MAGNETIC THIN FILM HEAD TECHNOLOGY FOR HIGH DENSITY DISC STORAGE

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ABSTRACT

Magnetic thin film transducers used to read and write information in digital rotating memories have been in production in recent years. These thin film magnetic heads feature a number of fabrication techniques unusual in the thin film hybrid industry.

Typical thin film head configurations for longitudinal and vertical recording are reviewed to point out some of the criteria guiding their design. The fabrication steps include the sputtering or electroplating of magnetic thin films, the photolithography of multilayer structures, the fabrication of thick (15 microns or more) sputtered Al_2O_3 protective overlays and the micromachining of alumina titanium carbide wafers into rigid disc sliders.

INTRODUCTION

With the doubling of data storage density in hard discs rotating memories every two and a half years for the past twelve years, thin film head manufacturing becomes critical to the future of the disc drive industry. The projected growth for world wide sales of hard disc drives from 7.4 billions in 1983 to 16.9 billions in 1986 by conservative industry observers (1) undoubtedly increases the pressure to built cost effective thin film heads in large volume.

Since the magnetic thin film head fabrication techniques do not readily fall in the usual circuit classification, such as most semiconductor active devices or thin film hybrids, they have received only sparce attention in the literature. They share the narrow line width and geometries of the semiconductor industry, however the materials are drastically different. Although they use ceramics as substrate like hybrid circuits, these ceramics are unfamiliar to most hybrid engineers.

The completed thin film head forms a three dimensional structure on its supporting slider, unlike most hybrid circuits which are essentially on a planar substrate. Furthermore, the micromachining accuracies in the microinch range are close to those of the optics industry.

Most thin film heads are designed to fill a dual role : during the write process they must create a magnetic field, strong enough to orient the microscopic permanent magnets forming the storage media, and during the read process they become low noise transducers sensing the weak magnetic fields fringing from the magnetic transitions stored in the disc media.

THIN FILM HEAD CONCEPTS

The information writing process relies on the generation of a magnetic flux in a gap. A current is forced in a coil wrapped around some magnetic material which provides a low reluctance outside of a gap which has been inserted to generate a fringing field as shown schematically in figure 1. This type of head is called ring head and is used both with longitudinal and vertical media. Longitudinal refers to the orientation of the microscopic magnets formed by the fringing field in the thin magnetic film to store the information. These magnets are parallel to the plane of the disc. In the case of vertical media, also known as perpendicular media, the orientation of the magnetic domains is normal to the plane of the disc. The ring can take the physical shape indicated in figure 2. This type of head is machined from ferrite material. The gap width is controlled by glassing together the ferrite elements as shown in figure 2. Beyond 20 Megabits stored per square inch of disc surface it becomes necessary to use thin film heads. It provides an easier control over the fabrication of an increasingly narrower gap between the pole tips. Ring heads can be used both for longitudinal and perpendicular recording, however in order to maximize the stacking density, different configurations can be used which will improve the efficiency in producing or sensing a magnetic field component normal to the disc surface.

A type of head useable, when access to both sides of the disc is permissible, usually in thin flexible media, is shown schematically in figure 3. For single side access the type of head shown in figure 4 can be used. This configuration favors the use of a high permeability longitudinally oriented magnetically soft underlayer. This layer provides a low reluctance closure path greatly enhancing the magnetic efficiency.

Translating these schematic configurations to thin film devices, leads to geometries of the type shown in figure 6-7 for longitudinal recording . Some early geometries (2) were very simple. However the efficiency was correspondingly low, therefore these heads required large currents to write and were lacking sensitivity in the read mode. Other designs were difficult to produce (3), due to a large number of superposed layers and the poor definition of the patterns obtained through shadow masks. The number of turns and the general layout complexity must reach a compromise to be producible in quantity. The magnetic thin film head designer should be process oriented as well as familiar with computer modelling of the magnetics.

