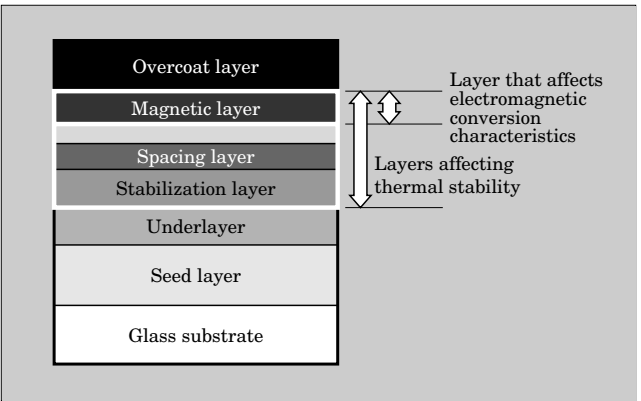
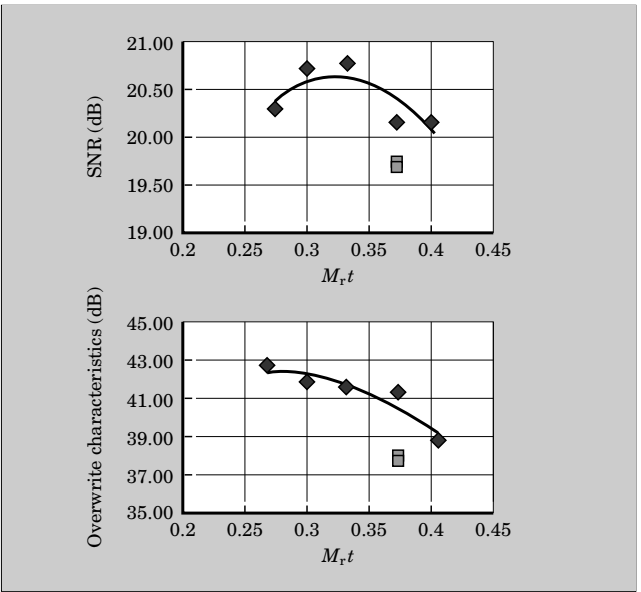


Fig.7 Typical overwrite and SNR characteristics for glass media made by Fuji Electric



However, as the magnetic layer becomes thinner, there is a greater likelihood that the external temperature environment will cause demagnetization to occur and the output amplitude to decrease (thermal decay). In order to solve these problems, it is important to increase the expression $K_u V / k_B T$ that is correlated to the thermal decay characteristics. In this expression, K_u corresponds to the magnetocrystalline anisotropy constant and V corresponds to the activation volume of the magnetic layer. k_B is the Boltzmann constant and T is the absolute temperature. If the same magnetic layer is used, K_u is constant and therefore it is necessary to increase the value of V . However, when V is increased, the magnetic layer becomes thicker and noise increases. With an AFC structure, due to the magnetic interactions corresponding to the strength of magnetization of a magnetic layer that is partially used as a stabilization layer, the V value of the magnetic layer is formed from the sum of the magnetic layer and the stabilization layer, and thermal decay characteristics are improved.

Fuji Electric uses a multi-dimensional magnetic layer optimized for low noise in the stabilization layer and for magnetic interactions in order to ensure greater thermal stability than in the past, as shown in Fig. 7. Moreover, by using a dual layer magnetic layer, low noise and good overwriting characteristics were achieved (see Fig. 7). These characteristics are both related to the abovementioned $M_r t$ -OR characteristic, and thus even if $M_r t$ increased, the magnetic layer can be made thinner than in conventional glass media. The glass media that Fuji Electric is presently fabricating and delivering to customers has a large output amplitude and provides parametrics performance that are comparable to those of aluminum media.

4. HDI Technology for Glass Media

4.1 HDI method for glass media

To achieve the same recording densities in glass media and in aluminum media requires essentially the same flying performance, and the basic difference is in the HDI method of the HDD.

Glass media uses the load-unload (LUL) method shown in Fig. 8, and a large difference between this and the method used with aluminum media is that the head does not contact the surface. Aluminum media uses the contact-start-stop (CSS) method in which contact with the surface occurs when the power supply

is switched on or off. At such a time, friction is generated at the head and at the substrate surface. Meanwhile, a phenomenon occurs in which lubricant that has adhered to the head returns to the media. In contrast, in the case of glass media, the lubricant continuously adheres to the head. If the quantity of adhered lubricant exceeds a certain limit, instability in the head's flying characteristics will occur and in some cases the flying condition cannot be guaranteed and the head will collide with the media surface.

Accordingly, glass media and aluminum media have different requirements of the HDI. Glass media requirements for the HDI are as follows:

- (1) The lubricant shall not adhere to the head
- (2) No scratches shall occur when the head collides with the media surface

The adhesion of lubricant to the head relates to the adhesive strength between the overcoat layer and the lubricant. In addition, it is important to control the film thickness to a suitable value for a non-adhered free layer that moves about freely. By increasing the adhesive strength, the free layer is made smaller and the lubricant does not adhere to the head. However, it is necessary to control the fluidity of the free layer so that the thickness of the lubricant film does not fluctuate during LUL operation.

In order to achieve the above-described requirements, Fuji Electric has optimized the properties of the overcoat layer and the lubricant's molecular weight, polarity control and additives, and has patented this technology (USP6730403).

4.2 Overcoat layer technology

Requirements of the overcoat layer are listed below:

- (1) Durability in LUL operation
- (2) Reduction of gas adsorption
- (3) Corrosion resistance of the glass substrate and magnetic layer

Durability in LUL operation is related to the lubricant and adhesion to the lubricant, and a specific description is given in paragraph 4.3.

To reduce gas adsorption, it is necessary to make the surface inert so that corrosive gas is not adsorbed and this is achieved by nitriding the surface.

To improve the corrosion resistance of the glass substrate and magnetic layer, the use of a dense overcoat layer is essential.

Fuji Electric uses a dual layer-type overcoat layer in order to satisfy the above-mentioned requirements. As shown in Figs. 9 and 10, corrosion is suppressed by using a chemical vapor deposition (CVD) film on the first layer and by suppressing gas adsorption by using an a-C:N film on the second layer.

4.3 Lubricant technology

In order to suppress adhesion of the lubricant on the head, a lubricant is used that bonds well with the

Fig.8 LUL test method

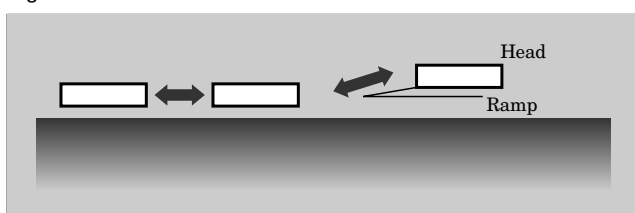


Fig.9 Co corrosion characteristics

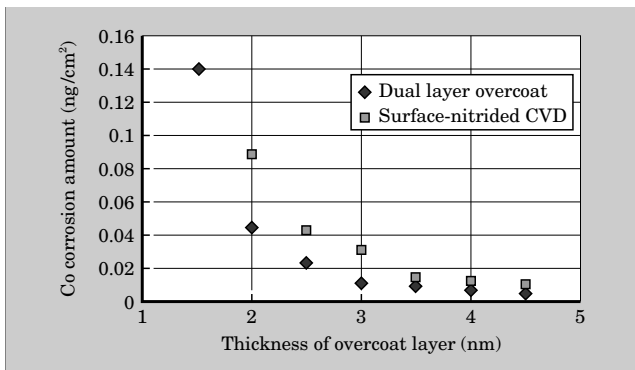


Fig.10 Gas adsorption dependency on overcoat layer property

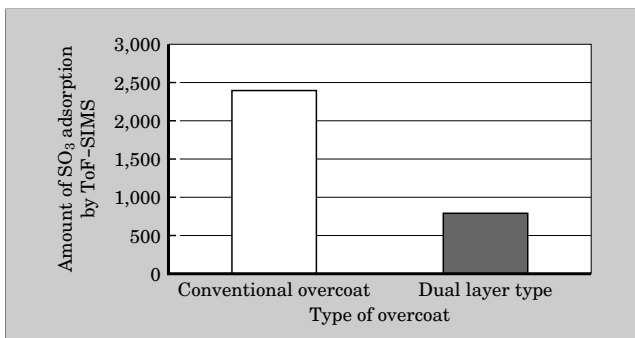
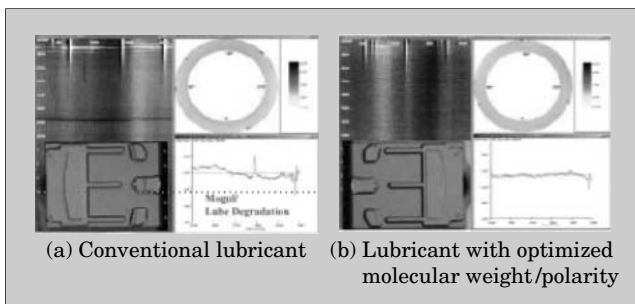
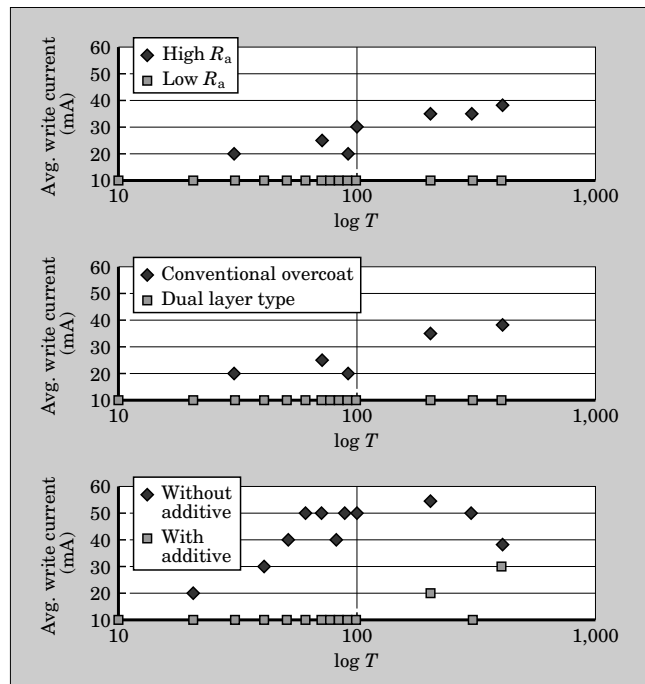


Fig.11 High-speed LUL test (1 cycle: 0.12 s)



overcoat layer, and to control fluidity, the distribution of the molecular weight and the polarity of the lubricant are controlled. An accelerated evaluation is performed and the film thickness of the lubricant is controlled so as to be substantially unchanged even under severe conditions. An environment in which the head does not fly stably is intentionally established as shown in Fig. 11 and HDI characteristics are secured for stabilizing the lubricant film thickness even after 100,000 LUL interactions have been performed. As head flying heights decrease in the future, there is a greater chance for the head to come into contact with the media surface and it is necessary to establish a high level of surface durability that resists scratching on the surface together with an impact relaxation characteristic that prevents the head from being scratched in cases when the head comes into contact with the surface. Fuji Electric provides solutions with

Fig.12 Head damage test



the above-described low R_a (average roughness), the dual layer overcoat film, and a new lubricant additive. Figure 12 shows the results of test to determine whether the head is easily scratched. When the additive is added, the head is not easily scratched, and similarly, the low R_a and dual layer overcoat film exhibit characteristics whereby the head is not easily scratched.

Fuji Electric is developing technology to control the optimum molecular weight and polarity of the lubricant in order to achieve the required HDI performance for the next generation of low flying heights.

5. Conclusion

Fuji Electric uses aluminum media processes to obtain a synergistic effect that enables glass media to be realized at low cost, and has begun mass production of 60 Gbits/in² media products that fully leverage results from the technical development described herein. By adding glass media products to Fuji Electric's existing line of aluminum media, Fuji Electric aims to secure future business opportunities in the growing market of non-PC HDD applications. In particular, for the typical non-PC HDD application of cell phones, which will ramp up in the future, the usage environment is severe and low cost is strictly demanded. Building on its technical development thus far, Fuji Electric intends to promote further improvement in environmental characteristics and cost reductions through dramatic improvements in throughput and the like, and is developing technology to become the market share leader in this field.

Granular-type Perpendicular Magnetic Recording Media

Hiroyuki Uwazumi
Tatsumi Kawata
Teruhisa Yokosawa

1. Introduction

Hard disk drives (HDDs) came into practical use in 1956, and recently their recording density has been increasing at rapid rates of 60 to 100 % annually, and is predicted to continue to increase at annual rates of 30 to 60 %. As a consequence of this remarkable growth, the method of longitudinal magnetic recording, which has been in use thus far, is finally approaching its limit in terms of recording density due to its tradeoff between low noise performance and thermal stability. The problem of thermal instability is a phenomenon in which the signal stability cannot be maintained due to an inversion of the recorded magnetism caused by thermal energy at room temperature. With longitudinal magnetic recording, thermal instability becomes larger as recording density increases.

The method of perpendicular magnetic recording was proposed by Iwasaki et al.⁽¹⁾ in 1975, and has characteristics which are completely opposite those of the longitudinal magnetic recording method. Namely, as recording density increases, this method of perpendicular magnetic recording becomes more effective at suppressing thermal instability. Because this method is in principle well suited for high density recording, in anticipation of its practical application, much research has been performed relating to magnetic recording media and magnetic heads.

