Thin-Film Magnetic Disks

Describes the thin-film disk technology used in IBM disk units.

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Introduction

IBM thin-film magnetic disks represent a major advance in the design and production of rigid-disk recording media. In the quest for higher recording densities on rigid disks, thin-film media present a major advantage over the existing particulate disk technology [1]. Uniform films can be easily deposited with thicknesses of only several hundred angstroms (Å), hence the origin of the term **thin film.** Thicknesses in this range are essential for high density magnetic recording.

Thin-film disks appeared in the marketplace in the early 1980s, and their magnetic benefits were immediately obvious. However, because of the design challenges surrounding disk durability, some reluctance emerged regarding incorporating thin-film media into disk unit designs. Implementing thin-film media into IBM products required significant advances in thin-film disk tribology and thin-film disk corrosion resistance. Thin-film disk wear mechanisms are poorly understood and, combined with the susceptibility to corrosive degradation, disk life can be sharply curtailed. The presence of a high fraction of chromium (Cr) in the sputtered magnetic film produces acceptable corrosion resistance. The addition of a thin sputtered carbon overcoat on top of the magnetic film, followed by the application of approximately one monolayer of lubricant, extends thin-film disk media life. The thin-film disks used in the IBM 0671, 0661, and 0681 disk units are the first such disks from IBM development laboratories to fulfill the stringent requirements for inclusion in an IBM disk unit.

Enhancements to the thin-film disk structure, its manufacturing process, its magnetic performance and mechanical durability, and its corrosion resistance have been made. (For more technical detail on thin-film magnetic disks, see the excellent review entitled "Thin-Film Recording Media" written by T.C. Arnoldussen [2].)

Disk Structure and Manufacturing Process

IBM thin-film magnetic disks consist of several layers of metallic and nonmetallic films. Well-known techniques are used to achieve the desired depositions. First, the aluminum substrate is chemically plated with a relatively thick layer of nickel that is brought to a desired finish using abrasive finishing processes. The magnetic layer and the associated underlayer and overcoat are then applied by a vacuum process known as **magnetron sputtering**. Chemical plating can also be used for magnetic film deposition, but sputtering was chosen because of the ease in sputtering ternary magnetic alloys of different compositions. This versatility in choosing magnetic alloys is needed for the thin-film disk used in current and future IBM products.

As a general example of a thin-film disk structure, Figure 98 on page 187 shows a cross-section view of an IBM 0671 thin-film disk. As in the majority of rigid-disk products, the disk's magnetic and overcoat structure is placed on an aluminum (Al) alloy substrate. IBM has shipped thin-film disks in three sizes: the 0671 130-mm disk with an inside diameter of 40 mm and a thickness of 1.9 mm, the 0681 130-mm disk with an inside diameter of 40 mm and a thickness of 1.3 mm, and the 0661 disk with an inside diameter of 25 mm and a thickness of 0.8 mm. The aluminum is layered with a 14-μ deposit of hard nickel-phosphorous (NiP) using a process known as electroless plating, which is a chemical plating process that does not require external batteries or power supplies. This surface is equivalent in hardness to carbon steel (600 kg/mm^2) and serves as a firm base for the thin magnetic layer. In addition, the NiP surface allows for a smooth and controlled surface finish after abrasive processing, which a soft aluminum surface alone could never provide. The surface morphology of the polished and textured NiP is replicated in the next three layers of the disk structure. The top surface must be free of asperities to allow recording heads to fly closely and to min-

