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PRESENT AND FUTURE OF SPUTTERED MAGNETIC DISK

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1. INTRODUCTION

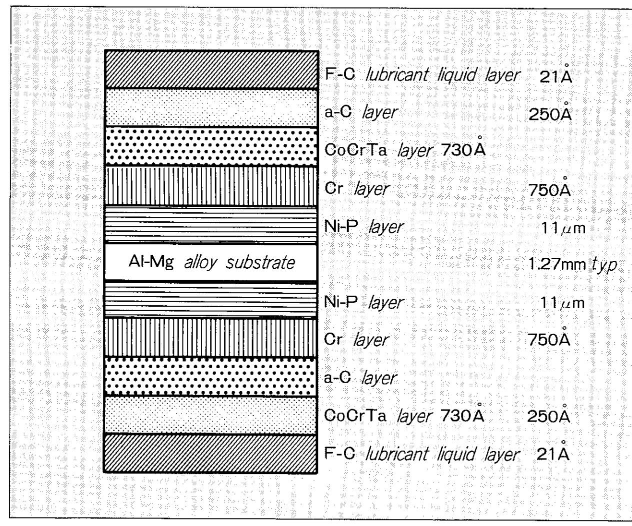
It is expected that, in the next century, there will be a high level of information community. The community. The community will be equipped with computers and their peripherals as the essential unit. Much closer relations between human life and the computer systems will be realized at the level of sixth generation computers for example. Those will be achieved by developments of ultra high speed of central processing unit, which is capable of parallel processing, as well as ones of ultra high capacity of memory devices, which can take tera bytes, for exampled central processing units that are capable of parallel processings. The peripherals will have a recording capacity of 100 tera bytes. Because of this fact, Hard Disk Drives, or HDDs, and other computer memory devices will maintain and gain its importance in technology developments for human life. The magnetic disk is the essential component of the HDD.

Fuji Electric started developing the sputtering technology of mass production in 1983. At this time, magnetic disks available in the market were of the iron oxide, or gamma hematites, coating types. A team of Fuji Electric had anticipated a needs of down sizing of HDD and its higher recording capacity. Studies and researches were then concentrated on comparisons and feasible studies on iron oxide sputtering, cobalt alloy plating and cobalt alloy sputtering. In 1985, the cobalt alloy sputtering was selected because of its best efficiency in mass production, and it's most corrosion resistivity as the thin film. The first mass production started and CoNiCr sputtered magnetic recording disk was introduced to the market. Since then, Fuji Electric has been successful and a successive type of product was also developed with CoCrTa for high performance application because of its low noise and high coersivity characteristics. CoCrPt product will be in a mass production as soon as market reaches to the level of higher linear recording density technology.

2. BASIC LAYER STRUCTURE OF SPUTTERED MAGNETIC DISK

A schematic structure of thin film layers is shown in *Fig. 1*. The non-magnetic aluminum substrate gets Ni-P layer by electroless plating. The surface of Ni-P is physically, or mechanically, processed to form tens of angstrom roughness. The successive sputtering process forms three layers such as chromium, Cr cobalt, Co, alloy and amorphous carbon, a-C, layer. A liquid lubricant of fluorocarbon, or F-C, is then coated uniformly by the order of angstroms. Both dip coating and spin coating are installed in the manufacturing process and exhibit equal performance.