In 1999, Fuji Electric began developing perpendicular magnetic recording media and investigated the major technical challenges of achieving a magnetic recording media that combines low noise performance, high thermal stability and overwrite capability, and also the practical application of an easier-to-manufacture soft magnetic underlayer for thick films. At present, solutions to these practical challenges are in sight, and Fuji Electric is now studying ways to achieve mass-production, which is expected to begin at the end of 2005 or the beginning of 2006.

This paper describes the status of Fuji Electric's development of perpendicular magnetic recording media including a perpendicular recording layer having a granular structure and an electroless plated soft magnetic underlayer having excellent manufacturability.

ty.

2. Basic Layer Structure and Development Challenges of Perpendicular Magnetic Recording Media

The basic layer structure of perpendicular magnetic recording media is shown in Fig. 1. Perpendicular magnetic recording media is produced by fabricating a soft magnetic layer on a substrate of aluminum or glass, forming a perpendicular magnetic recording layer on top of the soft magnetic layer, and then forming a protective lubricating layer. Figure 1 has been simplified, but each layer actually consists of multiple layers, and actual perpendicular magnetic recording media is fabricated by complex production processes and has a more sophisticated layer structure. The practical application of this perpendicular magnetic recording media faces the two main technical challenges listed below:

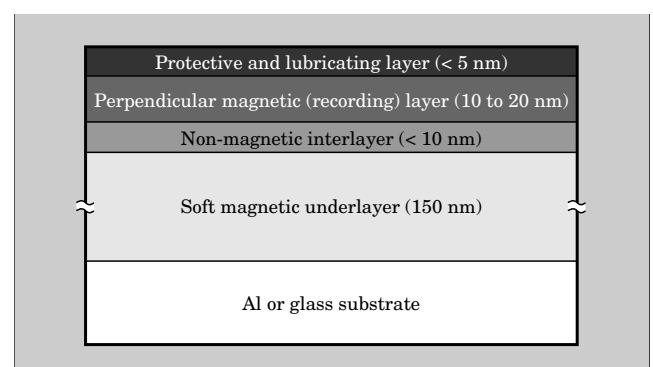
- (1) Technology for a soft magnetic layer that includes magnetic domain control

Development of a soft magnetic layer that is easy to manufacture, capable of extracting high precision performance from the magnetic head, and is unaffected by electromagnetic noise in the environment

- (2) Technology for a granular magnetic layer

Development of a magnetic layer having low noise, high thermal stability and good overwrite capability

Fig.1 Layer structure of perpendicular magnetic recording media



3. Development of a Soft Magnetic Underlayer

In order to achieve practical application of perpendicular magnetic recording media, development of a special layer structure known as a soft magnetic underlayer is necessary.

The perpendicular magnetic head generates a magnetic field while information bits are being written, and the purpose of the soft magnetic underlayer is to draw this magnetic field into the magnetic layer efficiently.⁽²⁾ Accordingly, a soft magnetic material having a high saturation flux density and fabricated to a film thickness of several hundred nanometers is required. The fabrication of such a film is considered to be extremely difficult with conventional sputtering techniques, both in terms of the manufacturability and production cost. Additionally, there is a need to suppress the spike noise. Spike noise is a large noise and is a serious problem caused by magnetic domain walls occurring within the soft magnetic layer.

Fuji Electric has previously developed process technology for sputtering a soft magnetic underlayer by inserting a pinning layer that actively performs magnetic domain control between the substrate and the soft magnetic layer, and by performing the necessary magnetic annealing to suppress spike noise. This process technology can be implemented inside a sputtering machine without adversely affecting manufacturability.

However, even when this processing method is employed, sputtering is required to fabricate a soft magnetic layer having a thickness of at least 100 nm and a multilayer that performs the magnetic domain control, and a technical breakthrough is needed in order to achieve the same manufacturability as with longitudinal magnetic media.

In addition to magnetic recording media, Fuji Electric also produces aluminum substrates plated with a non-magnetic nickel phosphorous (NiP) layer for use with recording media, and possesses advanced technology for fabricating electroless plated layers and polishing technology for achieving an ultra-smooth surface on the plated layer. Thus, for this soft magnetic underlayer which requires a thick film, Fuji Electric developed fabrication technology using an electroless plating technique having high manufacturability and surface smoothing technology, and successfully improved the prospects for practical application.

The soft magnetic plated layer achieves soft magnetic properties by using less phosphorous (P) additive than the non-magnetic NiP-plated layer conventionally used with aluminum substrates. This plated layer has a higher degree of hardness and can be made thinner than a conventional non-magnetic NiP layer. Moreover, the electroless plating process and polishing process we have developed use essentially the same production processes as in the conventional production

of aluminum substrates, thereby enabling the low cost production of a substrate having a high-performance soft magnetic underlayer.

Figure 2 shows an atomic force microscope (AFM) image of the surface of the NiP-plated soft magnetic underlayer we have developed. The surface roughness (R_a) of approximately 0.1 nm is smaller than the approximate 0.3 nm R_a of non-magnetic NiP-plated layers currently in use in commercial products, and this lower roughness is sufficiently low to support the lower flying heights of magnetic heads that will accompany the higher densities of recording media in the future.

Figure 3(a) shows a mapped image of the noise generated from the NiP-plated soft magnetic underlayer we developed, as read from a magnetic head. For the sake of comparison, Fig. 3(b) shows the noise generated from a 200 nm-thick Co amorphous soft magnetic underlayer produced by conventional sputtering techniques. The color shading in the figure corresponds to the magnitude of the noise. Magnetic domain control was not performed in either case.

In the soft magnetic underlayer produced by sputtering, there exist multiple regions in which a large amount of noise is generated. This is spike noise caused by magnetic domain walls that occur within the soft magnetic layer. On the other hand, in the NiP-

Fig.2 AFM image of the surface of NiP-plated soft magnetic underlayer

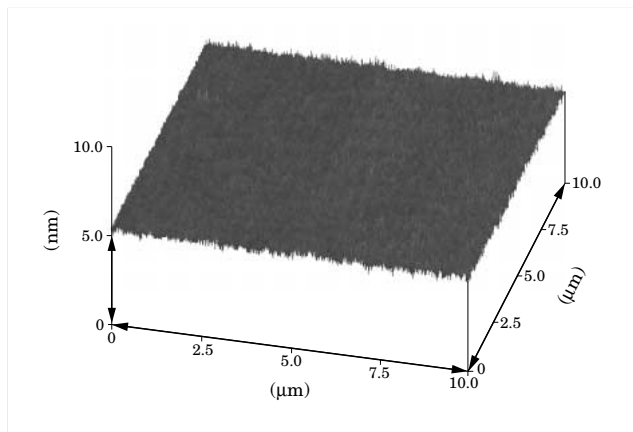
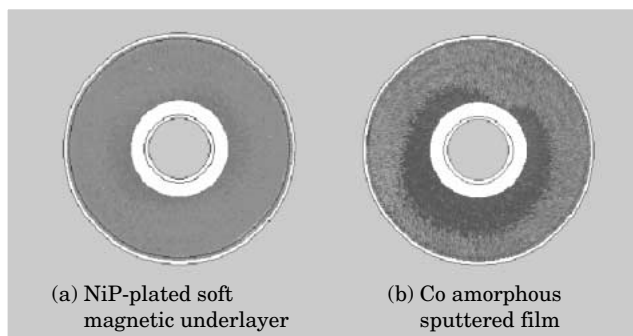


Fig.3 Spike noise observed at NiP-plated soft magnetic underlayer



plated soft magnetic underlayer we developed, it can be seen that spike noise is not generated despite the fact that no special magnetic domain control was implemented.

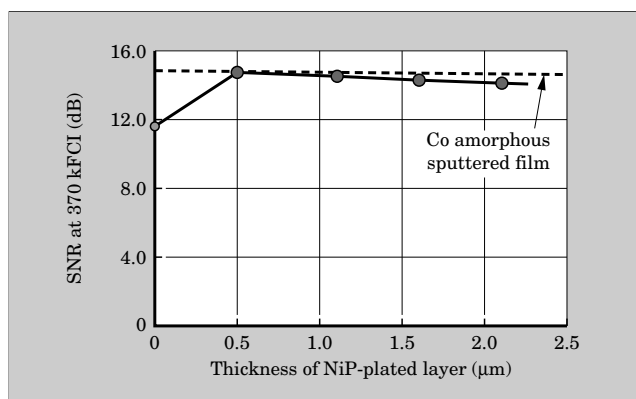
Figure 4 shows the signal-to-noise-ratio (SNR) dependency on thickness of the plated layer at a linear recording density of 370 kFCI (flux changes/inch) in perpendicular magnetic recording media produced using an aluminum substrate attached to an NiP-plated soft magnetic underlayer. The dotted line in the figure shows the SNR values of perpendicular magnetic recording media similarly produced on top of a 200 nm-thick Co alloy amorphous soft magnetic underlayer fabricated by sputtering.

The SNR values of the perpendicular magnetic recording media on an NiP-plated soft magnetic underlayer are essentially the same as those of the media on a sputtered soft magnetic underlayer. Moreover, a comparison between the overwrite performance of the media confirms that the media which uses the newly developed NiP-plated soft magnetic underlayer realizes almost same recording performance as the media that uses the conventional sputtered soft magnetic underlayer.

Fuji Electric is also developing technology for fabricating a plated soft magnetic underlayer on a glass substrate. This was previously considered difficult to achieve, but by developing a new glass substrate preprocessing technique, it is becoming apparent that sufficient adhesive force and manufacturability can be achieved simultaneously.

The use of aluminum and glass substrates to which this plated soft magnetic underlayer is attached will eliminate the need for the sputtered fabrication of thick soft magnetic underlayers. It is extremely advantageous that perpendicular magnetic recording media can be manufactured using the sputtering equipment of conventional longitudinal magnetic recording media and this is considered to be a large factor in approaching the practical application of perpendicular magnetic recording media.

Fig.4 Change of SNR vs. thickness of NiP-plated layer



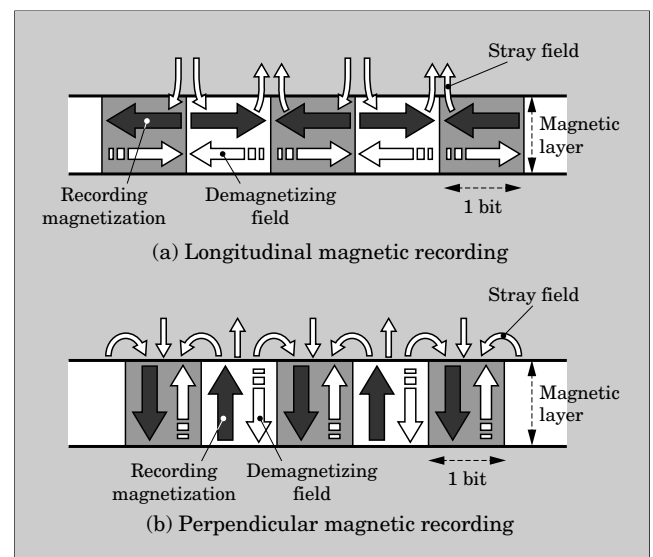
4. Granular Magnetic Layer Technology

4.1 Problems and challenges associated with conventional media

Figure 5(a) schematically shows the longitudinal magnetic recording method and Fig. 5(b) schematically shows the perpendicular magnetic recording method. In the case of longitudinal magnetic recording method media that magnetically records information bits in a direction parallel to the plane of the media, as the recording density increases, a demagnetization field increases in a direction that counteracts the recorded magnetization corresponding to the information bits, and thus the recorded information bits become unstable. If the trend toward higher densities progresses and the recorded bits become smaller in size, the corresponding magnetic energy of the magnetic grain will decrease and recorded bit information will gradually be erased by the thermal energy at room temperature. This is the so-called “thermal stability” problem. The longitudinal magnetic recording method is presently achieving recording densities of 60 to 100 Gbits/in², and its practical limit will probably be reached at densities of 160 to 200 Gbits/in².

On the other hand, because the perpendicular magnetic recording method records bit information in a direction perpendicular to the plane of the media, it is unlikely that a demagnetization field would cause a thermal stability problem as in the case of the longitudinal magnetic recording method. Because the magnetization tends to become more stable as the recording density is increased, and thus the recorded magnetization is better able to withstand a demagnetization field, the method of perpendicular magnetic recording is, in principle, well suited for high density magnetic recording.

Fig.5 Schematic diagram of longitudinal and perpendicular magnetic recording



In general, to achieve lower noise performance of magnetic recording media, regardless of whether longitudinal or perpendicular recording methods are used, it is necessary to make the grains that constitute the media as small and uniform in size as possible and to magnetically isolate them from one another. If the grain size is made even smaller in order to achieve lower noise performance, the magnetic energy of the grains will decrease in accordance with the decreased cubic volume of each grain and this will result in deterioration of the thermal stability. Therefore, it is important that a material having a large value of magnetocrystalline anisotropy energy (K_u) is utilized.

With longitudinal magnetic recording media, by sputtering a CoCrPt alloy onto a heated underlayer, the Cr atoms, which are less soluble to Co, segregate to the grain boundary, thereby achieving a small size and magnetic isolation of the grains, and because the main entity becomes the CoPt alloy which has a large intragranular K_u value, thermal stability is maintained.