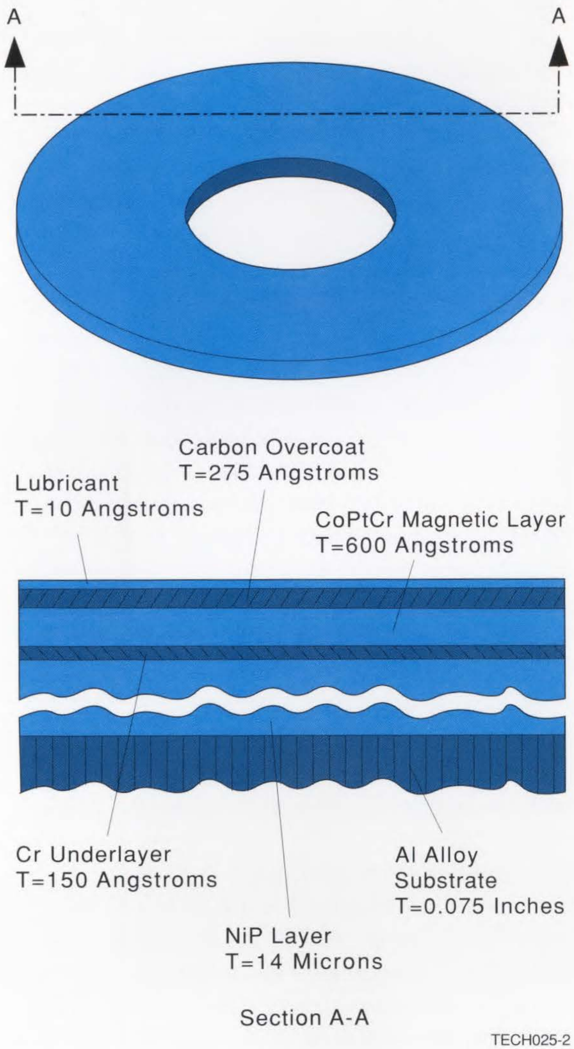

Figure 98. *Cross-Section View of an IBM 0671 Thin-Film Disk*

imize head-to-disk interactions that can accelerate disk wear.

Next, the thin-film NiP surface is polished to a high degree of smoothness (25 Å) and then given a circumferential texture (75 Å measured radially). This texture is readily identified by the eye and serves to reduce stiction (the static friction force resisting initial disk motion) and friction, while at the same time improving magnetic properties because of preferential magnetic-grain alignment along the circumferential grooves. Although a surface texture is purposely added, the resultant disk surface still allows a recording head to fly at 175 nm at its inner diameter without encountering any interference or interactions.

The essence of the IBM thin-film disk is built into the next four layers. After the hard NiP surface is polished and textured, a Cr underlayer followed by the cobalt-platinum-chromium (CoPtCr) magnetic layer is sputter-deposited in a vacuum chamber. A sputtered carbon (C) overcoat is subsequently deposited in a second vacuum chamber of the same sputtering apparatus. This entire process is accomplished using a moving vertical pallet containing twenty-three 130-mm disks or forty-five 95-mm disks, which are sputtered over the course of several minutes. This process can produce a large quantity of disks at low cost with uniform film thicknesses and magnetic properties. After emerging from the sputtering step, a lubricant layer is deposited by dipping the disks into dilute solutions containing hydrocarbon or fluorocarbon.

Disk Magnetics

Producing a high quality magnetic disk involves more than sputtering a uniformly thin metallic layer. Magnetic anisotropy (the tendency for a material to magnetize in a specific direction) must be rigidly controlled to prevent degrading effects, such as modulation in the read-back signal [3]. One of the keys to producing a suitable magnetic film for longitudinal recording (the recording of bits parallel to the direction of recording) is to ensure that the magnetic anisotropy is in the plane of the disk. This preferential horizontal alignment is necessary to produce high squareness hysteresis loops that, in turn, lead to high-density recording capabilities.

This alignment can be controlled by several factors, but a major contributor is the identity, orientation, and thickness of the underlayer as described by J.K. Howard and others [4,5]. Depositing the thin (100 to 300 Å) Cr underlayer at a high rate (2,000 Å per minute) results in a crystallographic-preferred (110) orientation that allows the CoPtCr film to grow epitaxially, with its easy axis of magnetization in plane. Figure 99 on page 188 shows a magnetization (M) versus magnetic field (H) hysteresis loop of a CoPtCr thin-film disk compared to a particulate disk. The thin-film disk's curve exhibits a high degree of squareness compared to the particulate film. This is a result of the preferred growth characteristics influenced by the underlayer and the general properties of magnetic-metallic thin films.