FABRICATION PROCESSES AND MATERIALS

Substrate

Because the thin film heads must be supported by a three-dimensional slider the substrate material must meet stringent and sometime conflicting requirements for its electrical, magnetic and mechanical properties.

Early attemps have been made to fabricate heads on thin wafers, particularly on silicon, then die attach the heads to the slider before or after completion of the machining of the slider. Serious difficulties occured because of the tolerances allowable for positional accuracy, in the micron range, to ensure control over the critical throat height. The final lapping of the slider must bring the throat height within microinches of its ideal location

Foremost, the substrate must be smooth and defect free to support geometries of two micron line width. It must also be wear resistant and have low static and dynamic coefficients of friction.

The surface finish requirements eliminate most ceramic materials because of the grain sizes, interstices at the grain boundaries and grain pullouts experienced during polishing. Single crystal materials available in large quantity are either too costly, for example sapphire, or unsuitable because of mechanical properties such as silicon or difficult to grow in large boules. Silicon is unfortunately unsuitable because of rapid wear experienced at the start and stop of the disc drive at which point the head and media come in contact.

Glass-ceramics have been used, for example Corning Glass' Fotoceram. The photosensitive and chemical machining properties available in this class of materials are not particularly useful however all other criterias are met, including favorable wear characteristics despite its relatively low Knoop hardness. The main difficulty in handling glass ceramic occurs in the machining with diamond wheels at high speed because of cold flow of the material at the kerf. In this respect the behaviour of glass-ceramic is similar to that of glass and fused silica.

Some hot pressed ceramics have been shown to meet the surface finish requirements but are extremely difficult to machine because of extreme hardness combined to cold flow behaviour. This is a surprising fact encountered with hot pressed alumina, silicon nitride or sialon.

The most popular material at this time is hot pressed alumina titanium carbide and its variations. Despite its extreme hardness this material can be machined reasonably well with conventional epoxy matrix diamond wheels, or less conventional machine tools such as lasers or electrodischarge.Alumina titanium carbide has a small grain size structure, approximately two microns, near theoretical density, as well as a favorable grain structure fracture during machining. Combined to excellent response to mechano-chemical polishing techniques this material is eminently suitable for machining in the microinches tolerance range without experiencing intolerable chipping. Chipping is unacceptable since the slider must form an air bearing over the recording disc surface and must meet precise aerodynamic requirements.

A few newer high performance hot pressed ceramics are starting to appear with improved machining or electrical properties based on zirconates or titanates. Some thin film head designs have also been using ferrite ceramics ( ) which are prepared either by hipping or hot pressing.

The virgin polished wafers are thicker that most common thin film substrates because they are destined to be cut into sliders standing on end. Nevertheless, these wafers are compatible with semiconductor wafer equipment like spinners, mask aligners with only very minor modifications.

The outside diameter rough machining of the wafers as well as the polishing are carried in a manner very similar to the techniques used with silicon wafer fabrication and or the diamond lapping of optical crystals. Abrasive slurries can be formulated with chemical or colloidal solutions to enhance cutting speeds by well over an order of magnitude over more conventional water or glycol based diamond slurries.

Substrate insulator

Because alumina titanium carbide, as well as other substrate materials, is electrically semi-conducting, an insulator must be deposited on the surface after the final polishing operation.

The insulator is usually a sputtered alumina several microns thick. The wafer is often repolished after this deposition to improve the surface finish; the sputtered Al_2O_3 behaving as a filler to cover minor blemishes. This alumina film can be sputtered at relatively high temperature to obtain a very dense film when no photolithographic etching is required in subsequent steps. The high sputtering temperature changes the properties of the film drastically from an amorphous easily etched film to presumably an a-alumina type structure which is extremelly resistant mechanically and chemically.

Some ferrite designs may require some glass filled groves in addition to an insulating layer (4). The function of these groves is to provide a non-magnetic material in the center of the magnetic core. The glass is usually reflowed in diamond wheel cut groves then lapped and polished. These techniques are similar to the ones used for fabricating the hand wound ferrite sliders.