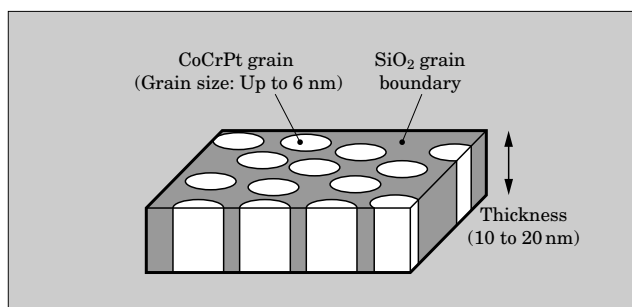
On the other hand, if heated film deposition using a CoCrPt alloy is similarly performed with perpendicular magnetic recording media, the Cr will be less likely to segregate to the grain boundary and the grain size will become larger than in the case of longitudinal magnetic recording media. Moreover, because the Cr is less likely to segregate at the grain boundary, the intragranular K_u values in grains containing residual Cr are lower than expected, and the simultaneous realization of low noise performance and high thermal stability is difficult to achieve. Because the axis of easy magnetization, the c-axis in a hexagonal close-packed (hcp) structure is oriented in a direction perpendicular to the film surface in the case of perpendicular magnetic recording media, the conjectured cause of this phenomenon is believed to be due to the orientation of the hcp (002) surface, having the lowest surface energy and whose grain size are likely to become coarse during thin film deposition. Consequently, a magnetic layer having low noise and high thermal stability must newly be developed for use with the perpendicular magnetic recording media.

4.2 Granular magnetic layers for higher recording densities

Prior to developing perpendicular magnetic recording media, Fuji Electric leveraged its experience in developing low-temperature-deposition capable, granular-type longitudinal magnetic recording media by developing a magnetic layer for use in granular-type perpendicular magnetic recording media that simultaneously achieves small granular size, decreased intergranular magnetic interactions and a high perpendicular orientation.^{(3), (4)}

In the granular magnetic layer we developed, CoCrPt-SiO₂ with an additive of SiO₂ or other oxide is used as the grain isolation material. Figure 6 shows a

Fig.6 Schematic diagram of granular magnetic layer



schematic diagram of this magnetic layer. Because the non-metal of SiO₂ is added, SiO₂ easily precipitates out at the grain boundary even without heating the substrate at the time of film deposition, and this has the advantage of increasing the degree of isolation among grains at room temperature and maintaining a large intragranular K_u value.

However, because the substrate is not heated, it is difficult to control the growth of grains in the granular magnetic layer. Consequently, it is important to control the microstructure of an intermediate layer provided underneath the magnetic layer. Specifically, by controlling the unheated film deposition conditions of a ruthenium (Ru) intermediate layer, this method decreases the variations in Ru crystallinity and grain size, thereby improving the crystallinity and grain size uniformity of the granular magnetic layer. The results of various studies have revealed that in order to grow a single magnetic grain on top of a single grain in the Ru intermediate layer, it is important to control the initial growth layer of the magnetic layer by controlling the size of grains in the Ru intermediate layer or by controlling the surface condition of the Ru intermediate layer. Based on this knowledge, we were able to control the desired microstructure by implementing extremely high level and precise control of the film deposition conditions.

As a corporate participant in the “Development of High Density and Small Size Hard Disk Drives” [IT program (RR2002) of MEXT] collaborative research project for which the Research Institute of Electrical Communication at Tohoku University plays a central role, Fuji Electric is conducting research into higher density granular magnetic layers.

This collaborative research has already confirmed that the CoCrPt alloy magnetic layer formed on the Ru intermediate layer has an extremely large K_u value of 9×10^6 erg/cm³ or above, and even when SiO₂ is added to this Co alloy magnetic layer to give it a granular structure, the intragranular K_u value is maintained at an extremely large value. This finding suggests that it will be possible to realize perpendicular magnetic recording media that maintains high thermal stability even if the grain size in the magnetic layer is reduced beyond its present size. Based on the results of this study, we believe that it is possible to realize perpen-

dicular magnetic recording media having a high areal density of 200 Gbits/in² or more by optimizing the composition of the existing granular magnetic layer to increase the K_u value, suitably controlling the microstructure of the Ru intermediate layer to obtain uniform magnetic grains, and advancing miniaturization and magnetic isolation.

4.3 Improvement of the overwrite performance

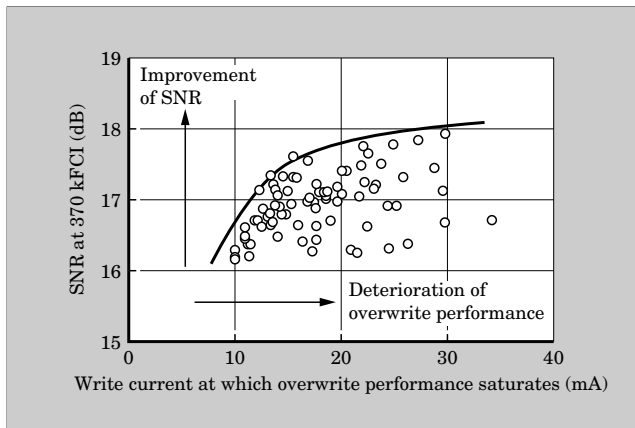
In the case where miniaturization and magnetic isolation of the grains in the magnetic layer are advanced in order to achieve lower noise performance and the intragranular K_u value is increased in order to maintain high thermal stability as described above, there is concern that coercivity (H_c) of the magnetic layer will increase, resulting in a deterioration of the overwrite performance. On the other hand, in order to support the higher track densities that accompany high density media, the track width of the magnetic head's writing element must be made narrower. This narrowing of the track width causes the magnetic field generated by the magnetic head to decrease. Consequently, improving the overwrite performance of the media will become increasingly important in the future.

As a result of advancing the control of the microstructure and magnetic layer composition in order to decrease noise while maintaining high thermal stability in the granular magnetic layer we developed, the larger H_c value caused the overwrite performance to become insufficient in the case of a narrow track head, and consequently the record and playback performance deteriorated.

Figure 7 shows a graph of the SNR at the write current at which overwrite performance saturates, indicating the overwrite capability of the media at a linear recording density of 370 kFCI in granular magnetic layer media produced under various conditions. From the graph, it can be seen that the overwrite capability of media deteriorates as the SNR value increases.

In order to overcome this tradeoff and to realize

Fig. 7 Relationship between SNR and overwrite performance



good write capability and SNR characteristics simultaneously in the media, we attempted to improve the composition of the granular magnetic layer and the film deposition process. In other words, in order to enhance the overwrite performance while maintaining low noise characteristics without changing the grain size and grain boundary structure of the magnetic layer, and instead of changing the controlled microstructure and surface conditions of the Ru intermediate layer, it is important to improve the composition of the granular magnetic layer and the film deposition process.

Table 1 lists the overwrite performance and SNR values for media A having improved write capability and conventional media B, which were evaluated using heads of different track widths. Here, media A has an H_c value of 5.3 kOe and media B has an H_c value of 6.6 kOe. In the case where measurement was made with a magnetic head having a wide track width of 0.3 μ m and generating a large magnetic field, the overwrite performance of approximately 40 dB was sufficient for both types of media and the SNR was essentially the same in both cases. On the other hand, when the measurement was performed with a magnetic head having a narrow track width of 0.2 μ m which is compatible with high density media, in contrast to the extremely poor overwrite performance of less than 30 dB and the low SNR of media B, media A exhibited a dramatic improvement with a relatively good overwrite performance of 36 dB and an SNR of 1.5 dB greater than that of media B. Accordingly, by improving the write capability without changing the microstructure of the magnetic layer, it is possible to realize media that provides sufficient overwrite performance and exhibits a large SNR even with a narrow-track-width head.

A spin-stand tester was used to measure the potential of the high density perpendicular magnetic recording media we developed, and those results are shown in Table 2. Because the spin-stand tester cannot be expected to have a precise tracking servo as in the HDD, measurement was performed with the on-track mode. Specifically, the byte error rate (BER) is measured while varying the linear recording density, the linear recording density is obtained at the time

Table 1 Recording performance of improved media

	Overwrite performance (dB) 379 kFCI overwritten by 50 kFCI	SNR (dB) 370 kFCI
Improved media A+ Wide-track head	39.2	15.05
Conventional media B+ Wide-track head	40.0	14.75
Improved media A+ Narrow-track head	36.4	21.25
Conventional media B+ Narrow-track head	29.9	19.68

Table 2 Recording density achieved

	Linear recording density (BER = 10^{-5})	Gbits/in ² (BAR = 1 : 5)
May 2002	727	106
September 2002	793	126
July 2003	867	150
February 2004	900	162

when $BER = 10^{-5}$ and then the obtained value is multiplied by the bit aspect ratio (BAR) of the linear recording density to track density which is set at 1 : 5 to compute the areal recording density. Here, the thickness of the carbon protective film in the perpendicular magnetic recording media ranges from 3.5 to 4.5 nm and this is 2.5 nm thicker than the design specification. The measured results reflect this correspondingly large spacing loss, but according to the results of a recent evaluation, the areal recording density of 162 Gbits/in² has been realized.

5. Conclusion

In order to realize the ubiquitously networked society of the 21st century comfortably, the existence of low cost cache memory capable of rapidly processing large quantities of intermediate information clusters is essential. The device exhibiting the best balance

among the requirements for large capacity, high speed and low cost is the HDD. If practical application of a palm-sized, large capacity, perpendicular magnetic recording HDD is achieved, it is thought that the market for HDD memory applications will expand endlessly.

The development of perpendicular magnetic recording media at Fuji Electric is the result of generous guidance and support from various members of Japanese and overseas research institutions, especially Professors Nakamura, Muraoka and Aoi, and Assistant Professor Shimatsu of the Research Institute of Electrical Communication at Tohoku University to which the authors express their deep gratitude.

References

- (1) Iwasaki, S. et al. An Analysis for the Circular Mode of Magnetization in Short Wavelength Recording. IEEE Trans. Magn. vol.11, no.6, 1975, p.1137-1139.
- (2) Iwasaki, S. et al. Perpendicular Magnetic Recording with Composite Anisotropy Film. IEEE Trans. Magn. vol.15, no.6, 1979, p.1456-1459.
- (3) Oikawa, T. et al. Microstructure and Magnetic Properties of CoPtCr-SiO₂ Perpendicular Recording Media. IEEE Trans. Magn. vol.38, no.6, 2002, p.1976-1978.
- (4) Uwazumi, H. et al. CoPtCr-SiO₂ Granular Media for High Density Perpendicular Recording. IEEE Trans. Magn. vol.39, no.4, 2003, p.1914-1918.

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# Organic Photoconductors for Printers

Seishi Terasaki  
Yutaka Ikeda  
Toshiki Obinata

## 1. Introduction

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

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

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

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

## 2. Product Overview

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

The CGL consists of charge generation material

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

Fuji Electric provides three product lines of low, medium and high sensitivity OPCs corresponding to the CGM characteristics in order to support various light exposure doses. By using five types of CGL material and controlling the film's thickness, Fuji Electric is able to regulate sensitivity over the wide range from 0.20 to 1.50  $\mu\text{J}/\text{cm}^2$  at a  $-100\text{ V}$  decay exposure as shown in Table 1.

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

Fig.1 Layer structure of negative-charging OPC

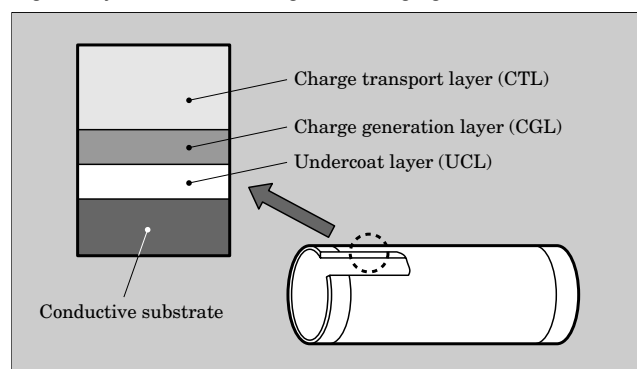


Table 1 Product summary

| Type                  | Class | Sensitivity<br>(at $-100\text{ V}$ decay exposure) |
|-----------------------|-------|----------------------------------------------------|
| 8A (Low sensitivity)  | 8A-02 | 0.80 to 1.50 $\mu\text{J}/\text{cm}^2$             |
|                       | 8A-15 | 0.70 to 1.20 $\mu\text{J}/\text{cm}^2$             |
| 8B (Med. sensitivity) | 8B-16 | 0.50 to 0.80 $\mu\text{J}/\text{cm}^2$             |
|                       | 8B-10 | 0.40 to 0.60 $\mu\text{J}/\text{cm}^2$             |
| 8C (High sensitivity) | 8C-03 | 0.20 to 0.40 $\mu\text{J}/\text{cm}^2$             |

\* Sensitivity : Exposure required to change the surface potential from  $-600$  to  $-100\text{ V}$

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

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

As shown in Fig. 4, OPC dimensions currently range from outer diameters of 24 to 242 mm and

