THIN-FILM MEDIA MEET INCREASED STORAGE DEMANDS

Mechanical properties and magnetic characteristics of thin-film media combine to meet today's high density storage needs and promise potential for next-generation recording technologies.

by James H. Smith

Traditionally, Winchester-type rigid disk drives have relied upon iron oxide particulate media. The rigid disks used in such devices consist of a 0.075-in. (0.190-cm) thick aluminum substrate that is stamped from aluminum sheets and then machined. The magnetic coating applied to this substrate is usually a mix of iron oxide particles, a wear-resistant material such as aluminum oxide, and an epoxy binder. Typically, 20 to 30 μin. thick, the magnetic coating fills in surface irregularities within the substrate. A lubricant overcoat is then applied over the magnetic coating (Fig 1).

In the manufacturing process, the iron oxide particles within the magnetic coating are oriented in one direction during the epoxy curing process to provide a uniform, basic magnetic orientation. During recording, the read/write head can flip these magnetic domains to change their magnetic orientation. These flux reversals represent the written digital data in the form of N-S pole orientations that are defined as "1s" or "0s."

Typically, thin-film media disks also consist of a machined aluminum substrate that is first plated with 300 to 600 μin. of electroless nickel, and then polished to provide a flat, hard surface. A 3 to 4 μin. thick magnetic coating is then applied. Usually a cobalt/phosphorous or cobalt/nickel/phosphorous layer, this coating is applied using one of several deposition techniques. A surface overcoat on top of this protects the disk from corrosion and lubricates it against abrasion.

No matter what deposition method is used, however, the resulting films are metallic and highly reflective. Alloys containing cobalt are most often employed in commercial magnetic recording devices, since they have the required magnetic properties of high coercivity and high resolution. However, they may also contain nickel and/or phosphorous. Alloys containing chromium, iron, tin, antimony, tungsten, and other metals have been reported. Cobalt/chromium alloys have recently received particular attention for vertical recording applications.

Thin-film media provide inherent advantages over iron oxide media. These include increased storage capacity, fewer errors, and greater durability (see the Table). Increased capacity results from the potential for greater bit and track densities that are supplied by the small particles. Bit size in iron oxide media must be larger than any magnetized particle. Typical limits are from 6 to 10 kbits/in. for oxide media. The smaller particles of thin-film media allow up to 20 kbits/in. or more. Thin-film media resolution also allows for more tracks/inch. This contributes to the higher storage capacity of drives that use this media.

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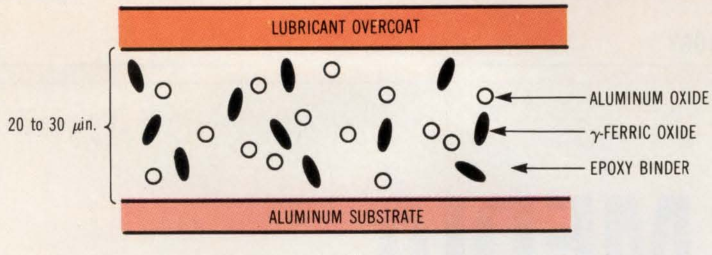

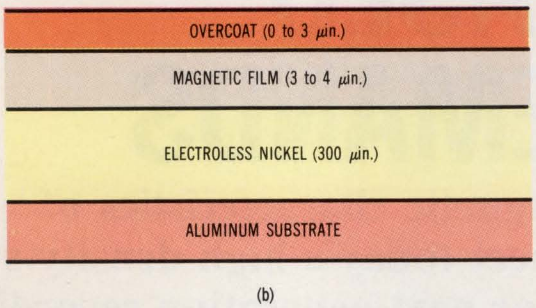

Fig 1 Depicted are cross sections of typical magnetic coatings of oxide (a) and thin-film (b) disk media. Magnetic material used to form thin-film media typically consists of cobalt/phosphorous or cobalt/nickel/phosphorous.

Fewer read/write errors are another mark of thin-film media. Flat, uniformly smooth disks provide better signal quality. A smoother medium allows lower head-flying height, which means increased amplitude and resolution. The thin medium needs a lower magnetic field to saturate it and a smaller head fringing field pattern. Fewer intrinsic read/write errors can reduce the need for advanced error correction techniques in drives using thin-film media.