Fig. 1 The basic structure of sputtered magnetic disk

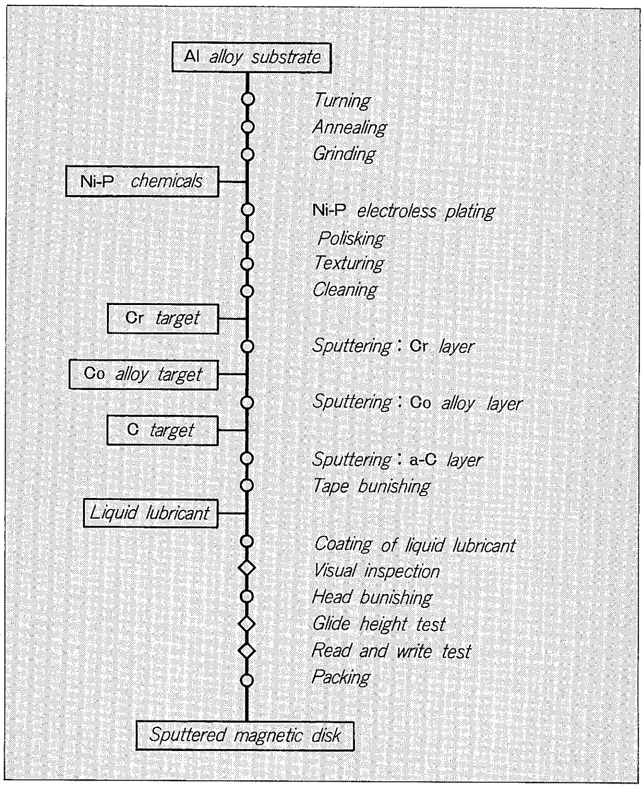


3. MANUFACTURING PROCESS OF SPUTTERED MAGNETIC DISK

An outline of manufacturing process of sputtered magnetic disk is shown in *Fig. 2*.

To fulfill various quality requirements of products, there are following technologies essential. Thin films of cobalt alloy as well as amorphous carbon should be formed through tight controls because these bear product functions such as magnetic recording and mechanical protection respectively. Aluminum alloy substrate should be physically trimmed with extra precisions. Ni-P plating should be

Fig. 2 Manufacturing process of sputtered magnetic disk



pit free. Polishing should achieve smooth surface less than 0.01 micron. A clean room operation is important to eliminate dusts and chemicals or gaseous contaminants so that the disk surface is uniform and clean.

In order to control qualities in each process, technologies of inspection, evaluation and measurement should be as precise as the order of angstroms. When it comes to product qualities such as electro-magnetic conversion property, reliability and durability should be controlled by electronic signal analysis of the order of nano second.

The manufacturing process of the sputtered magnetic disk can be summarized as follows:

3.1 Aluminum alloy substrate

The substrate made of aluminum alloy should fulfill the following requirements:

(1) No defects which may cause defect of thin film and signal error.

(2) Physical parameters should be controlled to take low flying height of head.

The first one is achieved by controls on non-metal contaminants in the Al substrate, controls of lath's bite, control of grinding abrasives and selection of a suitable cleaning scheme. The second requirement is achieved by selection of uniform aluminum blank, or raw substrate, and by selection of substrate fixtures in the processes.

The raw substrate have inner and outer diameter trimmed. Both surfaces are scraped by lath machine. And then, the trace of cutting edge, or bit, is eliminated by grinding its surfaces. It is therefore important to control not only machines and apparatus but also mounting/dismounting devices and transfering scheme should be optimized. The production line of Fuji Electric is automated through these and achieved a high throughput.

3.2 Ni-P plating

Requirements on the Ni-P layer are:

(1) Ni-P physically harden the surface of disk where the head makes mechanical contacts.

(2) Ni-P should be no magnetic and should hold this property against heating of sputtering.

The layer formed in this process should be free from defects such as nodules and pits that may result in signal errors. An irregularity on the surface results in corrosion seed through local electric potential and the product surface will get corrosion.

The controls of plating, or chemicals and other parameters, are achieved in the manufacturing line of Fuji Electric to the level of high plating rate under the condition that phosphorous concentration should be minimum 11% in the layer plated. To suppress local defect and seed of local potential, the plating chemicals as well as preceding chemicals are continuously refreshed by submicron filters. Ph control of chemicals, phosphorous concentration and temperature of chemicals are monitored by computerized automatic measurement system.

3.3 Polishing and texturing

Requirements on the polished surface of Ni-P substrate are:

(1) The finished surface should be flat to assure low and stable flying height of head.

(2) The surface roughness should be controlled so that there is no head stiction to the disk surface.

The surface of Ni-P layer should be as smooth as possible so that head can fly low and stable. For this purpose, a polishing process by slurry and artificial leather gives a mirror flat surface of approx. 25 angstrom of the arithmetic average roughness.

Immediate after the polishing, there is a process of texturing to get appropriate roughness on the surface in order to balance the friction between the head surface and disk and the stable flying of head. To control these, Fuji Electric adopts two stage tape texturing. The first stage forms necessary roughness and the second stage trims the roughness which removes irregularities as well as asperities which may have formed by the first stage. Recently, a slurry with tape backup for the second stage has developed and will be applied for higher performance products.

