Development of Higher Performance Tape Media for Enterprise Data Storage Systems by using Barium Ferrite Magnetic Particles

Hiroaki TAKANO*, Masahiko ASAI*, Masahito OYANAGI*,
Tadahiro OHISHI*, and Masayuki USUI*

Abstract

The magnetic tape using barium ferrite magnetic particles instead of traditional metal magnetic particles demonstrated much higher areal recording density of 6.7Gbit/in^2 in 2007 and 29.5Gbit/in^2 in 2010. We applied NANOCUBIC technology to the barium ferrite material through these demonstrations, and moved these technical achievements into the production phase while increasing the durability. For enterprise-class systems, we released in 2011 the reliable magnetic tape products that have an approximately three times larger storage capacity than LTO Generation 5 tape. This proves that Fujifilm's barium ferrite technology can contribute to an increase in the storage capacity of magnetic tape in response to the market needs for data storage systems having higher capacity.

1. Introduction

In the digital data storage market, demands for reliability and cost effectiveness have kept increasing. Magnetic tape is highly regarded in the market because of its low price per unit capacity and running cost as well as its high reliability for long-term storage. Since 1990s, a cartridge capacity of the linear tape system had kept increasing by 40% annually, that is, at a pace that nearly doubles the capacity every two years. However, in recent years, the uptrend of capacity increase has slowed down; for the micronization of metal magnetic particles is reaching its limit. As a breakthrough, magnetic particles with magneto-crystalline anisotropy such as barium ferrite (hereinafter "BaFe") had long been studied[1), 2)], but the potential of BaFe magnetic particles could not be fully realized for the following reasons: such fine particles as BaFe are difficult to synthesize and disperse evenly; and, because of their low magnetizability, low-sensitivity magnetic heads cannot achieve a satisfactory signal-to-noise ratio (SNR). Under such circumstances, we succeeded in deriving high performance from BaFe magnetic particles with NANOCUBIC technology [3) to 9)] and, in collaboration with system integrators, realized technology demonstrations[4), 8)] (hereinafter "tech demo") with areal recording densities of 6.7 Gbit/in^2 and 29.5 Gbit/in^2. Fig. 1 shows the trends of areal recording densities for hard disks and the linear tape system. The recording densities achieved by the two tech demos indicated that, by using BaFe magnetic particles, it is possible to re-establish the stalled upward progress of densities of linear tape products.

By applying the technology introduced to the 6.7 Gbit/in^2 tech demo, we developed an eminently practical, high-capacity magnetic tape and launched it onto the enterprise storage market where there is a requirement for high reliability.

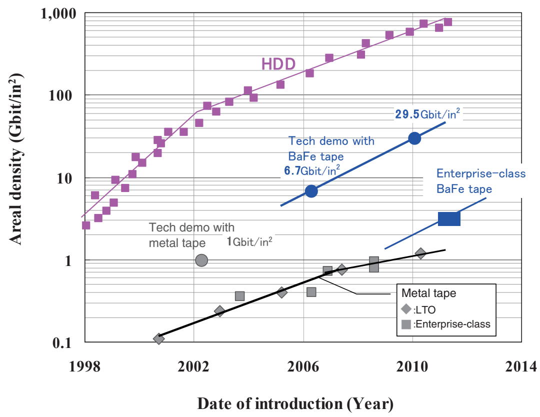

Fig. 1 Recording areal densities of general hard-disk drive and tape products, and the tape used in the demonstrations.

2. Design of high recording-density magnetic tape

Three key NANOCUBIC technologies are employed to increase the recording density of magnetic particle-coated tape: (a) nano particle utilization (nanonized magnetic particles); (b) nano dispersion (dispersion of nanonized magnetic particles); and (c) nano coating (even, thin magnetic layer coating). With those technologies, we enhanced the tape's recording density and succeeded in achieving a quality level that enables industrial mass production.