Magnetic thin films

The magnetic material surrounding the conductor coil has the shape of an elongated split ring. It must meet stringent magnetic requirements, in particular high permeability, well controlled anisotropy and zero magnetostriction. The films are often electroplated by an additive technique (5-6) although sputtering , E-beam evaporation or ion-plating can be used with either lift-off or etched back photo-lithographic techniques.

The anisotropy of the deposited film can be controlled by placing the film under growth, regardless of the deposition method, in a magnetic field which orients the film during its formation. Isotropic films are obtainable if steps are taken to cancel the earth or other stray magnetic fields normally present.

The material usually deposited is permalloy (80 Ni- 20 Fe).Permalloy electroplating can produce good films with permeability up to 3000 and coercivities below 1 Oe. however it is a difficult process to master with little analytical insight in the mechanism controlling the bath behaviour. There exist also , as in any electroless or electroplating process, the danger of incorporating small amounts of uncontrolled materials with implications on the long term corrosion or physical characteristics. This is in addition to the difficulties, occuring in the choice of materials due to electrochemical couples which can form when two materials are in contact, a consideration which must always underlay the choice of thin film materials.

The additive photolithographic process generally used in micro-electroplating enables the formation of nearly straight wall thin film edges when necessary. A thin window frame is formed around the areas where the magnetic film deposition is desired to form quasi-islands. Only small tabs are left in the window design to permit continuity of electrical connections. The area occupied by the windows is deliberately kept to a small percentage of the total plated area in order to be negligible factor when computing the effective plating current density.The extraneous plated material is later etched away after remasking.

Magnetron sputtering of magnetic materials is not straightforward because of the low reluctance path provided by the target to the bias magnetic field. There also will be some effect of the bias magnetic field on the anisotropy of the deposited material. In other words the target tends to severely shunt the strong magnetic field which must exist outside of the target to trap the electrons and obtain a magnetron behaviour and, if it does, it may interfere with the magnetic anisotopy of the deposited film. Thin target material or heating above the Curie point must be used which is at best inconvenient. Nevertheless, magnetron sputtering of soft magnetic materials has been shown to produce excellent films with permeability up to 7000 and coercivity less than 1 Oe. simultaneously with high deposition rates.

Depositing the material in sheet form, as in sputtering , requires ion etching or lift-off techniques. This is because wet etching of the permalloy without attack on the remaining structure is not usually feasible. The usual conductor being copper, there is no obvious wet etchant discriminating between copper and nickel-iron to obtain a convenient self-limiting etching process.

Conductor material

The deposition method favored by many to form the coils is also electrodeposition since this process is already used in the magnetic layer. Copper is the choice material because it is easy to plate and its conductivity is second only to silver which cannot be used because of electromigration problems.

Low resistance in the coils is desirable for power dissipation and for driver circuitry impedance matching reasons. During the write process high current pulses are needed and current densities around 10^6 amp per cm^2 are necesary to keep the crosssection of the coil as compact as possible.

Window frame microplating techniques are used in the way as for the magnetic material. The window frame edge profile control is also critical but gives flexibility once the process is mastered because sloped, straight, or even reentrant edges are feasible.

Insulation layer

Insulation layers are not only necessary to provide electrical isolation but also to provide a planarized surface on which the second layer of NiFe can be deposited. Sharp changes in the plane of the permalloy are undesirable for magnetic reasons.

Despite the superior properties demonstrated by some organic materials such as many polyimides, the most often used insulator is positive photoresist subjected to a relatively high temperature bake. By controlling the exposure, post-exposure and postbaking, it is possible tc repeatably control the reflow properties of the resist hence control the step coverage and planarization properties. This hard baked photoresist can be extremely difficult to remove.

