Glass Substrate Magnetic Recording Media

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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 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:

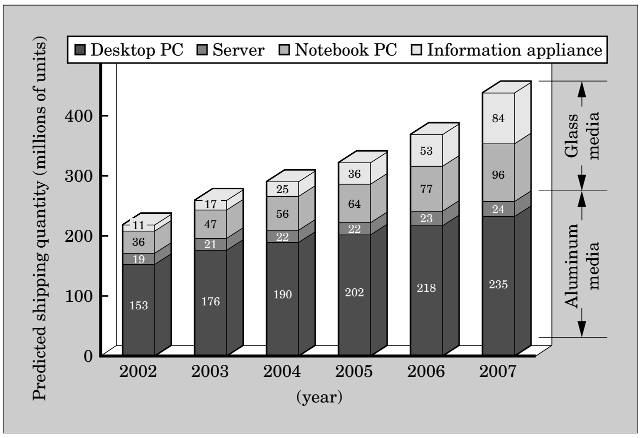
Glass media has the following characteristics.

(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°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 μm)
Number of tracks per inch		100,000 tracks (size 0.254 μm)
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 fractuation.

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

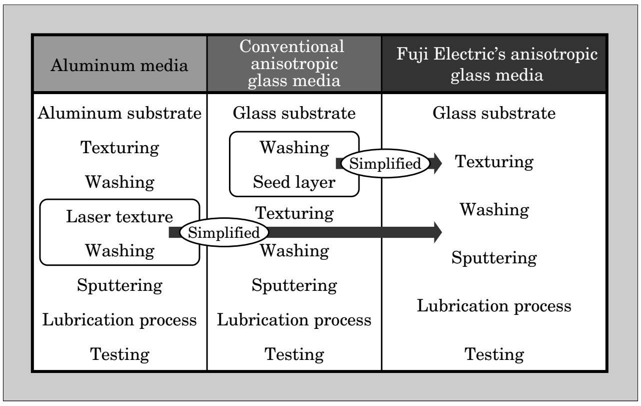
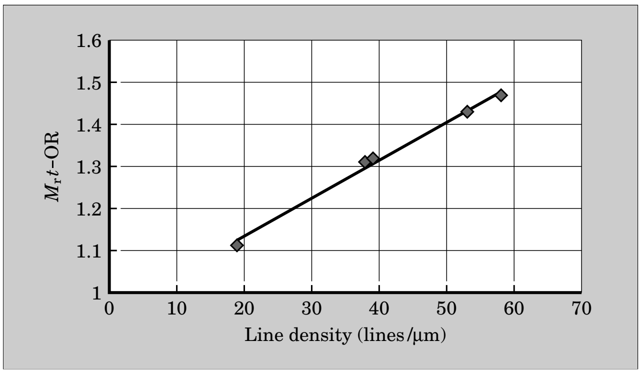