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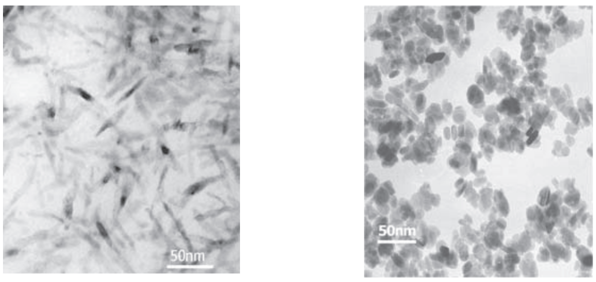
* Recording Media Research Laboratories
Research & Development Management Headquarters
FUJIFILM Corporation
Ohgi-cho, Odawara, Kanagawa 250-0001, Japan

2.1 Nano particle utilization (nanonized magnetic particles)

The magnetic anisotropy of conventionally-used metal magnetic particles is derived from shape anisotropy. Their major axis length has already been shortened and nanonized to a level previously regarded as impossible to achieve but further micronization cannot be expected because it is difficult to maintain coercivity provided by the acicular particle shape and to retain a film of oxide. In contrast, nanonization and high coercivity are compatible in BaFe magnetic particles because their magnetic anisotropy is derived mainly from magneto-crystalline anisotropy. They are hexagonal plate-like particles and the easy axis of magnetization is perpendicular to the plate face. In addition, as an oxide, they are more stable in the air than metal magnetic particles. Table 1 and Fig. 2 show the properties of the BaFe magnetic particles developed for the 6.7 $\mathrm{Gbit/in^2}$ tech demo and the metal magnetic particles used for LTO-5. In the tape media for enterprise systems, we employed the former nano particles with a plate diameter of 21 nm whose volume is 26% smaller than that of the latter particles.

Table 1 Comparison between a metal particle and BaFe particle.

	Metal particle (LTO5)	BaFe particle
Size [nm]	37	21
Volume [$\mathrm{nm^3}$]	2850	2100
Hc [Oe]	2380	2280
σs [emu/g]	105	50



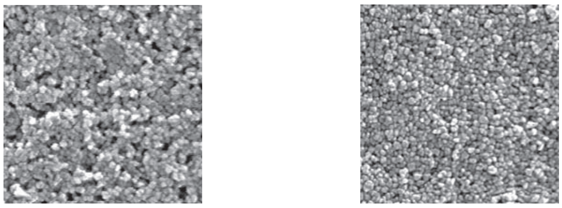
(a) Metal particles (b) BaFe particles

Fig. 2 TEM images of magnetic material: (a) Metal particles and (b) BaFe particles.

2.2 Nano dispersion (dispersion of nanonized magnetic particles)

In magnetic tape, to suppress the generation of noise signal, it is important to form an uniform coating of magnetic particles without causing their aggregation. In this industry, sand mill disperser is commonly used with ceramic or glass beads. To disperse the employed BaFe nano magnetic particles uniformly, a high-dispersion mass production line has been installed on which the efficiency is improved dramatically over conventional lines. BaFe magnetic particles can readily become stacked because their axis of easy magnetization is perpendicular to the plate face, which can easily cause the re-aggregation of particles after dispersion. To prevent this problem, we introduced a technology to make organic materials such as binders adhere between magnetic particles as a steric hindrance. The more binders that exist between magnetic particles, the more easily the steric hindrance can be formed. However, it decreases the recording performance of magnetic tape because the packing density of the magnetic particles declines. Having studied dispersion agents and the polar groups of polymers optimal for BaFe magnetic particles, we then succeeded in making the minimum necessary amount of binders adhere uniformly to the magnetic particle surface with a high adhesion rate, thereby preventing re-aggregation caused by stacking.

Fig. 3 provides SEM images of the surface of the magnetic layer applied to the base material after dispersion. As shown in Fig. 3 (b), magnetic particles are separated evenly with our new dispersion technology, compared with the conventional dispersion conditions in Fig. 3 (a).

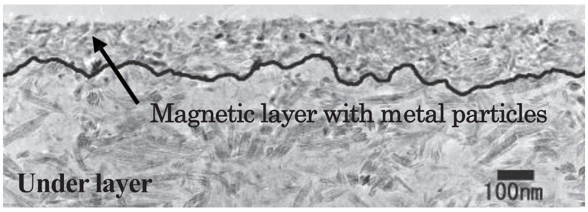


(a) Conventional dispersion conditions (b) New dispersion conditions

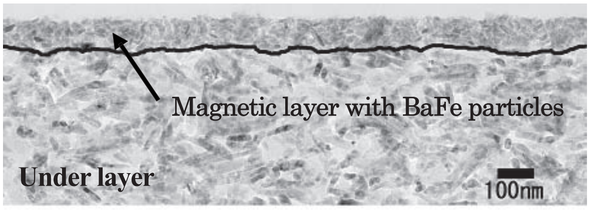
Fig. 3 SEM images of magnetic layer surfaces under (a) conventional dispersion conditions and (b) new dispersion conditions using nano-dispersion technology.