Fig.2 Spectral sensitivity

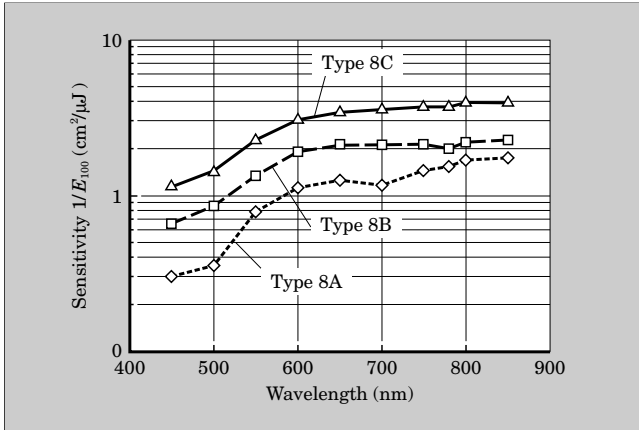


Fig.3 CTM mobility and ionized potential

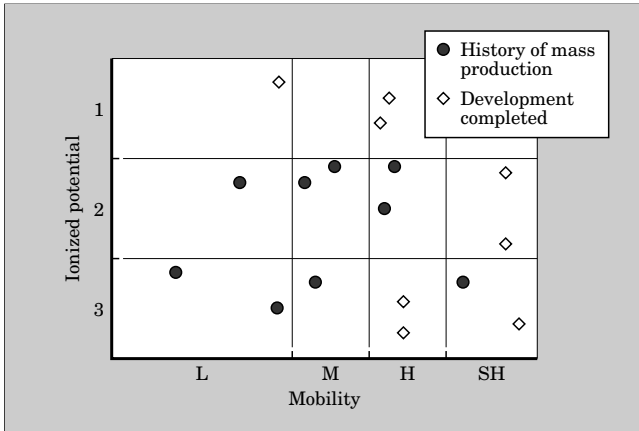
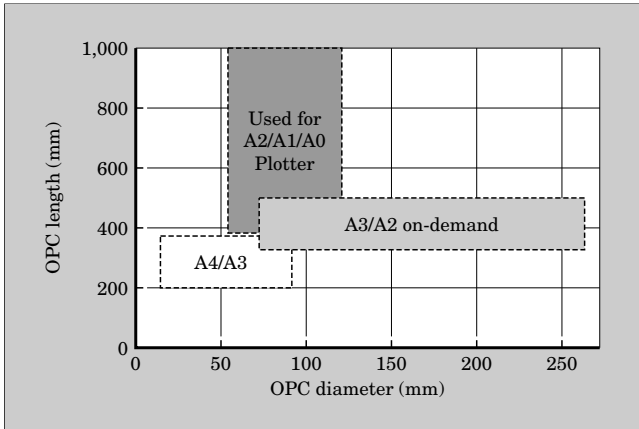


Fig.4 Applicable range of OPC length and diameter dimensions



lengths of 236 to 980 mm, and a wide variety of products are being developed ranging from A4-size page printers to A0-size plotters.

### 3. Product Features

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

#### 3.1 High-speed response

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

Figure 6 shows the dependency of the surface

Fig.5 Required OPC performance and quality

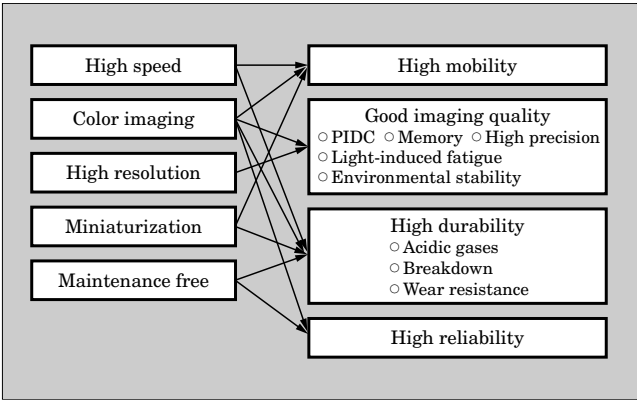
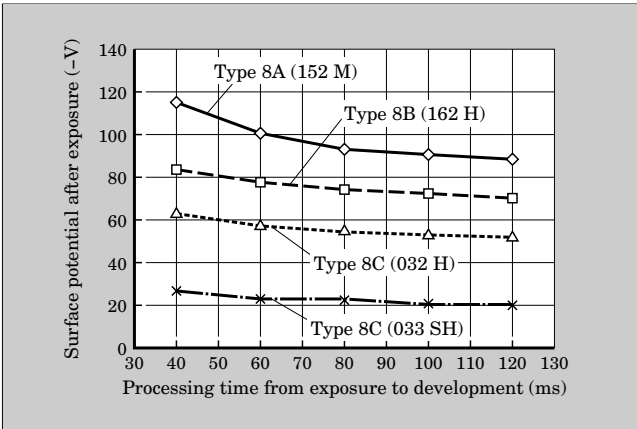


Fig.6 Photo response



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

### 3.2 Good imaging quality

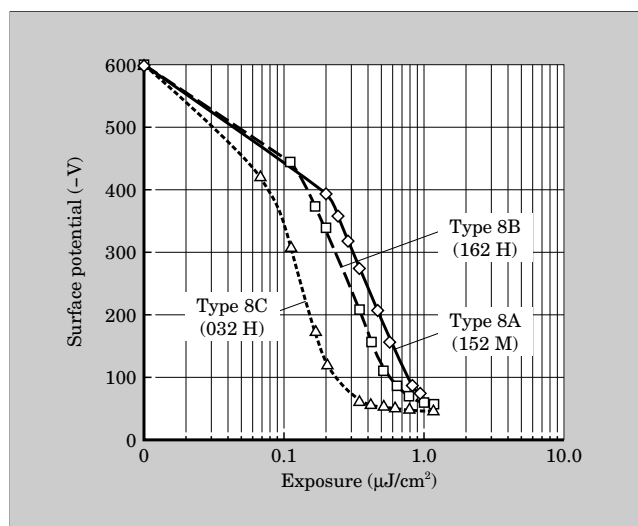
#### (1) Photo-induced discharge characteristics

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

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

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

Fig.7 Photo induced discharge characteristics



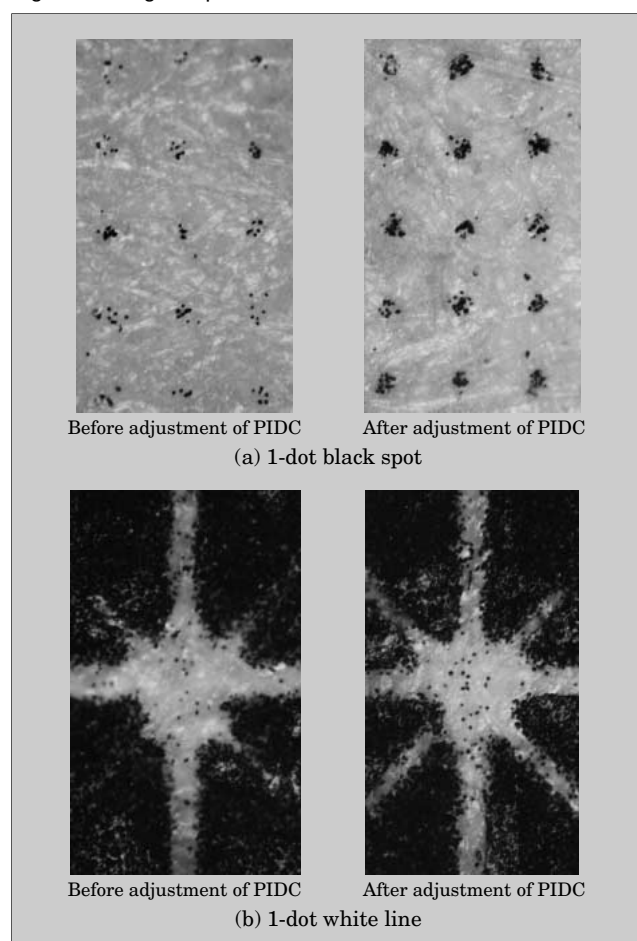
#### (2) Uniformity of the halftone potential

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

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

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

Fig.8 Printing samples



order to reduce potential differences.

### (3) Light-induced fatigue

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

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

### (4) High dimensional precision

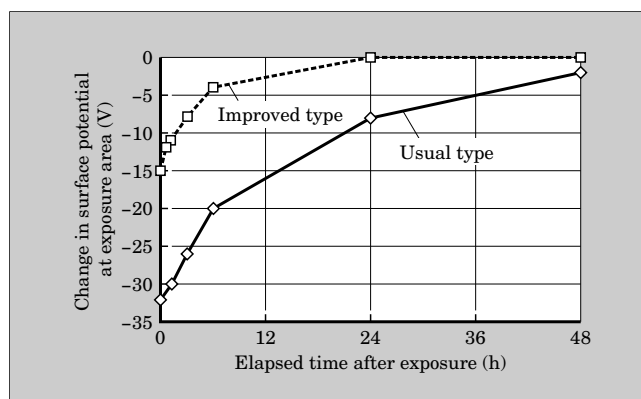
Printers are classified as either a 4-cycle type that uses a single OPC and a transfer drum or transfer belt to superimpose four colors onto the transfer object, or a tandem type that uses four OPCs to directly superimpose four colors onto a sheet of paper. In order to prevent the misalignment of the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

### (5) Environmental stability

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

Using a commercially available contact electrification-type laser printer equipped with a 24 mm-diameter OPC, 10,000 A4-size longitudinally fed sheets were each printed under the environmental conditions of normal temperature and normal humidity (N/N), low temperature and low humidity (L/L), and high temperature and high humidity (H/H), and the surface potential was measured after every 2,000 sheets. This data is shown in Fig. 10. Fuji Electric's OPC was compared to another company's OPC made of anodic oxide film (ALM), and good characteristics were observed without any large change in surface potential in

Fig.9 Light-induced fatigue characteristics



all environments.

## 3.3 Technology for higher durability

### (1) Resistance to acidic gases

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

Fig.10 Surface potential stability during printing

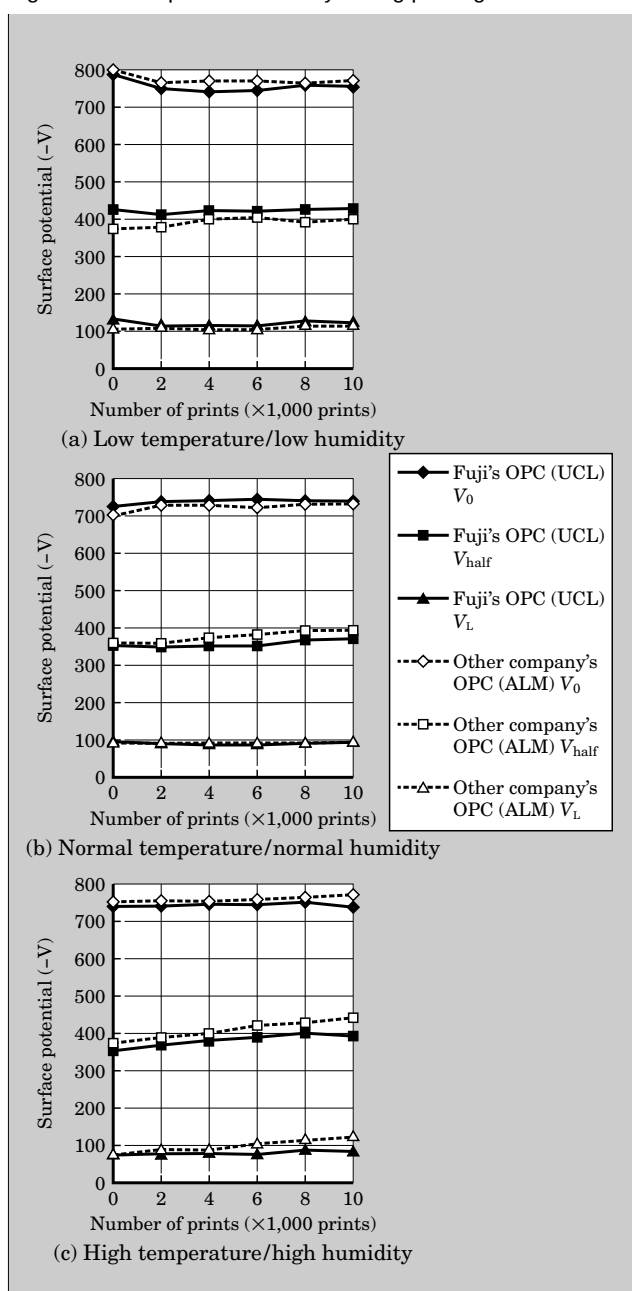
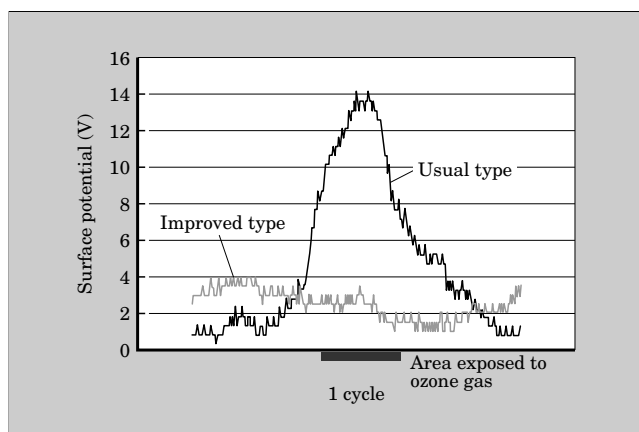


Fig.11 Resistance to ozonized gases



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

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

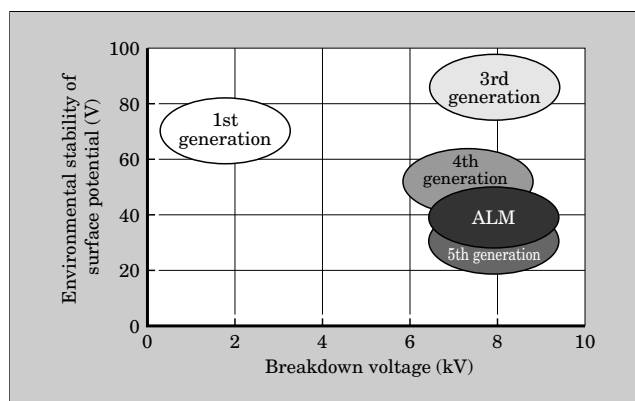
#### (2) Improved resistance to dielectric breakdown

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

#### (3) Wear resistance and photoconductor surface properties

Factors that determine the useful service life of an OPC include abrasion from contact parts such as the

Fig.12 Resistance to dielectric breakdown



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

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

### 3.4 High reliability

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

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

## 4. Conclusion

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

# Organic Photoconductors for Digital Plain Paper Copiers

Michio Shinozaki  
Takahito Miyamoto

## 1. Introduction

With the recent trend toward digitalization there has also been an increase in digital products in the copier market. In accordance with this increased digitalization, copier technology is trending towards colorization and higher speeds, higher image quality, better stability and lower cost than conventional analog copiers. Accordingly, photoconductor characteristics such as sensitivity, durability, environmental stability and reliability are being improved.