Durability of the media also supplies a number of advantages to users. The disks are better protected in transit (a plus for portable computers with integral disk drives) and in business settings. Particulate spilling does not occur as with oxide media because the magnetic coating is more strongly bonded to the substrate. Fewer particles generated inside thin-film media drives lessen the chance of damage from head crashes. Corrosion problems have largely been overcome by using aluminum substrates and overcoatings.

The combination of higher data capacities with fewer errors and increased physical durability enables high performance drives to be put in smaller packages. For those manufacturers who incorporate thin film into their drives, especially

Comparison of Oxide and Thin-film Recording Media

	Oxide media	Thin-film media	Advantages of thin-film media
Magnetic properties			
Coercivity (oersteds)	350 to 400	500 to 700*	Higher amplitude and resolution and reduced bit shift is possible
Remanence (gauss)	3500 to 4000	7000 to 8000	
Squareness (M_r/M_s)	0.45 to 0.55	0.80 to 0.95	
Thickness (µin.)	8 to 10	3 to 4	
Physical properties			
Surface smoothness (µin.)	1.0 to 1.5	0.5 or less	Lower flying height possible
Surface hardness		~1000 x harder	Less susceptible to head crashes
Overcoat	fluid	dry	Reduces attraction of particulate contaminants
Possible head-flying height (µin.)	~18	~10	Significant amplitude increase to the disk surface
Surface adhesion	poor to good	excellent	
Recording properties			
Bit density (bits/in.)	~8000	>15,000	Increased bit density and storage capacity
Resolution (percent)	~65	>80	Improved signal to noise
Amplitude**	low	high	Decreased bit shift and fewer errors
Bit shift	high	low	

*The upper limit of the coercivity is about 1700 Oe with thin-film media, but this is not useful in longitudinal recording because the heads cannot erase the disk.
**For a given head and head-flying height