Fig.3 Correlation between line density and $M_r t$-OR



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

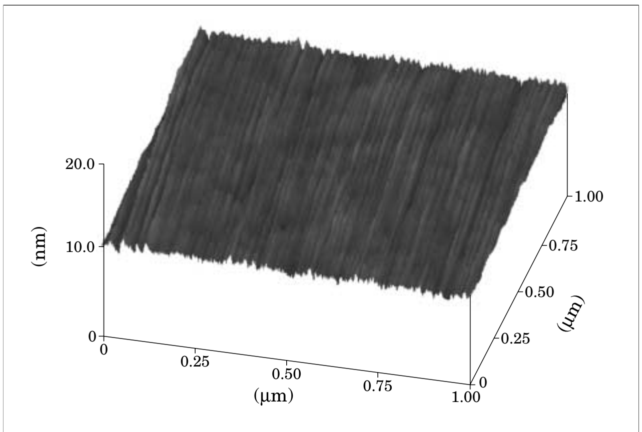


Fig.5 Correlation between seed layer process conditions and $M_r t$-OR

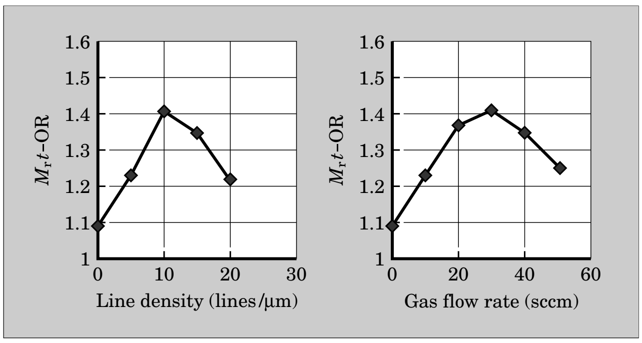


Fig.6 AFC-structure magnetic layer

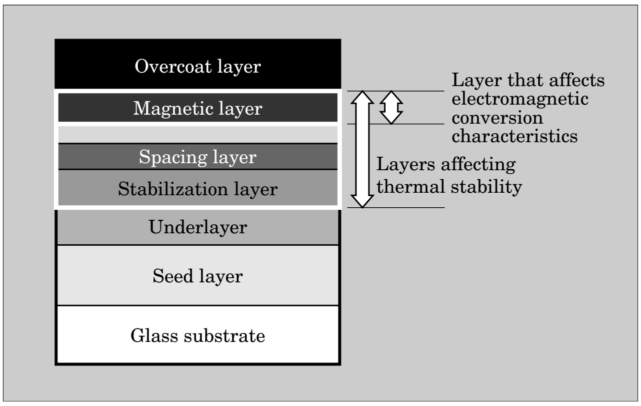
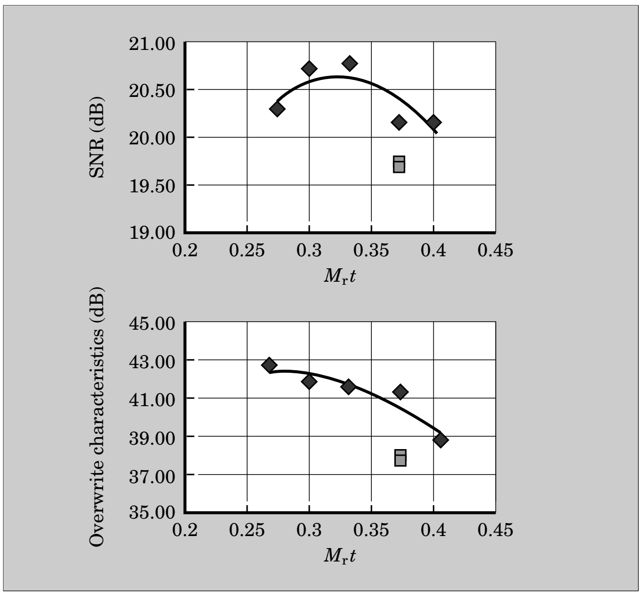


Fig.7 Typical overwrite and SNR characteristics for glass media made by Fuji Electric



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 Bolztmann 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.

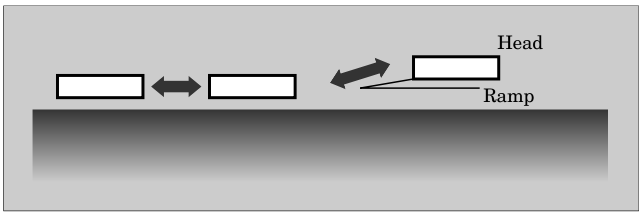
4. HDI Technology for Glass Media

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.

Fig.8 LUL test method



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.9 Co corrosion characteristics

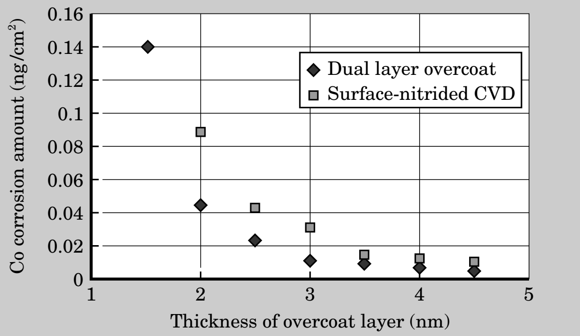


Fig.10 Gas adsorption dependency on overcoat layer property

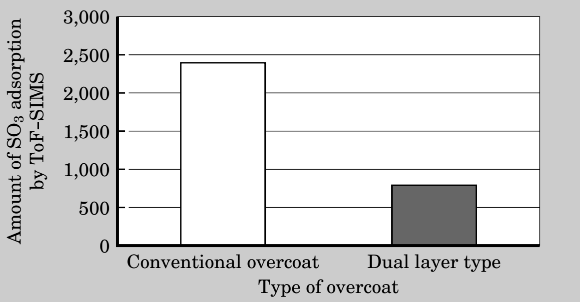
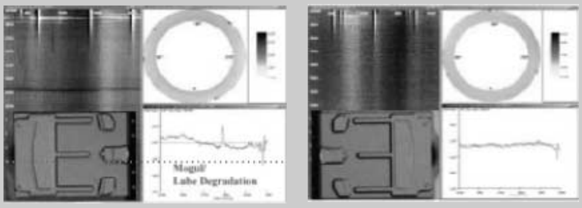
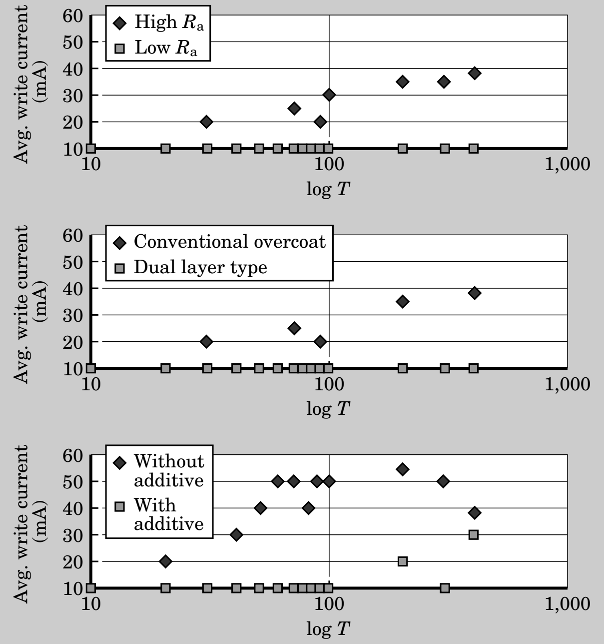


Fig.11 High-speed LUL test (1 cycle: 0.12 s)



(a) Conventional lubricant (b) Lubricant with optimized molecular weight/polarity

Fig.12 Head damage test



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 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/in^2 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.

e-Front runners