Fuji Electric supplies organic photoconductors (OPCs) as a type 9 series for use in analog copiers and a type 10 series for use in digital copiers. This paper presents an overview of the type 10 series of OPCs for use in digital copiers.

## 2. Product Overview

Copiers that use OPCs can be categorized according to their copying speed as low-speed copiers (up to 20 sheets-per-minute), medium-speed copiers (20 to 50 sheets-per-minute) and high-speed copiers (50 sheets-per-minute and above). Fuji Electric is developing three types of OPCs (10A, 10B and 10C) to support these different types of digital copiers. Typical characteristics of these types of OPCs are listed in Table 1. The applicable sensitivity range differs for each type of OPC and customers are free to select a desired type to meet their needs.

Figure 1 shows a block diagram of the OPC structure and operating principle. A multilayer OPC having distinct functional layers is formed by applying an undercoat layer (UCL) on top of a cylindrical conductive substrate made of aluminum or the like, and then by applying a charge generation layer (CGL) on top of the UCL, and finally by applying a charge transport layer (CTL) on the CGL as the top surface.

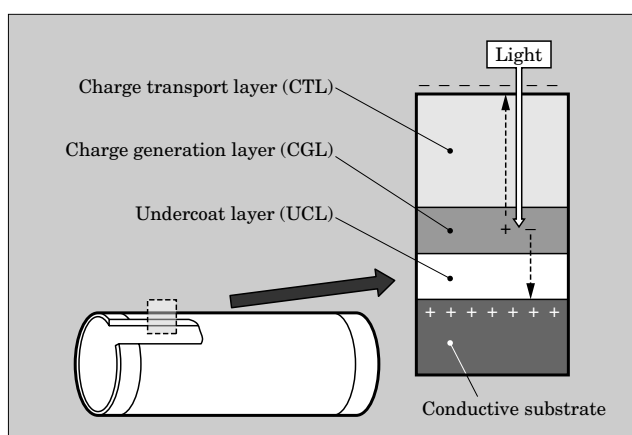
## 3. Product Characteristics

With the migration from analog to digital technology, copiers have achieved higher speeds, higher image quality and higher reliability. As such, an increasingly

Table 1 Typical characteristics

| Type                     | Half decay exposure for adopted sensitivity band ( $\mu\text{J}/\text{cm}^2$ ) | Half decay exposure ( $\mu\text{J}/\text{cm}^2$ ) | Retentivity [after 5 s] (%) | Residual potential (–V) | Applied range of copying speed (sheets/min) |
|--------------------------|--------------------------------------------------------------------------------|---------------------------------------------------|-----------------------------|-------------------------|---------------------------------------------|
| 10A (low sensitivity)    | 0.20 to 0.60                                                                   | 0.37                                              | 97.5                        | 52                      | Up to 40                                    |
| 10B (medium sensitivity) | 0.12 to 0.24                                                                   | 0.17                                              | 95.8                        | 21                      | 20 to 60                                    |
| 10C (high sensitivity)   | 0.06 to 0.14                                                                   | 0.07                                              | 96.1                        | 6                       | Over 40                                     |

Fig.1 Structure and operation principle of OPC for digital copiers



diverse and higher level of characteristics are being required of OPCs and new materials are being developed to support these required characteristics.

Fuji Electric's copier-use OPCs can be installed in low-speed, medium-speed and high-speed copiers and are provided with the following features.

- (1) High sensitivity
- (2) High responsiveness
- (3) High durability
- (4) High environmental stability
- (5) High reliability

### 3.1 High sensitivity

Because digital copiers use lasers or light emitting diodes (LEDs) as exposure sources, their OPCs are required to be sensitive to wavelengths ranging from 600 to 800 nm. Fuji Electric uses a phthalocyanine pigment which exhibits good sensitivity characteristics in this wavelength range. Figure 2 shows the spectral sensitivities of the low-speed type 10A, medium-speed type 10B and high-speed type 10C OPCs.

Figure 3 shows the photo-induced discharge characteristics of these OPCs. High-speed OPC type 10C has higher sensitivity than types 10A or 10B by 50 % and 30 %, respectively. Moreover, each type exhibits a sharp reduction in the vicinity of the residual potential and this is advantageous for the design of the digital copying process in a copier.

### 3.2 High responsiveness

Within a wide lineup of digital copier machines, from low-speed machines to high-speed machines, higher responsiveness is especially required of OPCs for super high-speed machines having greater than 100 sheets-per-minute capacity and which target the on-

demand copying market, the point of purchase (POP) advertising field and the like.

The key points to enhancing responsiveness are mobility of the material, a consistent ionization potential among materials, and purity. Therefore, in order to realize high responsiveness, Fuji Electric investigated high mobility charge transport materials (CTMs) and developed a high mobility CTM having a mobility of  $7 \times 10^{-5} \text{ cm}^2/\text{V}\cdot\text{s}$ , which is greater than 10 times the performance of a conventional product. Figure 4 shows the dependence of surface potential after exposure on the exposure-development time and Fig. 5 shows the development characteristics when installed in a copier. A highly responsive OPC that employs high mobility CTM stabilizes within an exposure-development time of 0.05 seconds. This performance provides sufficient support for high-speed processes of 45 sheets-per-minute or more in the case of an OPC having an external diameter of 30 mm or 105 sheets-per-minute or more in the case of an OPC having an external diameter of 100 mm. Also, the copy quality (black density) is improved compared to prior products, thereby enhancing reproducibility.

Fig.2 Spectral sensitivities

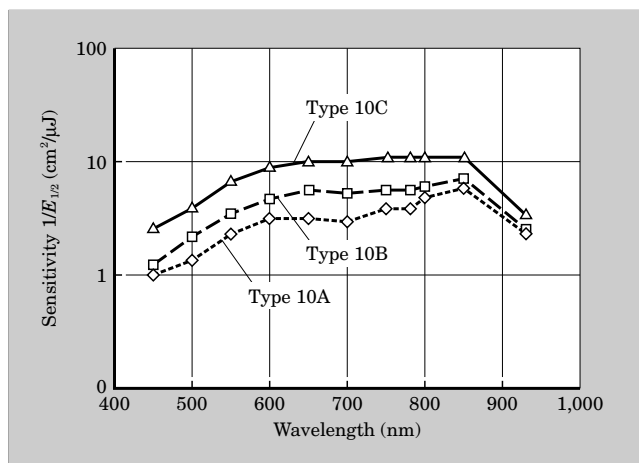


Fig.3 Photo-induced discharge characteristics of OPC

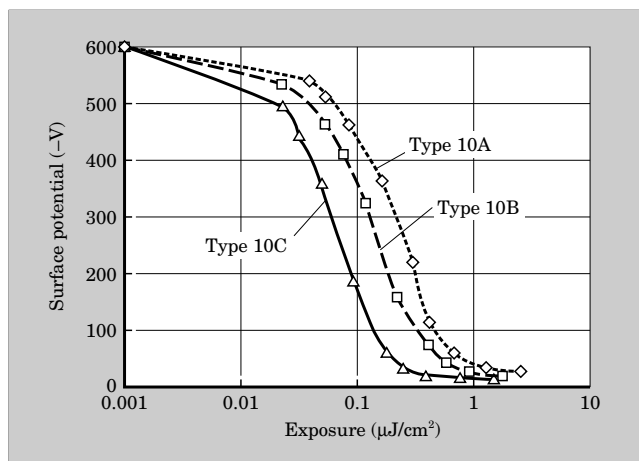


Fig.4 Time dependence of exposure-development (surface potential after exposure)

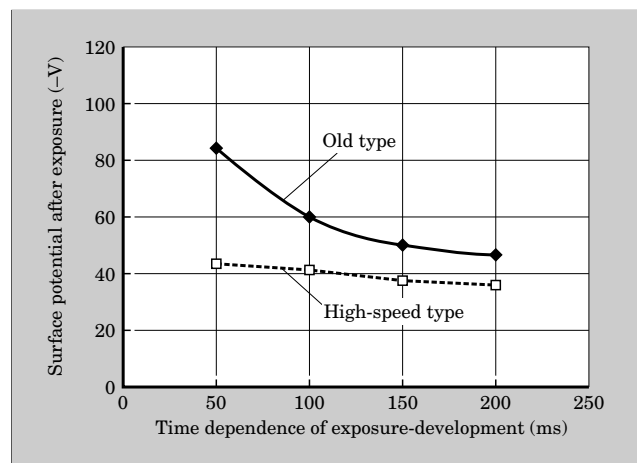


Fig.5 Developing characteristics

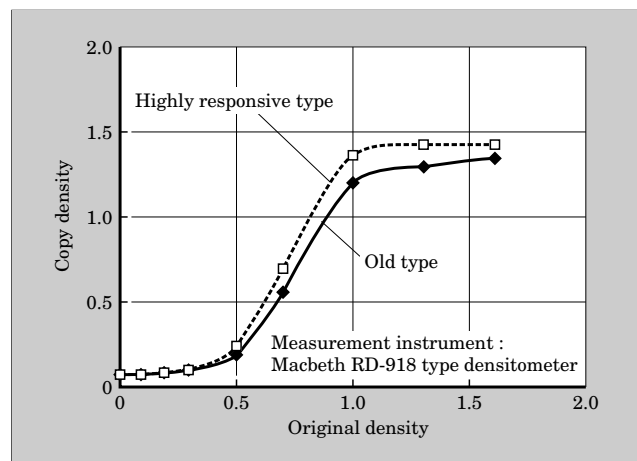


Fig.6 Running characteristics (charge acceptance)

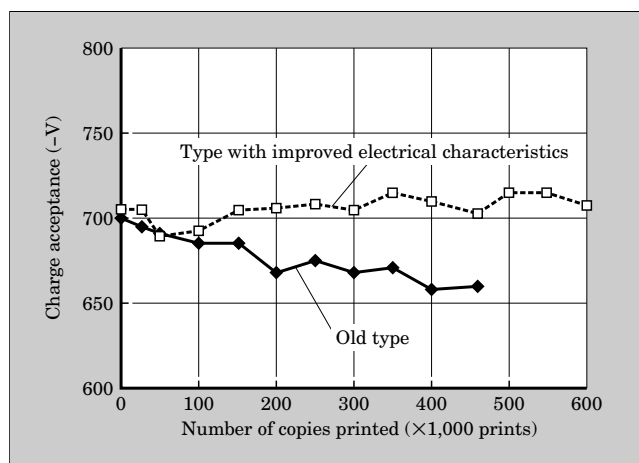
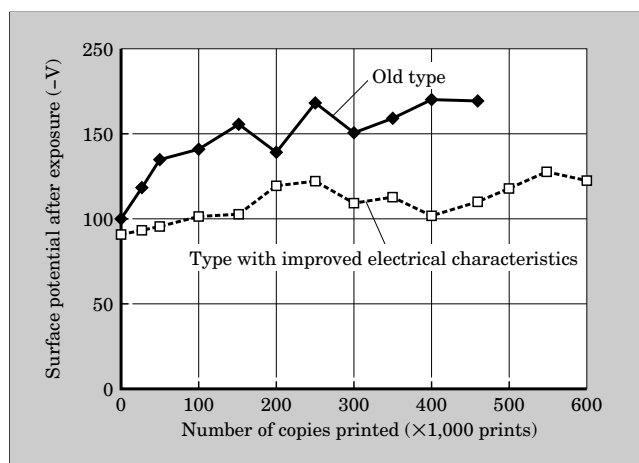


Fig.7 Running characteristics (surface potential after exposure)



### 3.3 High durability

Because OPCs have a high frequency of use, and in order to simplify the maintenance of a copier in which an OPC is installed, OPCs for digital copiers are required to have approximately 2 to 10 times higher durability than printer-use OPCs. This higher durability is realized through improvements to the electrical and mechanical characteristics of the OPC.