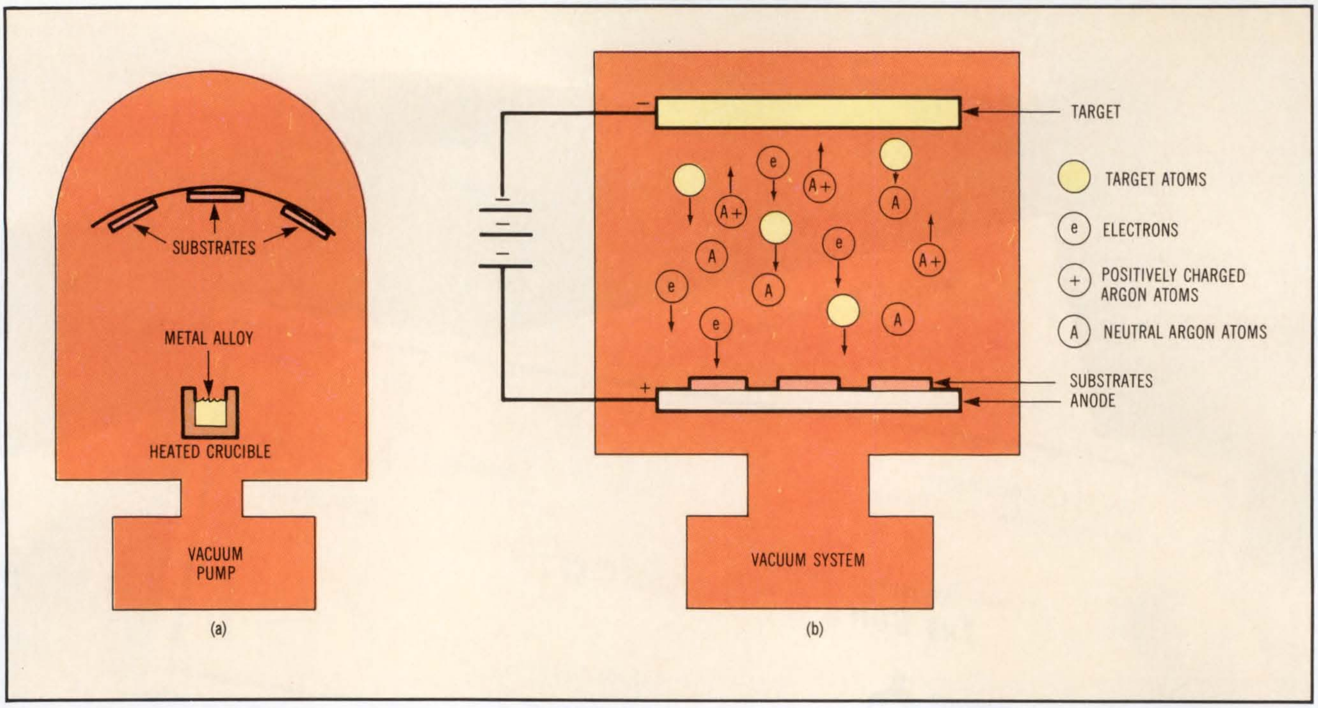

Fig 2 Thin-film vapor deposition occurs in an evacuated bell jar (a). The alloy to be deposited is heated in a crucible until it vaporizes. The vapor condenses on the cool substrate and forms the thin-film layer. In a basic sputtering system, the electrons are rapidly accelerated by the electric field (~2000 V) and collide with neutral atoms of argon gas (b). The argon atoms are then ionized and accelerated toward the target. When they hit the target, they knock off target atoms, which drift toward the substrate. Since the substrate is relatively cool, the target atoms condense onto the substrate, forming the thin film.

those manufacturing their own plated media, the pathway from longitudinal to vertical recording becomes easier.

At present, it may seem that oxide media are easier to produce. However, this perception is influenced by the large technological and capital investment in oxide media over the years. Although a thin-film medium requires somewhat more sophisticated production capability, its production is becoming commercially feasible.

Thin-film deposition methods

Four basic methods are currently used for depositing magnetic thin films on a disk substrate. These include vacuum deposition, sputtering, electroless (chemical) plating, and electroplating. Each method exhibits unique characteristics. Vacuum deposition has been used to prepare thin-film media for both longitudinal and vertical recording. The material to be deposited is first heated in a crucible (by direct electrical current, radio frequency, or electron beam) above the melting point of the metals. Metal vapor deposition occurs on the cooled surface of the disk substrate [Fig 2 (a)].

While deposition rates are usually high, the vacuum deposition method has a serious drawback when it requires alloy deposition. Since the two or more metals in the alloy have different vapor pressures, they evaporate at different rates. This causes the stoichiometric ratio of the diverse materials in the deposited alloy to change as the materials in the crucible evaporate. The continuously changing composition of deposited material makes it extremely difficult to maintain accurate control of the deposited alloy's composition. Since small composition changes usually have a large effect on the film's magnetic properties, producing large quantities of disks becomes difficult.

In the laboratory, sputtering produces excellent longitudinal and vertical thin films. The process involves a glow discharge in a high vacuum chamber. Target materials to be sputtered act as the cathode, and the substrate to be coated acts as the anode. When argon is introduced into the evacuated chamber at low pressure, and a glow discharge current is applied across the cathode and anode, the electrons in the discharge region accelerate rapidly. These high energy electrons collide with the argon atoms, ionizing them and producing a positively charged argon atom and a second electron. This positively charged atom is accelerated toward the target (ie, the cathode). The resulting impact knocks neutral atoms from the target material. These atoms drift toward the disk substrate and build up the magnetic film [Fig 2 (b)].

Sputtering has advantages over other thin-film deposition methods. The most important advantage is that the deposited material's composition is identical to that of the target material. This means that alloy deposition can be done repeatedly with excellent composition control. In addition, the process is easily automated, resulting in high process yields and reduced labor costs compared to plating techniques. Moreover, the process results in minimal toxic chemical waste, significantly reducing disposal problems.

Sputtering is not without problems, however. The equipment necessary to produce disks on a commercial scale is just becoming available. In addition, the high sputtering rates needed to make the process economically feasible are difficult to achieve, and anticipated capital costs are high.

The electroless plating process produces deposits similar to those obtained through electroplating. However, it is a chemical process in which the metals to be deposited are present as sulfate or chloride salts in aqueous solution. A reducing agent such as sodium hypophosphite is also necessary. Sodium hypophosphite serves first to reduce the metal salts to their elemental form at the disk surface. Secondly, the hypophosphite ion provides a source of phosphorous in the desposited film. This raises the film's coercivity, thereby improving its magnetic recording properties [Fig 3 (a)].