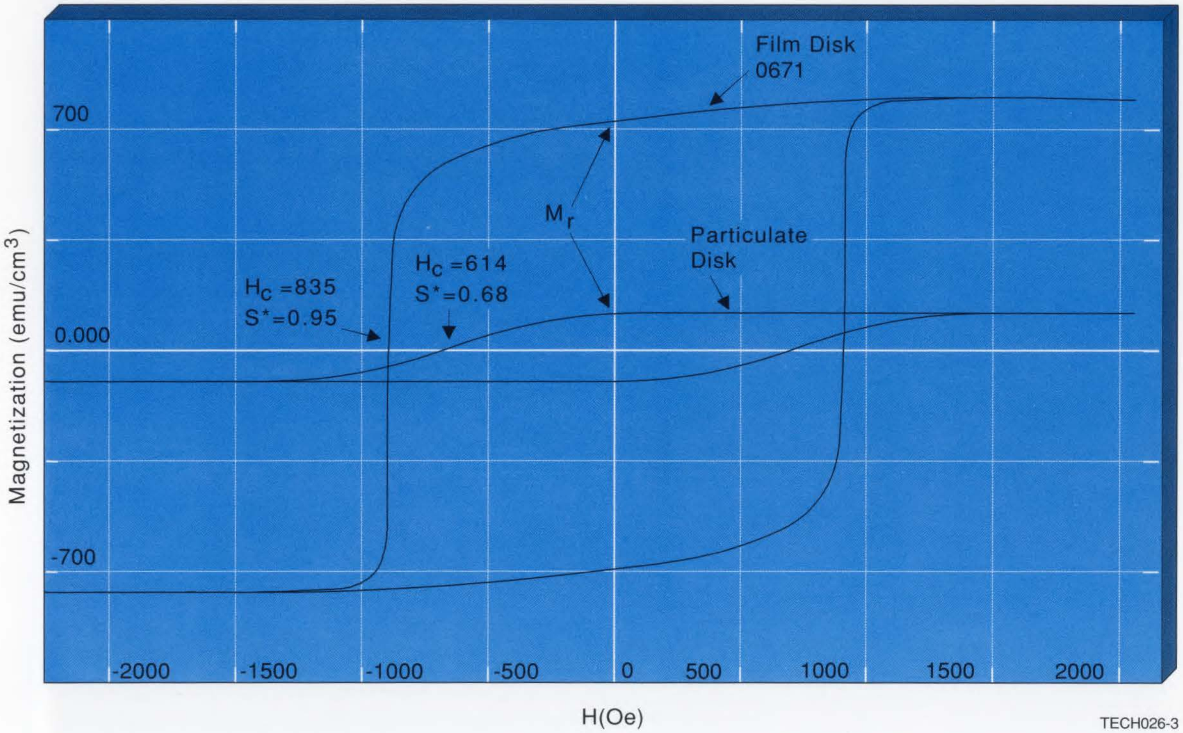

Figure 99. *M-H Hysteresis Curve for an IBM 0671 Thin-Film Disk and a Particulate Disk*

Two squareness parameters, the coercive squareness (S*) and the remanent squareness (S), describe a hysteresis loop. S* is especially important and high values are obtainable with thin-film media. S* is a measure of how steeply the hysteresis loop rises through the coercivity (H_c). The film-disk value of 0.95 is near the maximum S* value of 1.0 and is significantly improved over the particulate value of 0.68. High S* values indicate the magnetic medium's ability to switch over a narrow range of field values, which is necessary to pack bits closely together for high recording densities.