#### (1) Improvement of electrical characteristics

The repeated exposure of the OPC to ozone generated by the corona discharge during the charging process and to light during the exposure process causes the functional material to undergo a change in its chemical properties. As a result, electrical characteristics deteriorate, for example, a decrease in charge acceptance or a rise in residual potential occurs, causing such problems as blank pages or low print density. By developing a proprietary charge control agent that suppresses the occurrence of electrical defects in the photoconductive layer and by maintaining a consistent ionization potential among the OPC layers, Fuji Electric is able to suppress this decrease in

Fig.8 Mechanical characteristics

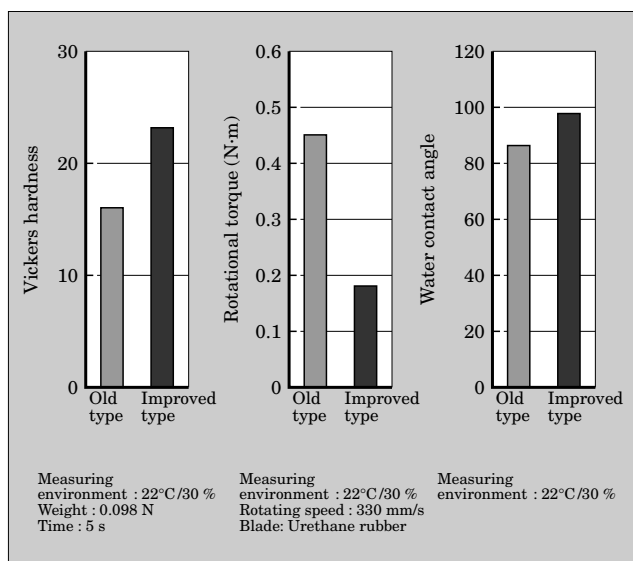
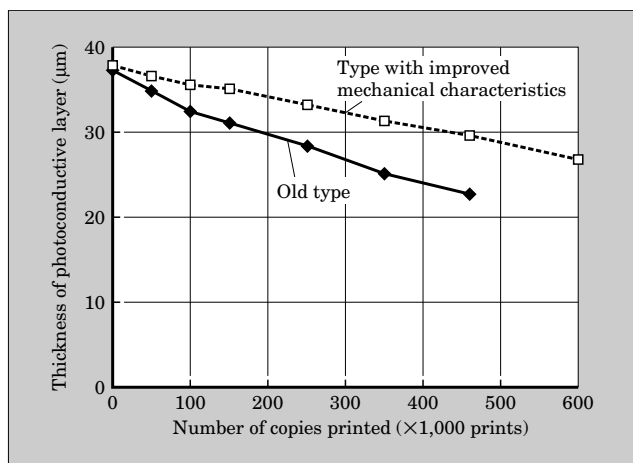


Fig.9 Running characteristics (abrasion)



charge acceptance and increase in residual potential and to supply an OPC that operates stably in various machine processes.

Figures 6 and 7 show the change in surface potential for an OPC evaluated in a digital copier in which a high degree of durability (a guaranteed OPC service life of 460,000 printed sheets) is required. As can be seen, the OPC having improved electrical characteristics exhibits less fluctuation in potential than a conventional OPC, indicating excellent operating stability and minimal change in the picture quality.

#### (2) Improvement of mechanical characteristics

Contact between the OPC and the charging roller, toner, paper, transfer roller, cleaning blade and the like degrades the physical and mechanical characteristics of the OPC by causing wear and scratching of the photoconductive layer and the adhesion of toner or paper dust particles. The degree to which this degradation occurs varies according to the machine process, but is largely dependent on the properties of

Fig.10 Environmental surface potential characteristics

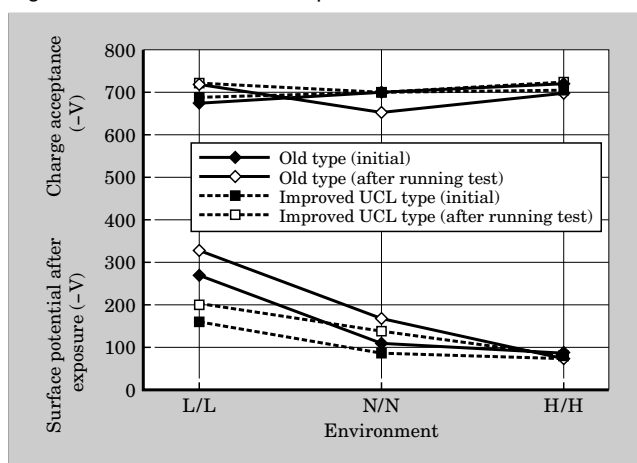


Table 2 Environmental reliability tests

| Item                                               | Condition                                                                                                                                |
|----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Ozone exposure test                                | 100 ppm, 2 h                                                                                                                             |
| Light-induced fatigue test                         | 1,000 lx, 5 min                                                                                                                          |
| High temperature exposure test                     | 45°C, 1,000 h                                                                                                                            |
| High humidity exposure test                        | 40°C, 90 %RH, 1,000 h                                                                                                                    |
| Low temperature exposure test                      | -20°C, 1,000 h                                                                                                                           |
| Cyclic test of temperature and humidity (5 cycles) | 20°C, 1 h<br>→ Normal temperature, normal humidity, 0.5 h<br>→ 45°C, 1 h<br>→ Normal temperature, normal humidity, 0.5 h<br>→ -20°C, 1 h |

the binder, which is a component of the CTL. By installing durability test equipment to evaluate the binder performance within a short time interval and by performing an accelerated evaluation test, Fuji Electric has successfully achieved a dramatic increase in binder performance.

Because the binder in the CTL has a polymer structure and uses material having excellent lubricating properties, it increases film hardness while reducing the frictional coefficient between the OPC and the cleaning blade. Figure 8 shows the mechanical characteristics (Vickers hardness, OPC rotational torque and water contact angle) and Fig. 9 shows an example of the improved wear characteristics of the photoconductive layer in a digital copier. By reducing the friction with other contact parts, wear and scratching of the photoconductive layer have been reduced and the service life of the OPC has been increased by approximately 50%. Fuji Electric is working to further increase the OPC service life as an environmental measure to reduce the amount of used OPC that is discarded as waste.

### 3.4 High environmental stability

The OPC is desired to be environmentally stable in order to support usage in a variety of copier environ-

Table 3 Ozone resistance characteristics (type 10C)

| Measurement time           | Half decay exposure ( $\mu\text{J}/\text{cm}^2$ ) | Retentivity (after 5 s) (%) | Residual potential (-V) |
|----------------------------|---------------------------------------------------|-----------------------------|-------------------------|
| Before exposure            | 0.07                                              | 96.0                        | 6                       |
| Immediately after exposure | 0.07                                              | 94.4                        | 10                      |
| 24 hours after exposure    | 0.07                                              | 95.2                        | 8                       |

Table 4 Light-induced fatigue of OPC (type 10C)

| Measurement time           | Charge acceptance (-V) |
|----------------------------|------------------------|
| Before exposure            | 610                    |
| Immediately after exposure | 585                    |
| 1 hour after exposure      | 590                    |
| 24 hours after exposure    | 607                    |

ments.

Fuji Electric has optimized the UCL filler and binder and suppressed fluctuations in volume resistivity due to the environment in order to ensure stability in normal temperature and normal humidity (N/N), low temperature and low humidity (L/L) and high temperature and high humidity (H/H) environments. Figure 10 shows measured data of the initial potential and the potential after printing 600,000 sheets. The figure shows good characteristics with little change in any of the abovementioned environments.

### 3.5 High reliability

Environment testing was performed as shown in Table 2 in order to assess OPC reliability. Ozone resistance characteristics were tested in an environment of ozone which was assumed to be generated by the corona discharge in a copier. Test results are shown in Table 3. There is almost no change in characteristics after 2 hours of exposure at an ozone concentration of 100 ppm. The light-induced fatigue test assumes that the OPC is exposed to light while maintenance is performed, and test results are shown in Table 4. The various characteristics remain stable after exposure for 5 minutes to a fluorescent light at an intensity of 1,000 lx.

## 4. Conclusion

In the copier market digitalization is driving a trend toward multifunctional machines that combine printer, copier and facsimile capabilities in a single unit and is eliminating the distinction between printers and copiers in the low and medium-speed fields. In the high-speed field, however, operating stability of twice to 10 times that of printers is required. Fuji Electric intends to continue to develop desirable OPCs by accurately assessing required characteristics in accordance with market needs.

# A Study of 1-dot Latent Image Potential

Kouichi Aizawa  
Yoshihiro Ueno  
Motohiro Takeshima

## 1. Introduction

Color printers and digital copiers are the main types of image information output devices and are classified according to the technology they employ, either ink jet technology or electrophotography. In the future, the use of ink jet technology is expected to increase for low-end home-use devices, while the use of electrophotographic technology is predicted to increase for applications that require high speed. However, better image quality is required of electrophotographic technology. Image quality includes such criteria as resolution, gradation and image density, but resolution is regarded as most important. At present, the resolution capabilities of commercially available electrophotographic devices range widely from 600 dpi (dots per inch) to 1,200 dpi or 2,400 dpi. The future trends toward colorization and digitization present the technical challenge of providing even higher levels of resolution.

In order to enhance the level of resolution, manufacturers of devices such as printers and copiers and manufacturers of materials such as photoconductors, toners and exposure lights have analyzed the factors that determine the resolution and have improved the photoelectric processes of charging, exposing, developing, transferring and fusing and have also improved the photoconductive materials used in photoconductor drums. Fuji Electric has also been moving forward with the development of high resolution photoconductors capable of forming electrical latent images with good reproducibility on a photoconductor. However, electrophotographic processes are complex and, at the present point in time, it is difficult to clearly identify which factors determine resolution quality.

The direct measurement of the static latent image, which is believed to have a large effect on the degree of resolution, has been proposed but there is no suitable way to measure the latent image on a photoconductor drum.<sup>(1)</sup>

Simulation of the formation of a latent image has been attempted by Watanabe<sup>(2)</sup> and Chen,<sup>(3) - (5)</sup> however, these simulated results have not been directly compared to the latent image on a photoconductor.

In order to analyze the factors that determine the degree of resolution, Fuji Electric has developed a new evaluation device that measures the 1-dot latent image potential using a micro-area surface potential probe (MASPP), and has investigated the effect that changes in the organic photoconductor (OPC) material, and the layer structure have on latent image formation.

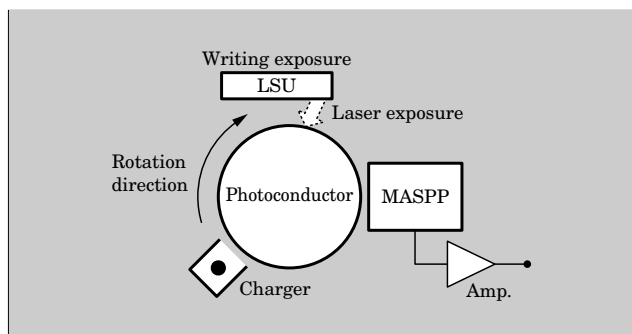
This paper describes in detail the principles of the MASPP-based latent image measurement and describes the relationships between the interpretation of the MASPP signal and electrophotographic properties. It is the authors' hope that this paper will contribute to improved photographic technology in the future.

## 2. 1-dot Latent Image Potential Measurement Device

### 2.1 Configuration of the latent image measurement device

The measurement device consists of a charging stage, an exposure light for writing, and the MASPP (see Fig. 1). A commercially available laser scan unit (LSU) for a printer is used as the writing exposure light. The LSU writes a 1-dot-wide line in the axial direction on a photoconductor that has been charged to a desired surface potential  $V_0$ . Then, the written area is moved to the location of the MASPP and the potential of the micro-area is measured. At this time, the latent image profile can be acquired by taking multiple measurements, with a measurement step size of several tens of  $\mu\text{m}$ , of the micro-area potential around the periphery of the photoconductor.

Fig.1 Latent image potential measurement system



## 2.2 MASPP mechanism

The MASPP operates<sup>(6)</sup> by detecting, as an induced current, the change in surface charge due to light decay of the photoconductor, and Fig. 2 shows the concept of the MASPP.

The surface of a charged photoconductor is exposed by a detection laser through a transparent electrode, which is located parallel to and approximately 1 mm from the photoconductor surface.

The photoconductor exposed by the detection laser undergoes light-decay, thereby changing the capacitance between the photoconductor and the transparent electrode and generating an induced current which is proportional to the change in surface charge of the photoconductor. The MASPP outputs a signal which is the amplified value of this induced current.

Figure 3 shows the measured values and a curve calculated according to a pulse function to be described later.

In the case where exposure from the detection laser nearly neutralizes the surface charge on the photoconductor, the size of the induced current will depend on the surface potential prior to exposure from the detection laser and the light decay characteristics of the photoconductor. Based on this relationship, by back-calculating the surface potential, it is possible to

measure the surface potential in the area that has been exposed by the detection laser. Fuji Electric has miniaturized the beam size of this detection laser to a diameter of approximately 10  $\mu\text{m}$ , thereby enabling measurement of the surface potential at a micro-area.

## 2.3 Measurement of the latent image potential

Based on the results of various studies, the time for measuring the surface potential at a specific point by MASPP has been set to 650 ms. Figure 4 shows the MASPP signal obtained under this condition when a negatively charged multilayer OPC on which a latent image is formed is scanned at a 30  $\mu\text{m}$  pitch.

Fifty-five different points are scanned, and the latent image potential profile can be obtained from this signal by calculating the change in charge due to exposure from the detection laser, and then converting that value into the surface potential.

In Fig. 4, the time required to measure the 1st to 55th points on the photoconductor surface was 35.75 seconds. Because the photoconductor has dark decay, this time must be reduced as much as possible, but present-day current measurement systems require approximately 200 ms for signal acquisition by detection laser exposure, approximately 100 ms to change the position by rotating the drum, and 100 to 300 ms to dissipate vibrations of the measurement system due to rotation and stopping. Accordingly, a further reduction of the measurement time would be difficult to accomplish at present.