Used by commercial suppliers of thin-film media for computer storage systems, the electroless process allows several hundred disks to be plated at one time. Problems associated with the process result from the difficulty of controlling the film's magnetic properties. In addition, the film has low amplitude and resolution at high bit densities (above 8×10^6 flux changes/s).

The electroplating deposition process uses an electric current to cause dissolved metal salts to plate on the disk substrate. Direct current is applied between the anodes and the cathode (the substrate) to be plated. The plating bath commonly contains cobalt and nickel sulfates or chlorides, sodium hypophosphite, and various organic and/or inorganic buffers. The hypophosphite anion serves as a phosphorous source to raise the magnetic film's coercivity, as in the electroless deposition method [Fig 3(b)].

Electroplating has several advantages over other deposition methods. Since agitation, pH, temperature, hypophosphite concentration, and metal salt concentrations have a predictable effect on the magnetic properties of the thin-film deposit, the method allows excellent control of read/write characteristics. From the manufacturer's point of view, the capital investment in electroplating equipment is low for manual operation and the process can be readily automated or robotized.

Mechanical properties of thin-film media

Important mechanical properties of thin-film media include wear characteristics, types of overcoating materials, and surface finish characteristics. Evaluation criteria for these mechanical properties are now being formulated with a view toward establishing industry-wide test standards and specifications.

Wear is an important factor in today's high speed/high capacity disk drives. Thin-film media are substantially harder than traditional oxide media and therefore much more resistant to scratching. This hardness also makes skip-type head crashes much less likely, thereby reducing the risk of lost data. Even without surface lubricants, a greater number of start/stops can occur on thin-film media—wihout significant wear—than on oxide media.

Nonlubricating overcoats, which cannot be used with oxide media, are usually based upon silicon oxides (SiO or SiO_2) or nitrides (Si_3Ni_4). Oxide overcoats are often brittle, porous to various corrosive ions, and somewhat porous to moisture, depending upon the application technique. Although the hard nitride overcoats exclude moisture quite well, they provide no lubricity. In addition, a contaminant on the disk surface can cause SiO_2 to agglomerate and form sharp unwanted surface protrusions.

Lubricating overcoats, such as sputtered amorphous carbon, which also cannot be used with oxide media, provide significantly better wear characteristics than nonovercoated or SiO_2 overcoated media. In this process, a bonding layer of nickel oxide or chromium metal about 50Å thick is first

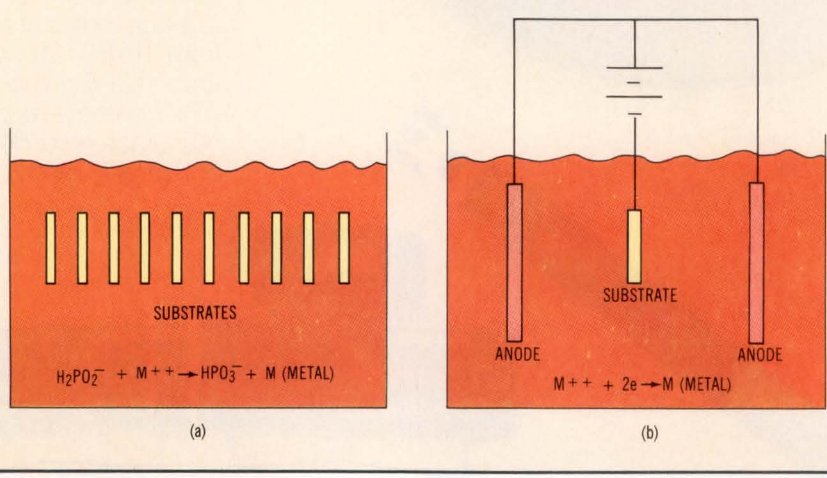

Fig 3 Electroless plating is a chemical reaction of hypophosphite and metal ions to form a metallic alloy of the metals and phosphorous (a). Electroplating is an electrochemical reduction of metal ions to form the metallic thin film (b). If hypophosphite ions are also present, they codeposit to form metal/phosphorous alloys.