Also note in Figure 99 that the H_c is higher than that of the particulate disk and is approximately 850 Oersteds (Oe). Current IBM thin-film disk designs cover a coercivity range from 800 to 1300 Oe. Particulate disks consist of small magnetic particles dispersed in polymer resins; the particles control magnetic properties and have limitations on their coercivity range. Thin-film disk technology allows easy control of the coercivity by adjusting film compositions and sputtering conditions. IBM thin-film disks are designed to have as high a coercivity as possible within the write capabilities of the head. Future thin-film disks will have even higher coercivity values to achieve the high storage densities envisioned for future disk storage products.

The advantage of thin-film disks is further shown in Figure 99 by the comparison of the remanent magnetization (M_r) values. The M_r value is a measure of the magnetic strength of the material and governs how much signal the disk is able to generate. Thin-film disks have much higher M_r values than their particulate counterparts because no dilution of magnetism by nonmagnetic polymer binders occurs. Additionally, thin films are naturally stronger magnetic materials than their oxide counterparts (used in particulate films). Because of this 6-to-10 times higher M_r value, thin-film disks can be made thinner than particulate disks and still maintain equivalent signal output. The thinner layers allow the recorded bits to be placed closer together, yielding higher storage densities. This combination of high magnetization with low thickness is the essence of the performance advantage of the thin-film disk.

Because thin films have such high magnetization values, a process is required to precisely apply the magnetic film to the disk substrate and at low thicknesses. Magnetron sputtering vacuum equipment rapidly deposits thin films with precision and uniformity. IBM thin-film disks have film thicknesses from 500 to 700 Å and are controlled to a thickness of ±70 Å.

Of the many potential cobalt magnetic-alloy systems available, CoPtCr was chosen for the magnetic layer in IBM thin-film disks for several reasons [6]. First, the higher coercivity requirement in the design is easily achieved with this alloy, and any coercivity changes necessary for future disk designs can be attained by making slight composition changes. Secondly, the M_r value in CoPtCr is sufficiently high to produce a strong signal at low thicknesses. Third, the CoPtCr formulation gives a magnetic film with a high signal-to-noise ratio. Finally, the Cr, in addition to aiding in the control of M_r and H_c values, also serves as a corrosion inhibitor, allowing the disk to withstand extremes in temperature and humidity and to withstand the presence of foreign corrosive gases.

Each IBM thin-film disk undergoes a dynamic magnetic test of parameters, such as signal strength, resolution, signal-to-noise, and missing-bit and extra-bit defect counts. Disk drive design criteria defines the disk signal requirements, which are related to the fundamental magnetic description of the CoPtCr film. The magnetic defects are typically about one in 1,000,000 bytes and are maintained at this low level as a result of high-quality disk substrates, sputtering conditions with minimal contamination, and a series of cleaning steps performed during manufacturing that eliminate environmental and process debris.

Mechanical Durability

Thin films, even though they rest on an extremely hard surface, cannot withstand the sliding of a recording head during normal operations of the disk unit. Because IBM imposes strict standards on the durability of its recording components to ensure long disk life, designs to meet these standards were implemented on IBM thin-film disks. The sputtered amorphous carbon overcoat of 275-Å thickness protects the magnetic layer by providing a sufficiently hard surface to eliminate wear of the magnetic layer. A thin lubricant film applied to the carbon overcoat minimizes wear of the carbon film.

This lubricant minimizes long-term wear by minimizing both static and dynamic friction. Overcoming high static friction requires excessive starting torque, and high dynamic friction wears the surfaces excessively. Figure 100 shows friction traces of a thin-film disk with