Possible small irregularities, slurry residues and some dusts on the substrate surface should be eliminated from the polishing because they will cause serious defect such as signal error or even lead to head crash. There is an intensive quality control on slurry, tape, cleaning chemicals etc.

3.4 Sputtering

The textured substrates get its surface cleaned equivalent to semiconductor wafers before sputtering. Three layers of thin films are formed by sputtering of in-line type apparatus. The layers are a buffer layer of Cr, a magnetic layer of Co alloy and an overcoat layer of amorphous carbon. These are formed by this order while the substrate travel through the in-line and continuous sputtering apparatus. The chromium, Cr, underlay has a property that its crystal lattice matches well with the one of cobalt, Co, so that the crystallization of Co gets its magnetically preferable axis aligned parallel to the plane of substrate. It is therefore important for achieving magnetic performance of product to control both chromium crystallization and metrological property of cobalt alloy.

Qualities of thin films depend on control parameters of sputtering, and they are substrate temperature, level of vacuum, sputter gas or argon gas pressure, sputtering rate or power, electrical bias or voltage and magnetic field of dc magnetron sputtering. Particularly two parameters, the substrate temperature during material deposition to form thin film and the vacuum control in the vicinity of the substrate surface, are the primarily factors that determine magnetic performance of disk product. Optimizations of sputtering over factors and parameters listed above have been worked out through studies of material and dimensions of the system assemblies, studies of substrate heating scheme, and sputter bias or electric field.

At the points of loading as well as unloading substrates to and from the in-line sputter apparatus, there are chances that foreign materials may fall on the substrate surfaces. Once this happens, it causes various hazards to the product such as surface defects of R/W signals, mechanical head adhesion or 'head crash' etc. These are fully automated by multi-axis arm robots. Additionally, there is a scheduled maintenance of transport assemblies of the in-line sputter apparatus as well as subassemblies of target mounts.

3.5 Liquid lubricant coating

Disks sputtered goes to a process of a relatively light burnishing by tape, or Floating Tape Burnish, so that accidental asperities generated in sputtering are eliminated from the disk surfaces. Disks are then coated by a liquid lubricant. Basic functions of the liquid lubricant are:

(1) Increase mechanical resistivity against wear of the amorphous carbon layer.
(2) Increase stability of the amorphous carbon against various external gaseous material that may cause stiction trouble.

To ensure these functions of the liquid lubricant, the a-C surface should be prepared for the lubricant coating. Also, the lubricant should be the kind wettable to the amorphous carbon and should be coated uniformly across the surface. Further, the lubricant should be of a proper molecular weight and the one which bonds chemically to carbons of a-C. It is therefore important to control water of disk surface, or amorphous carbon, and to coat a lubricant which is liquid type fluoro-carbon, F-C, and has low surface energy.

It has been confirmed that there is a range of molecular weight that exhibits the preferable properties for mechnical stress. That is, a large molecular weight tends to lead head stiction, and a small one tends to exhibit insufficient effect for wears of carbon overcoat. The lubricant applied in the manufacturing process is the one of refined and formulated so that the average molecular weight is approx. 4,000. The refining process of the lubricant is a proprietary technology.

3.6 Testing and inspection

Test process consists of Glide Height Test, or GHT, which detects irregular asperities of the disk surface, Read and Write, or R/W, test that certifies electro-magnetic conversions as well as signal errors and Visual Test.

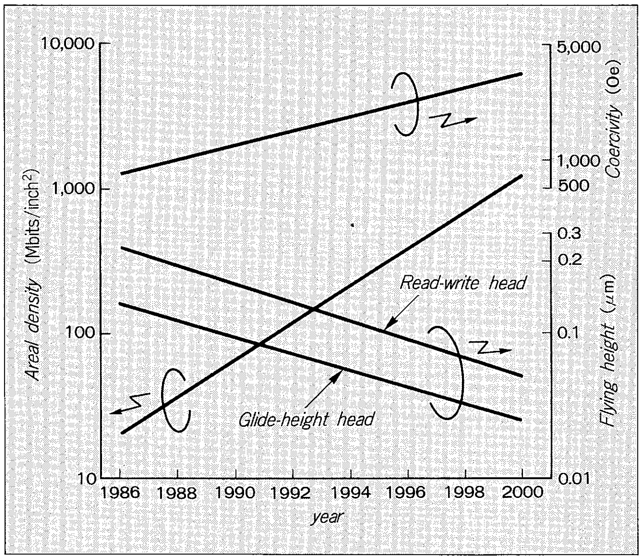
All of these are done in a clean room of Class 100 so that the surface under tests are kept from dusts or other objects.