## 2.4 MASPP output signal

Examination of the MASPP output signal in response to detection laser exposure shows that the output signal can be approximated by the pulse function of Equation (1) (see Fig. 3). The signal can be approximated by Equation (1), and is independent of the layer structure and electronic properties of the

Fig.2 Principle of MASPP operation

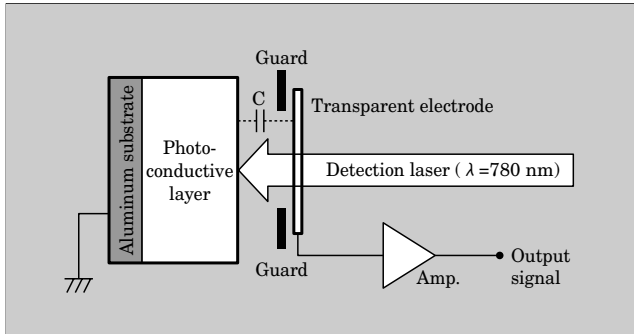


Fig.3 MASPP output signal

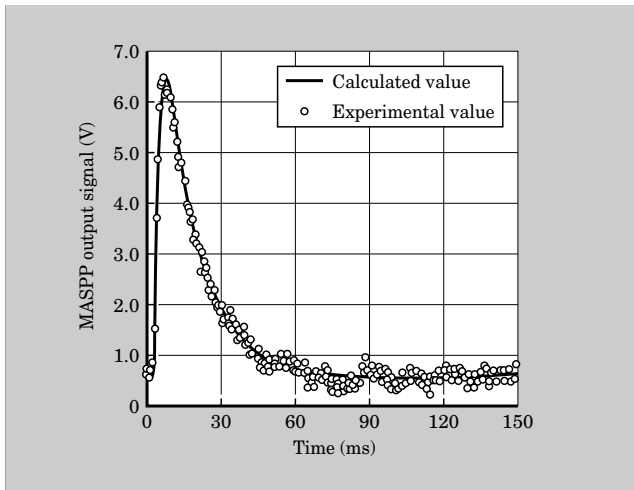
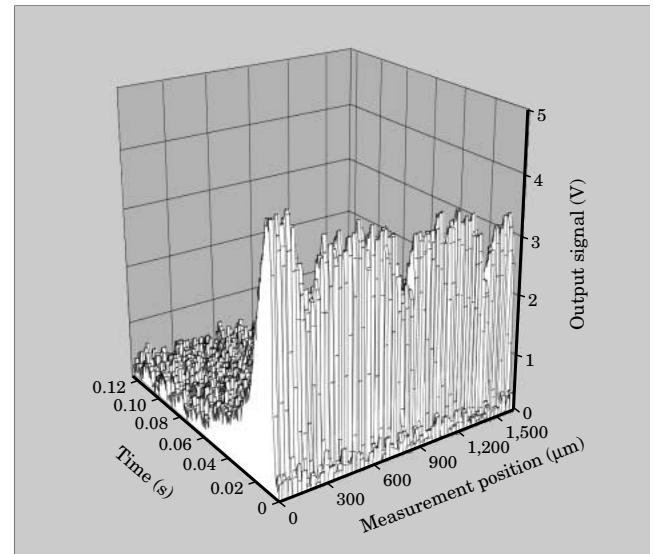


Fig.4 Example of MASPP signal



photoconductor and the polarity of the discharge.

$$S = S_{bg} + A \left\{ 1 - \exp \left( - \frac{t - t_0}{k_1} \right) \right\} \exp \left( - \frac{t - t_0}{k_2} \right) \dots\dots\dots(1)$$

In the above equation,  $S$  is the MASPP output signal,  $S_{bg}$  is the offset value of the signal,  $t$  is time, and  $A$ ,  $t_0$ ,  $k_1$  and  $k_2$  are constants.

Each parameter in the above equation can be determined by curve fitting the MASPP signal according to Equation (1).

The results of experiments about the correlations between various electronic properties of the photoconductor and numerical values of Equation (1) are described below. In anticipation of the capability to deduce the level of resolution even without measuring the latent image profile, analyses were conducted to clarify these correlations.

## 2.5 Charge retention and signal offset value ( $S_{bg}$ )

Samples having different dark charge retention rates  $V_{k5}$  (charge retention after 5 seconds) were prepared in a negatively charged multilayer OPC. Measurements were taken at the initial charge potential of  $-500$  V, and  $S_{bg}$  was obtained by curve fitting Equation (1) according to the obtained MASPP signal. Figure 5 shows the correlation between  $S_{bg}$  and the dark charge retention rate.  $S_{bg}$  increases as  $V_{k5}$  is made smaller (as the dark decay becomes larger). This phenomenon can be understood because the MASPP mechanism outputs a signal proportional to the change in charge of the photoconductor per unit time.

## 2.6 Maximum signal amplitude and sensitivity

Negatively charged OPC samples having different light sensitivities were prepared, and with the surface potential set to  $-600$  V, the MASPP signal during exposure from the detection laser was analyzed. The maximum amplitude of the MASPP signal during exposure from the detection laser was  $S_{max}$ .

The correlation between  $S_{max}$  and light sensitivity  $E_{200}$  (quantity of light exposure required for the surface potential to decay from  $-600$  V to  $-200$  V) is shown in Fig. 6.

Similar to the case of  $S_{bg}$ , this correlation can also be understood based on the MASPP mechanism. A photoconductor that is highly light sensitive is thought to exhibit a large  $S_{max}$  due to its large change in charge per unit time while exposed to light.

## 2.7 Signal peak time and charge mobility

The correlation between the time from exposure by the detection laser until the MASPP signal reaches its maximum ( $t_{peak}$ ) and charge mobility of the charge transport layer (CTL) is shown in Fig. 7. As the CTL charge mobility increases,  $t_{peak}$  becomes smaller. This phenomenon is due to the correlation between  $t_{peak}$  and the transit time of charges that move in the CTL and also to the correlation between transit time and charge

Fig.5 Correlation between charge retention and offset value

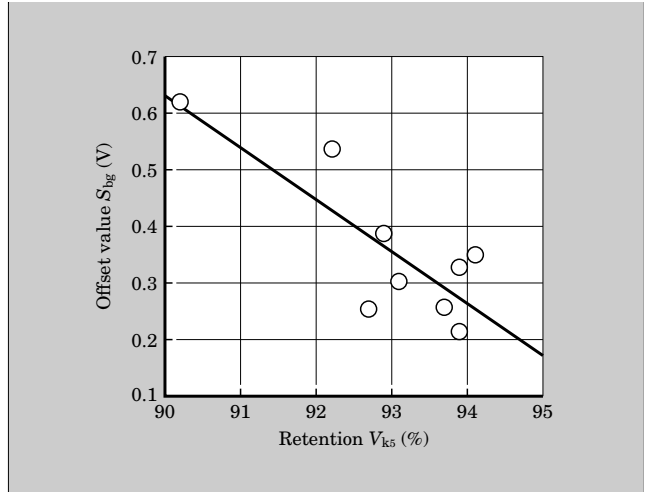
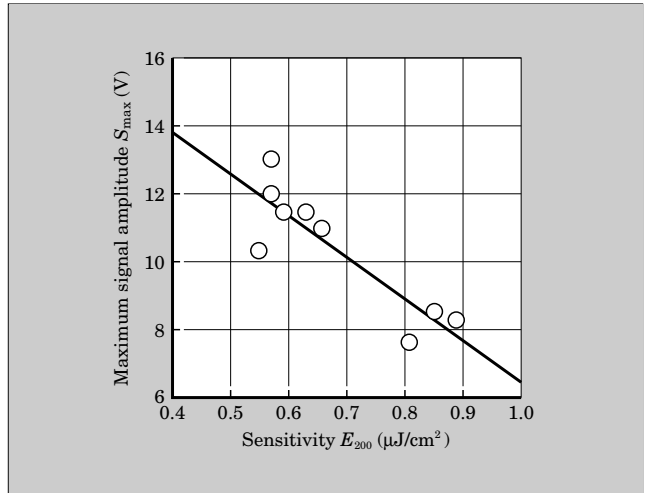


Fig.6 Correlation between sensitivity and maximum signal amplitude



mobility. The measured OPCs had identical thicknesses and charge potentials.

## 2.8 Change in charge and surface potential

Measurement by MASPP detects the change per unit time in the surface charge of a photoconductor. Consequently, the total change in charge can be calculated by integrating the MASPP signal generated by exposure to the detection laser. As has been described above, because the MASPP output signal contains both a component due to dark decay and a component due to light decay, the dark decay portion must be excluded during integration. Figure 8 shows the integrated signal value ( $\Sigma$ ) for various values of initial charge potential  $V_0$  on a negatively charged multilayer OPC.

The surface potential is computed by generating this type of calibration curve for each photoconductor that is measured. The static latent image profile is generated by computing the surface potential, using this calibration curve, from the change in charge

Fig.7 Correlation between charge mobility and maximum signal time

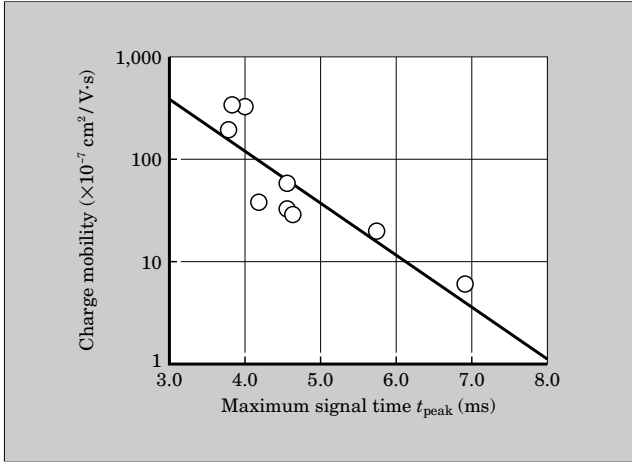
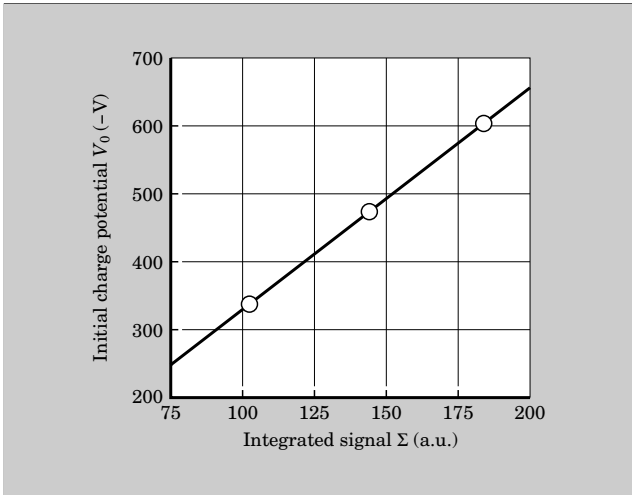


Fig.8 Correlation between integrated signal and initial charge potential



caused by exposure from the detection laser.

### 2.9 Latent image potential obtained by the 1-dot latent image measurement device

Figure 9 shows an example of the 1-dot latent image potential obtained with this device in the case of a negatively charged multilayer OPC.

In order to obtain the shape of the latent image potential, the potential is repeatedly measured 17 times with the MASPP at different positions. As described above, 650 ms are required for each MASPP measurement and therefore approximately 11 seconds elapsed from the 1st measurement point until the final 17th measurement point. Moreover, due to constraints of the device, 3 seconds are required from the time at which writing is performed until the time at which MASPP measurement begins. In the graph of Fig. 10, the vertical axis is the same as in Fig. 9 and the horizontal axis shows the time ( $t_m$ ) that elapses after a 1-dot line has been written until the MASPP measurement is performed. In Figs. 9 and 10, there is an

Fig.9 1-dot latent image profile

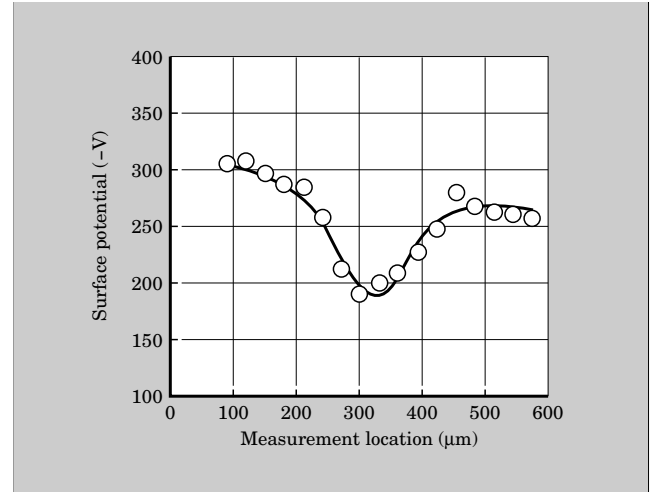
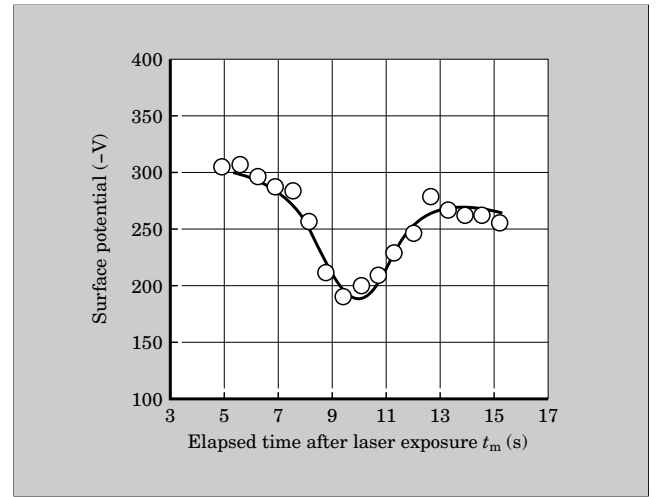


Fig.10 Elapsed time after writing and latent image potential



approximately 50 V difference in surface potential between the initial measurement point and final measurement point, and the latent image profile has an overall downward slope from left to right. In this system, because it is not possible to measure each point simultaneously, the time that elapses after writing will be different for each point, and this is the reason for the downward slope from left to right in the latent image profile obtained with this device.