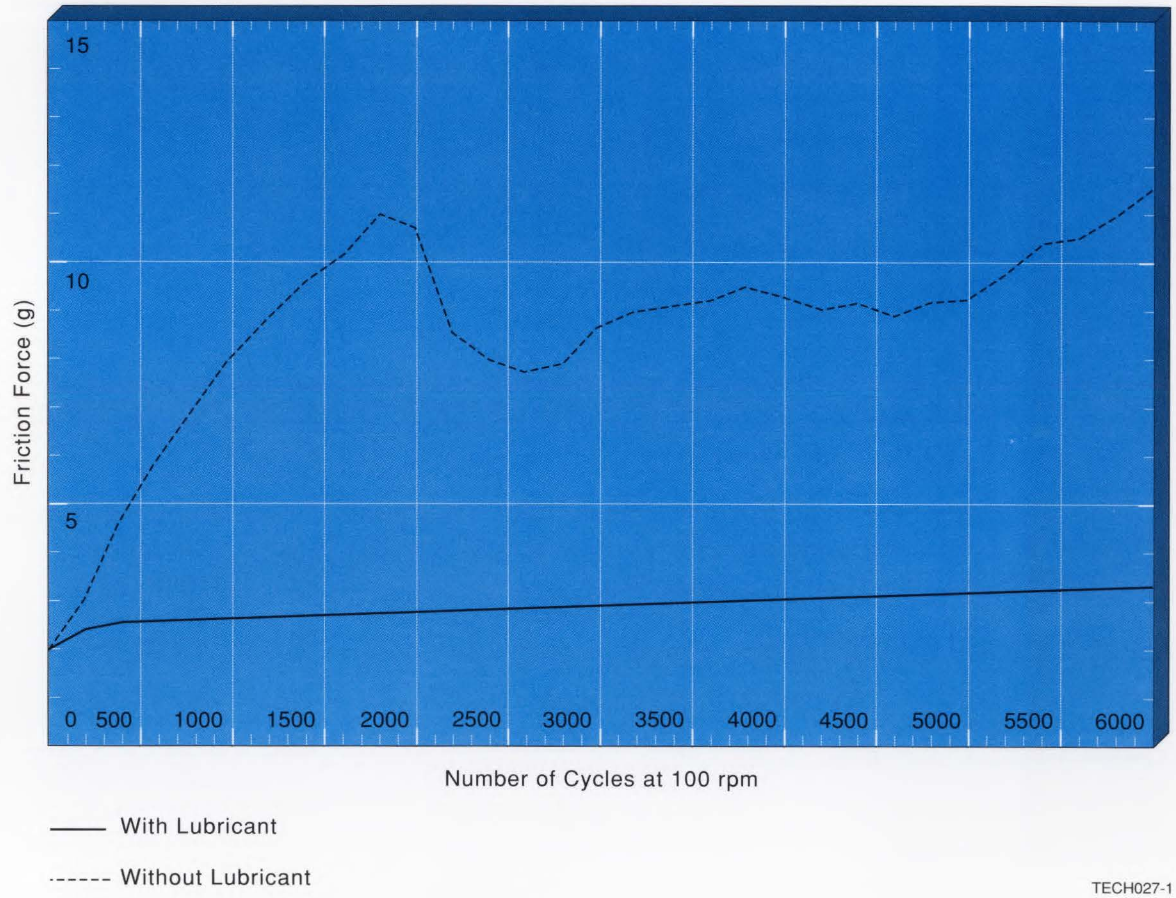

Figure 100. *Friction Force versus Number of Cycles on a Thin-Film Disk with and without Applied Lubricant*

and without an applied lubricant overcoat. The carbon surface with no lubricant has initial friction values that are low. However, after some time passes in this accelerated test, friction increases to a dangerously high value. The trace with the organic lubricant applied is extremely flat and low in value [7].

The amount of lubricant applied to the carbon surface is critical. Too little can lead to excessive wear, while too much can lead to large static friction coefficients (stiction). The optimal value is about one monolayer.

Multiple mechanical durability tests to simulate disk drive conditions were conducted. Start and stop tests mimic the take off and landing of the head on the disk surface. Flyability tests investigate the effects of intermittent contact of a flying head with disk asperities. Friction and stiction testing ensures that the head-to-disk interface is not prone to excessive drag forces. IBM thin-film disks perform these mechanical tests exceptionally well.