Tests and inspection should be performed over 100% of disks and surface. These are the technology of detecting micron order of signal errors and sub-micron order of asperities and the technology is achieved through an integration of state of art technologies. It should be emphasized that a system of test and inspection should be configured through a consistent philosophy in order to assure product quality to customers, to feed back quality information to production line, to integrate process data and product data, and to do systematic analyses on time. Fuji Electric developed a tester by its proprietary technology and installed to the line.

Table 1 Classification of the sputtered magnetic disk

	Hc (Oe)	GHT (μ")	Linear recording density (BPI)	Track recording density (TPI)	3.5" disk capacity (MB)	The span of products (year)
The 2nd Gen.	1,200	4-5	30K	1,400	40	1987-1992
The 3rd Gen.	1,400	3	45K	1,800	80	1989-1995
The 4th Gen.	1,600	2-2.5	70K	2,400	160	1992-1997
The 5th Gen.	1,850	1.5-2	100K	3,000	320	1994-1999
The 6th Gen.	2,200	1-1.5	150K	4,000	640	1997-2002

Fig. 3 Trend on hard disk drive



4. MARKET AND TECHNICAL TREND

The trend of recording capacity of small HDDs has been monotonically increasing by the same rate as the one of DRAM. It has been approximately doubled every 2.5 years. Another factor is a distinct 'down sizing' of form factor of computers, and the factor forces HDD to be smaller and thinner. As the diameter of magnetic disk reduces, becomes the physical volume of HDD smaller by half every two years. They are 5.25 inch disk, 1.905 mm in thickness, 3.5 inch disk, 1.27 mm thick, and 2.5 inch disk, 0.89 mm thick. Further, the 1.89 inch disk, 0.635 mm thick, product has recently been introduced and also the 1.3 inch disk is ready for a prototype of subminiature HDD.

The smaller form factor can be achieved by state of art technologies of magnetic disk, head, mechanical design, signal processing circuits. Also, it depends on developments of mass production for volume as well as cost oriented. These technologies have been interrelated each other and contributed to the evolution of product generations.

The generations which classify HDD technology are schematically shown based on the latest market data in *Fig. 3*. According to this, environments and trend of the small HDD are:

(1) The product life of the first generation is about to terminate in the market.
(2) The second generation ceased its production growth.
(3) The third generation is increasing its quantity rapidly.
(4) The fourth generation started mass production, and HDDs of 1.89 inch as well as 1.3 inch are under development already.

A possible growth of 2.5 inch HDD has actually become in reality as a topic this year. There has been always next small HDDs as discussed above. The articles in later sections will discuss what and how this fact has been stimulated and developed technologies of sputtered magnetic disk.

5. AFTERWORD

Small form factor HDD has an open future, and will achieve larger capacity, higher response speed, lower bit cost, higher reliability and smaller/thinner in size. The 1.3 inch HDD as well as 1.89 HDD has been under development, and these HDD technology, magnetic disk technology and also thin film head technology will develop in synchronous and interactive manner to bring HDD market a prosperous level.

In 1983 when research and development started in Fuji Electric, market research companies and research institutes were anticipating the longitudinal recording would terminate its life at the level of 100 to 200 Mbit/inch^2 and would be replaced by the perpendicular recording. In other words, the conventional technology would have failed to fulfill market requirements and would have diminished at the level of the third or the fourth generation products today. But, at present, the fourth generation is moving toward mass productions, and some projects of the fifth generation have gone through developments. Research studies published that state of art technology reached as high as 2 Gbit/inch^2 by the longitudinal recording. The optical and magneto-optical recordings were expected to dominate peripheral memory market, but there is no indications yet. There is a new and competitive device of memory brought up as flash memory, but it will not affect to a significant level as long as the evolution rule holds with small HDDs. The sputtered magnetic disk product of Fuji Electric was developed through integration of every proprietary resources so that technical resource, vector and potential are firm base for the product in even next century. Our effort will be primarily on realization of this possibility.