## 3. Experimental Results

### 3.1 Measurement conditions

While the photoconductor drum is rotated at a speed of approximately 5 r/min, the drum surface is uniformly charged to the range of about  $\pm 500$  to  $\pm 700$  V. Then, an LSU having a dot width of approximately  $80 \mu\text{m}$  at a strength of  $e^{-2}$  times its maximum strength, or if not specified, at an exposure power of 0.28 mW, writes a 1-dot-wide line, and the latent image potential is measured by MASPP with a measurement step size of  $30 \mu\text{m}$ . The width of the latent

Fig.11 Definition of surface potential width and depth

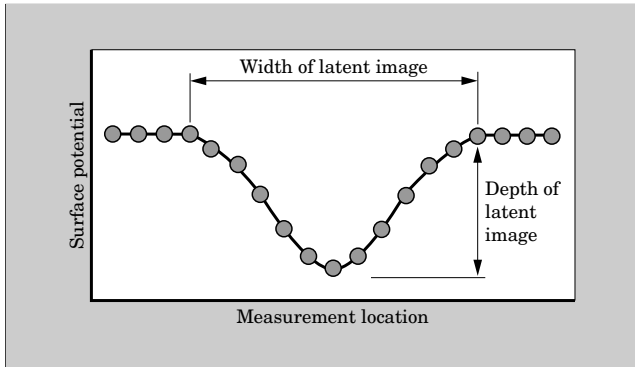


Fig.12 Writing light strength dependency of latent image

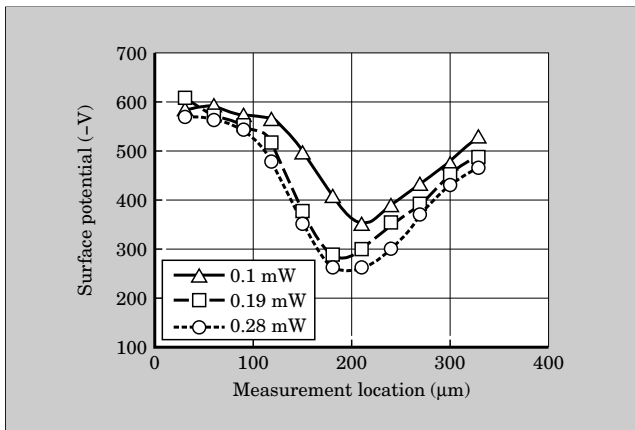


image in these experimental results indicates the width of the change in surface potential as shown in Fig. 11.

### 3.2 Exposure power dependency of the latent image

Figure 12 shows the change in latent image shape on a negatively charged multilayer OPC in the case where LSUs of various exposure powers are used to write a 1-dot-wide line. An increase in exposure power causes the latent image to become deeper and wider. This figure is in agreement with the generally known result that image density and line width increase with greater exposure power.

These results are important because they suggest that this measurement of a latent image profile is similar to the actual static latent image profile in an electrophotographic process.

### 3.3 Comparison of negatively charged OPC and positively charged OPC

Latent image potentials were measured for a negatively charged OPC and a positively charged OPC. Results of the measured latent image potentials are shown in Figs. 13 and 14.

Each OPC has the following layer configuration:

- (1) Negatively charged (multilayer) OPC: Aluminum substrate / charge generation layer (CGL) / CTL (CTL mobility:  $1.0 \times 10^{-6} \text{ cm}^2/\text{V}\cdot\text{s}$ )

Fig.13 Film thickness dependency of latent image on negatively charged OPC

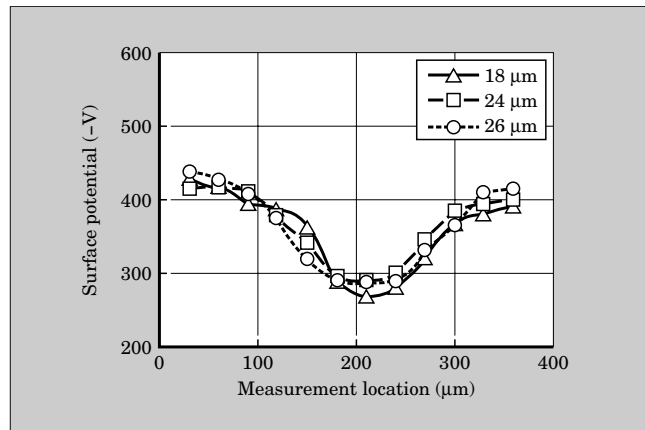
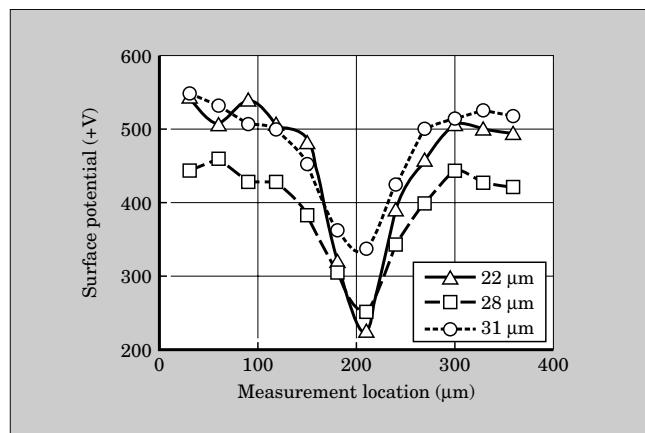


Fig.14 Film thickness dependency of latent image on positively charged OPC



- (2) Positively charged (single layer) OPC: Aluminum substrate / photoconductive layer

With the negatively charged OPC, the width of the latent image was 150 μm for a film thickness of 18 μm, but the width increased to 240 μm in the case of a film thickness of 26 μm. With the negatively charged multilayer OPC, an increase in film thickness due to the generation of charge at the substrate causes charge to distribute in the lateral direction, thereby decreasing resolution. These results are in agreement with prior observations.

On the other hand, the positively charged single-layer OPC has less dependency on film thickness, and for film thicknesses ranging from 22 to 32 μm, the latent image width was narrow and ranged from 150 to 180 μm. Figure 15 shows latent image widths for a negatively charged multilayer OPC and a positively charged single-layer OPC. The results support the theory that the single-layer has higher resolution because charge is generated at its surface.

### 3.4 Charge mobility dependency of the latent image potential

In order to investigate the correlation between the

Fig.15 Difference in latent image width due to layer structure

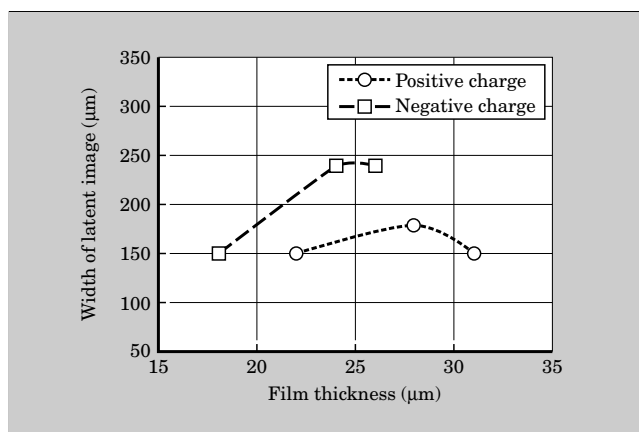
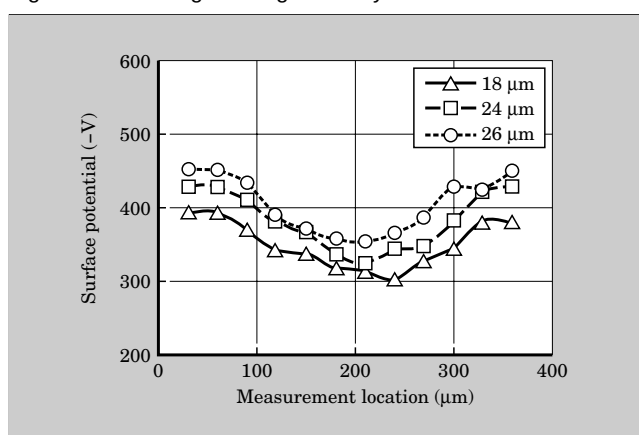


Fig.16 Latent images of high mobility CTL OPC

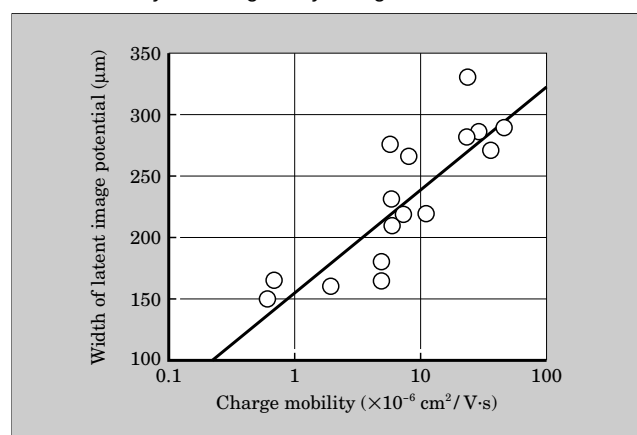


latent image shape and the electrical characteristics of the photoconductor, 1-dot latent image profiles were measured for negatively charged multilayer OPCs in which charge transport materials (CTMs) having different mobilities were used in the CTL. The CTMs used were selected for their different mobilities only, and each CTM had a different chemical structure. The mass ratio of CTM contained in the CTL to the binder was 1:1 in all cases.

Figure 16 shows the result of measurement of the latent image potential of OPC on which a CTL of even higher mobility was laminated. The CTL mobility was  $1.5 \times 10^{-5} \text{ cm}^2/\text{V}\cdot\text{s}$ .

In the case of the OPC of Fig. 13, at a CTL film thickness of 18 μm, the latent image width was 150 μm. However, in the case of the OPC on which a higher mobility CTL is laminated in Fig. 16, at a CTL film thickness of 18 μm, the latent image width was 270 μm. The latent image becomes wider when a higher mobility CTL is laminated. On the other hand, the latent image depth was approximately 150 V in Fig. 13 and approximately 100 V in Fig. 16, showing the OPC having the laminated layer of higher mobility CTL to have a shallower depth. The use of higher mobility CTL to support higher speed printing has opposing effects on the 1-dot latent image, its width

Fig.17 Correlation between latent image width and charge mobility on a negatively charged OPC



increases by depth decreases.

As described above, the width of the latent image is observed to increase when the film thickness of a negatively charged multilayer OPC is increased. However, the latent image potential of the negatively charged multilayer OPC is hypothesized to be dependent on the carrier mobility of charges that move within the CTL. Figure 17 shows the mobility dependency of latent image width for various types of CTMs. These experimental results confirm that increasing the mobility of the CTL causes the latent image to become wider.

The width of a 1-dot latent image on an OPC that uses a high mobility CTL is thought to be wider than in the case of using a low mobility CTL. This is in agreement with the experience thus far in which 1-dot images of low mobility CTLs have been printed as clear and sharp images.

Oka et al. have used simulations to explain that a significant deterioration in static image potential occurs when the ratio of the carrier diffusion coefficient  $D$  to the mobility  $\mu$  in a CTL ( $D/\mu$ ) exceeds the value of 10. There is a high probability that the deterioration of a latent image is closely related to the charge transport characteristics of the CTL, and the correlation obtained in this experiment between latent image width and CTL charge mobility seems to support that relationship.

#### 4. Conclusion

It has been reported that Fuji Electric's proprietary surface potential measurement method enables measurement of the static latent image, and several examples have been presented. Furthermore, the correlation among various parameters obtained from the MASSP signal, the photoconductive characteristics and the static latent image have been described.

In the future, Fuji Electric intends to shorten the required measurement time, to use a finer detection laser in order to achieve a more advanced 1-dot latent

image measurement device, to acquire even more detailed latent image potential profiles and to compare them to various simulated latent images in order to contribute to the development of OPCs with higher resolution.

Additionally, Fuji Electric intends to investigate the optimal exposure profile (light quantity, exposure waveform and the like) by making more flexible types of exposure lights for latent image formation and to contribute to the development of high resolution technology in the field of electrophotography.

## References

- (1) Yarmchuk, E.J.;Keefe,G.E. High-resolution surface charge measurements on a organic photoconductor. J.Appl.Phys.vol.66, 1989, p.5435-5439.
- (2) Watanabe, Y.et al. A Numerical Study of High Resolution Latent Image Generation by Laser Beam Exposure. IS&T's NIP 16, 2000, p.822-826.
- (3) Chen, I. Optimization of photoreceptors for digital electrophotography. J.Imaging Sci. and Technol. vol.34, 1990, p.15-20.
- (4) Chen, I. Developability of interposed imagewise charge in color electrophotography.J.Imaging Sci. and Technol. vol.35,1991, p.365-372.
- (5) Chen, I. Electrostatic image densities in digital hybrid halftone methods. J.Imaging Sci. and Technol.vol.39, 1995, p.302-305.
- (6) Lin, C.W.; Nozaki, T. The measurement of Photoconductive Characteristics on Kicro-Area Surface of Photoconductor Drum. Proceedings of IS&T's 11th International Congress on Advances in Non Impact Printing Technologies.1995, p.138-141.



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