Resistance to Corrosion

Thin films can react chemically with a variety of materials in the environment. A major engineering effort was applied to stabilize the thin-film disks from environmental degradation. By greatly restricting air flow and using filters, the IBM disk drive design minimizes contact by airborne corrosive elements, such as chlorine and sulfur compounds, that can occur in minute quantities in disk unit operating environments. High humidity, particularly at high temperatures, then becomes the more severe corrosive exposure [8]. To alleviate surface degradation from water condensation and temperature and humidity extremes, the use of Cr in the magnetic layer is crucial. Cr readily forms a thin, nonmagnetic oxide layer, which protects the rest of the disk structure.

Film disks of other cobalt alloys, especially the cobalt-phosphorous- (CoP) plated alloys, are more reactive under stressed humidity and temperature conditions and are not acceptable for the ranges of temperature and humidity that IBM thin-film disks will experience. Figure 101 shows a corrosion-rate comparison among a plated CoP thin-film disk with a carbon overcoat (Curve 1) and IBM CoPtCr thin-film disks *with* (Curve 3) and *without* (Curve 2) a carbon overcoat. Corrosion occurs at a much greater rate on the CoP with the carbon film. Furthermore, the presence of carbon on top of the sputtered CoPtCr diminishes the corrosion rate even further. The carbon layer, although somewhat porous, serves as a protective barrier between the environment and the thin film [9].

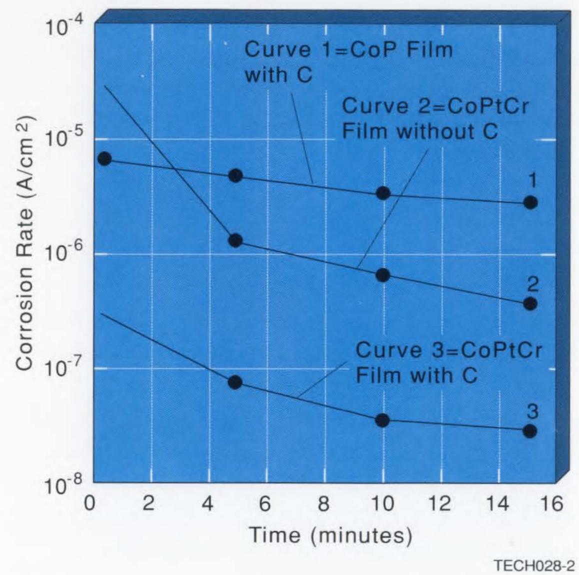

Figure 101. *Rate of Disk Corrosion in a Deionized Water Droplet*

Conclusion

The benefits of recording on thin-film disks are realized from two innovations in thin-film disk technology: improved mechanical durability from innovations in surface lubrication and improved resistance to corrosion because of the high-chromium-content magnetic alloy. The versatility in modifying thin-film magnetic properties, specifically the CoPtCr film system, makes the design of a film disk for higher densities practical. Developmental work in improved magnetic alloys will continue, with an increased emphasis on low-noise film compositions. Overcoat and lubricant technology for film disks is still in its infancy, and new discoveries are expected that will prolong disk durability over today's thin-film disks. Developments are expected that will minimize corrosion and extend mechanical life beyond today's goals. The advent of thin-film disks within IBM and the magnetic-media industry in the 1980s, coupled with other advances in storage device technology, ensure the continuation of exponential increases of storage densities in the 1990s.

Acknowledgments

IBM thin-film disks were developed at the Rochester, MN, site and are the result of a collaboration of many talented people in the disk manufacturing and development group. These disks are now manufactured at IBM sites in San Jose, CA, and Mainz, Germany, as well as in Rochester, MN. Important support work has also been done in IBM San Jose, CA, and the IBM Research Division located in Yorktown Heights, NY, and Almaden, CA.

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