2.3 Nano coating (uniform, thin magnetic layer coating)

To increase recording densities, it is important to improve the resolution of recording signals by obtaining sharp, inverted solitary waves, which requires the thinning of the magnetic layer. We have introduced onto the market an extensive range of products including the consumer-use video tape Hi8 in the 1990s and data storage DLT or LTO, with a technology to enable the thinning of the magnetic layer by coating it simultaneously on the non-magnetic underlayer (i.e., ATOMM technology). However, with the progress of the shortening of recording wavelengths, the required thickness of the magnetic layer has become 100 nm or even less, which has brought us a new problem. The irregular interface between the two layers resulting from the upper layer thinning causes noise, which affects the electromagnetic conversion characteristics. Mixing of the upper and under layer coatings is the cause of the fluctuations of the interface. Therefore, we reviewed the thixotropy and application method of the coating solutions and realized a coating method that can form a thin magnetic layer while keeping the fluctuations to a minimum. Fig. 4 provides cross-sectional TEM images of the interfaces observed between the magnetic layer and the non-magnetic underlayer. As shown in Fig. 4 (b), the interface formed with the newly introduced thin coating technology is far flatter than that formed with a conventional coating method in Fig. 4 (a).



(a) Conventional coating conditions



(b) New coating conditions

Fig. 4 Cross-sectional TEM images of interfaces between magnetic and non-magnetic-layer under (a) conventional coating conditions and (b) new coating conditions using nano-coating technology.

3. Design of durability

3.1 Compatibility of slidability and electromagnetic conversion characteristics

The spacing between the magnetic head and tape surface results in a decrease of read/write performance. Decreasing this spacing can greatly improve the SNR, particularly in the short wavelength area. However, at the same time, the consequent widened real contact area increases friction. Table 2 shows the surface roughness of the magnetic layers and the coefficients of friction of the newly developed tape for enterprise use, the 6.7 Gbit/in^2 tech demo, and an LTO-5 product using metal magnetic particles. The surface roughness profiles of those three media are shown in Fig. 5. The surface roughness was measured with an optical interferometric profiler (OIP). Ra and Rz values represent mean surface roughness and ten-point mean roughness, respectively. The coefficients of friction were measured at a tape tension of 0.98 (N) and at a low tape speed of 14 mm/s against an AlTiC bar whose surface roughness is equivalent to that of the magnetic head.

Table 2 Surface roughness measured with optical interferometric profiler (OIP) and friction with AlTiC bar.

	LTOG5	6.7 Gbit/in2 tech demo tape	Enterprise-class tape
Ra [nm]	1.7	1.3	1.4
Rz [nm]	35	23	20
Number of 20 nm-high protrusions (ratio)	12	1	5
Coefficient of friction	0.30	＞0.5	0.28

The 6.7 Gbit/in^2 tech demo tape had a very smooth magnetic layer surface. This achieved a small spacing between the tape surface and the magnetic head, as a result the SNR was improved. However, the friction against the magnetic head became higher. Therefore, in the development of the enterprise-class tape, to solve that problem, we controlled the particle distribution of fillers which were added to magnetic layer to ensure slidability and durability. By doing so, it became possible to maintain the Ra and Rz values of the enterprise-class tape to the same level as those of the 6.7 Gbit/in^2 tech demo tape while the number of small protrusions increased a little. In this way, a narrow spacing between the magnetic head and tape surface and high slidability have been achieved.

Fig. 6 shows reproduced signal spectra at a track recording density of 275 kfci with a GMR head whose track width is 0.5 μm. It indicates that the enterprise-class tape achieves a high SNR, obtaining a very sharp signal spectrum, while keeping a noise level as low as that of the 6.7 Gbit/in^2 tech demo tape.