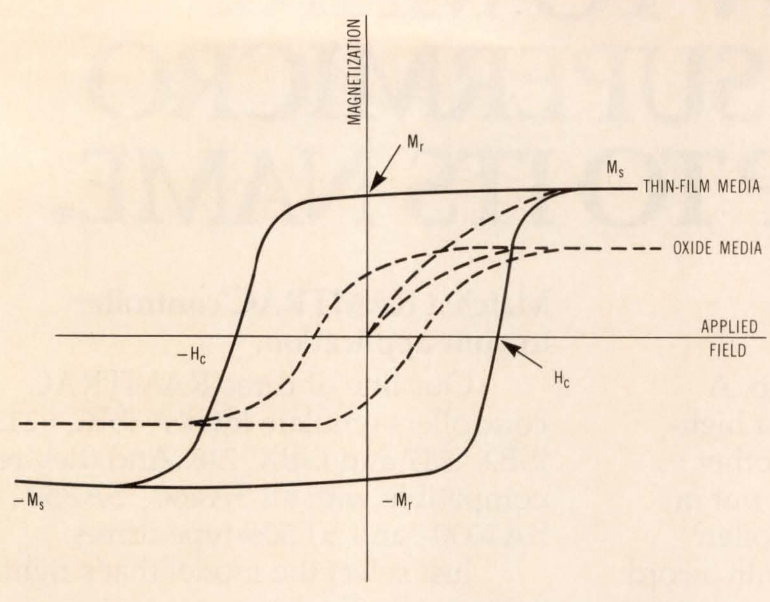

Fig 4 With magnetic hysteresis or M-H loops, when a magnetic field is applied to a magnetic field and slowly increased, the film is magnetized until it reaches a saturation level, M_s. When the applied field is reduced, then reversed, the material remains magnetized. At zero field ($H = 0$), the material remains magnetized at a level of remanence (M_r) until the applied field is reversed. The applied field required to demagnetize the material (H_c or $-H_c$) is the coercivity.

sputtered on the magnetic film. Then 2 to 3 μin. of carbon are sputtered from a graphite target without exposing the disk to air. The amorphous carbon deposit has characteristics of both graphite and diamond. If the head and disk are very clean, more than 230,000 start-stop cycles can be achieved with a 5¼-in. Winchester disk and a 3350-type manganese/zinc/ferrite head flying at 8 to 10 μin.

Surface finishing of the substrate is extremely important with thin-film media. Electroless nickel substrates can be polished to a surface finish of less than 0.5 μin., peak to valley. The magnetic thin-film media and their overcoat mirror the substrate's surface finish coat because they are so thin. Since the surface is so smooth, head-flying heights of 10 μin. or less can be achieved, significantly improving the disks' signal amplitude and resolution. In contrast, typical peak-to-valley tolerances for oxide media are 1.0 to 1.5 μin. and head-flying heights are 18 μin. or higher.

The deposition method used for thin-film media affects the surface finish. The electroless method performs least efficiently since the resulting film is most porous. Altering deposition conditions cannot modify the surface finish. Electroplating thin-film media is significantly better because the process allows finer control of plating conditions. Organic additives, usually polybasic acids, can be added to the plating bath to further improve the finish. Sputtering methods produce very smooth surface finishes, but available equipment limits production quantities.

There are as yet no standardized evaluation criteria for thin-film media disks. Of special concern to the ANSI *ad hoc* committee on thin-film disk media standardization—presently at work defining standards for thin-film magnetic media—are questions relating to the adhesion of thin film to substrate. The adhesive properties of oxide media, for instance, range from poor to relatively good when a common test is applied. The Scotch tape test consists of pressing tape to the medium and pulling it off again to see if the medium comes off with the tape. Thin-film media disks pass this test easily, whereas oxide media disks do not always perform well. Another criterion, the bend test, involves bending a disk against a round mandrel and examining the results. Thin-film media will fracture but will not come off, however, oxide media will flake off easily. Such flaking can contaminate the disk drive, causing data loss and damaging drive components.

Recording characteristics

Magnetic properties of thin-film media result in a significantly higher, sharper output signal. The greater resolution that results enhances the system's ability to distinguish data on the disk. Classically, magnetic properties are measured by plotting the amount of magnetization that remains in the media after an applied field is removed, against the external magnetizing force (applied in this case by the drive head). The resulting hysteresis cycle is an image of the interplay between coercivity and remanence (Fig 4).