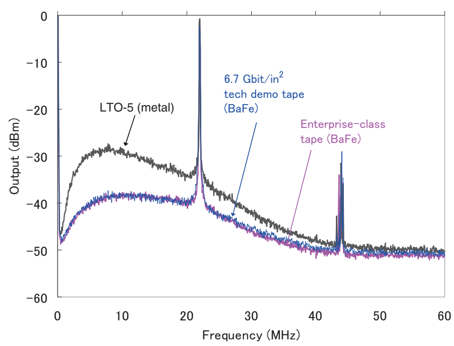
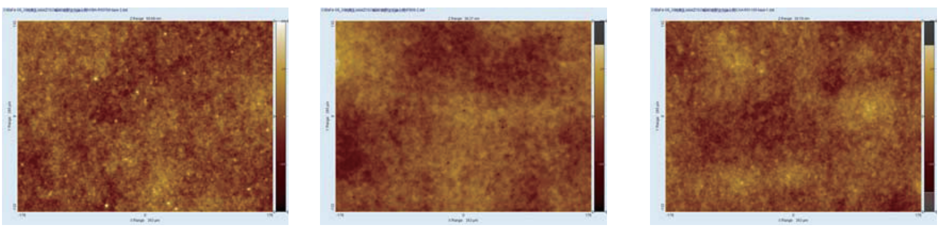


Fig. 6 Signal and modulation noise spectra.



(a) LTO-5 (b) 6.7 Gbit/in^2 tech demo tape (c) Enterprise-class tape

Fig. 5 Surface profiles measured with optical interferometric profiler.

3.2 Long-term storage

The test method widely used in the magnetic tape industry as an index for the storage performance of magnetic tape is the aging test carried out under an accelerated environment with corrosive gas, the Battelle Class II[10] environment, developed by Battelle Memorial Institute[11), 12)].

The Battelle Class II environmental conditions of the test that we conducted are as shown in Table 3. The duration was fourteen days accelerated by approximately 400 to 1000 times[13], which is equivalent to fifteen to thirty-eight years. The tape using BaFe magnetic particles was left with its surface exposed in the environment. For the tape using metal magnetic particles, we prepared two test pieces: one was left with its surface exposed in the environment and the other was left in a cartridge. After fourteen days, we investigated the changes in the tape surface conditions and in the products of residual magnetization and magnetic layer thickness[9]. Normally, magnetic tape is reeled inside a cartridge and makes hardly any contact with the external air. Therefore, the condition in which the surface is exposed is quite a harsh environment for it. The metal magnetic particle tape, including the portion just after the leader, left inside the cartridge was not corroded at all and no change occurred in its magnetization. However, the one with its surface exposed to the environment was corroded and its magnetization level decreased greatly. In contrast, any changes were hardly observed on the surface of the tape using BaFe magnetic particles and its magnetization level was kept unchanged as shown in Table 4. These results indicate the extremely high chemical stability of BaFe magnetic particles. Further nanonization of magnetic particles will become essential in the future. Under such circumstances, BaFe magnetic particles are promising compared with conventional metal ones in the light of stability for long-term data storage.

Table 3 Conditions for gas environmental test.

Cl_2 concentration	10ppb
NO_2 concentration	200ppb
H_2S concentration	10ppb
Relative humidity	70%
Temperature	30℃

Table 4 Change in Mrt (remanent magnetization X thickness) value in Battelle Class Ⅱ test.

	Before [mA]	After [mA]	Ratio
BeFe tape	3.1	3.1	1.00
Metal tape (LTO4)	19.5	12.5	0.64
Metal tape (in cartridge)	21.4	21.7	1.01

4. Conclusion

In 2011, five years after the 6.7 Gbit/in^2 tech demo in 2006, we launched onto the market a highly reliable, high-capacity magnetic tape for enterprise data storage systems. The product is the fruit of our original BaFe magnetic particle technology cultivated in the development of the tech demo and NANOCUBIC technology with durability improved. The recording capacity is about three times as large as that of LTO-5 released in the previous year. It revitalized the declining rate of recording capacity expansion of tape systems more than expected by the industry. In recent years, information terminals have been becoming more and more diverse, and it is expected that needs for high-capacity data storage will keep increasing in the future. As the recording capacity and density requested from customers have already reached a level that cannot be achieved with conventional metal magnetic particles, expectations for magnetic tapes using BaFe magnetic particles are high. We will keep developing higher-capacity magnetic tape by improving the performance of BaFe magnetic particles, introducing more advanced uniformly coating techniques and improving the interfacing of the magnetic head and tape surface.

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