Read/write characteristics relate directly to magnetic properties. Thin-film media produce higher amplitude, resolution, and phase margin than oxide media, thus permitting higher bit and track densities. With oxide media, bit size is limited to the size of the ferric oxide particle. Bit size in oxide media, therefore, exceeds the minimum bit size found in thin-film media.

Oxide media particles have partially random pole orientations that lower the signal-to-noise ratio and broaden the signal peak. This reduces bit density. The problem is partially compensated for by applying an orienting magnetic field that causes the oxide particles to line up magnetically. This manufacturing step is not required in the thin-film media process. Furthermore, particles within the oxide media appear in a range of sizes. This affects bit density and uniformity of output amplitude. Extremely large particles cause a bit "dropout" since the energy available during write mode is not sufficient to flip polarity.

The uniform small magnetic domains present in thin-film media do not pose these problems. Bit density is limited only by the size of the microcrystal in the metal film. Minimum size for a single magnetic domain in thin-film media is an order of magnitude smaller than that for oxide particulate media. Microcrystal size can be closely controlled using the electroplating deposition method.

Error characteristics also provide a means of comparing oxide with thin-film media. Errors in oxide media arise from variations in media thickness, particle size variations, and nonuniform distribution of particles in the epoxy binder. Both oxide and thin-film media occasionally exhibit pin holes in the surface that cause missing bits. These error-causing traits can be controlled within certain constraints. The thin-film media are not subject to problems associated with particle size variation or nonuniform particle distribution. Pin holes in thin-film media can be controlled by paying careful attention to production details such as cleaning, and using pure chemicals and deionized water. However, modulation errors may occur in thin-film media because of slight thickness variations. Local areas of very high coercivity may cause extra pulses to occur if previously written data cannot be erased completely by the read/write head. These problems can be controlled by providing adequate agitation to the plating bath during manufacture.

The ability to closely control both the magnetic and mechanical properties of thin-film media during manufacture allows production of reliable, highly durable storage devices. These factors combine with thin-film media's inherently high bit density to not only feed today's increased storage demands, but to pave the way for the vertical recording devices of the next generation.

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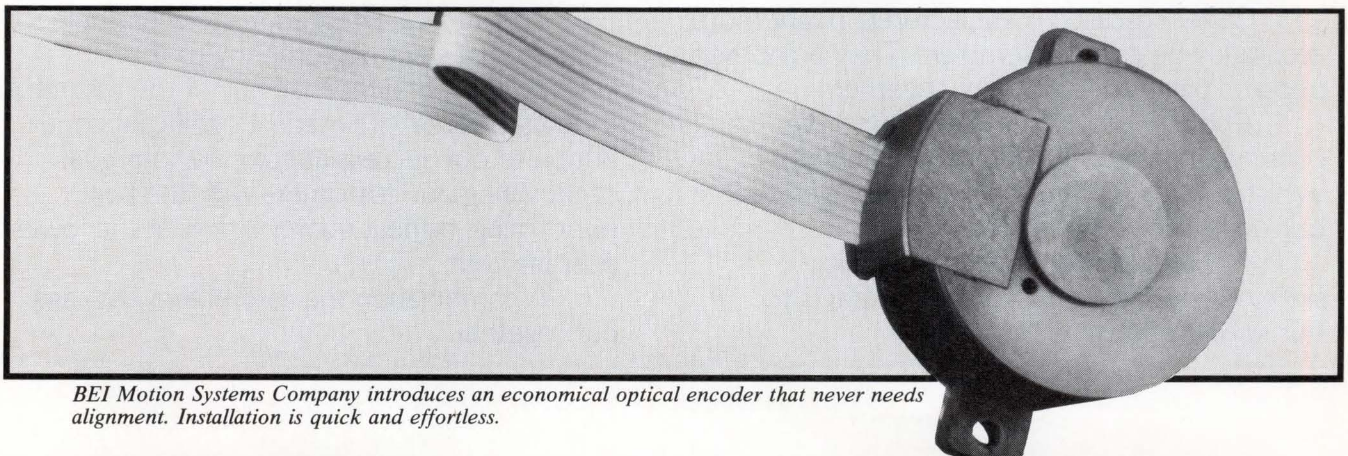

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