Polyimides have inherent chemical stability advantages. However they have been avoided because higher temperatures are needed to fully imidize the material and drive all absorbed water out. Permalloy undergoes permanent changes in magnetic properties at approximately 240 degrees centigrade due to re-crystallization which permanently deteriorates electroplated NiFe. The minimum temperature needed to fully cure most polyimides is 300 degrees centigrade. Temperatures of the same order are needed to deposit plasma enhanced CVD SiO_2 Si_3N_4 or oxynitrides. All of these materials can be used with sputtered permalloy with some precautions. Etching can be accomplished with CF_4 O_2 plasma or a combination of both as the case may be. Polyimide is the most convenient to planarize the coil structure and the edge profile can easily be manipulated with plasma etching just as is done in the semiconductor industry.

Al_2O_3 is often the material used as a gap spacer because of the better thickness control given by an inorganic film and also for mechanical and chemical reasons. The alumina sputtered deposition must be kept at low temperature to preserve the plated permalloy integrity and obtain reasonable etching properties.

Protective Overlayer

Bonding pads are provided for connection to the preamplifier. These pads are suitable for ultrasonic or thermocompression bonding. Copper is used to built up thick pads made to penetrate through a thick overcoating placed over the entire head. Due to the thickness of the alumina overcoat, the copper pads look and are built like bumps for the inner bond in silicon wafers prepared for tape automated bonding. A layer of alumina, 25 microns thick or over, is sputtered over the completed heads and bonding pads. This will provide mechanical and some chemical protection during the machining of the sliders.Later when the heads will actually be flown over the media it will also provide wear protection to the pole tip. Again this alumina deposition must be kept at low temperature both for etching and permalloy properties reasons. The deposition times can last 24 hours or more; therefore, excellent cooling of the anode substrate holder must be provided. The surface of the wafer is then polished to bring copper and alumina to the same level. Finally, the copper is protected for future bonding by an electrodeposited gold film. The gold thickness and properties are a function of the type of bonding prefered.

Slider completion

Completion of the wafer is only half of head building operations. Machining of the sliders and static testing remain to be done. The wafers are usually tested for a few electrical parameters and then sliced with thin diamond wheels into bars of side by side sliders. The air bearing rails are individually shaped by diamond wheel grinders and then diamond lapped and polished to bring the thin film head gap throat to the proper height. This calls for tolerances in the microinches range. The flatness and finish of the rails is often checked with an interferometer and must be kept within one light band (approximately 2500 Angstroms) since it is of critical importance to the flight characteristics of the slider. The slider and its suspension assembly are designed to keep the pole tip of the thin film head flying at a nearly constant height typically 14 microinches above the media surface.

CONCLUSIONS

The thin film fabrication process allows to circumvent the manufacturing difficulties encountered with machined bulk ferrite heads as aeral density continues to increase for rotating magnetic recording memories. However, the greatest potential for thin film head comes from an overall decrease in disc drive manufacturing costs. Beyond the manufacturing costs of the head slider assembly itself, the smaller gap combined with a smaller slider configuration allows lower flying height. Greater bit density, particularly if thin film media is used, enables the disc drive manufacturer to reduce the number of heads and recording surfaces for an equal storage capacity hence, reduce the overall manufacturing costs.

Although the magnetic thin film heads are not usually recognized as hybrid microcircuits they fully deserve the name due to the variety of techniques necessary to built them.

They have demonstrated that high quality inductive devices can be mass produced and stimulated the production of newer high performance substrate materials. Conceivably, a number of other devices based on high permeability or hard magnetic films could be devised to further exploit the techniques pioneered by the digital recording industry

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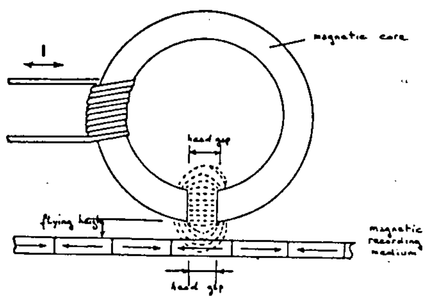


Figure 1

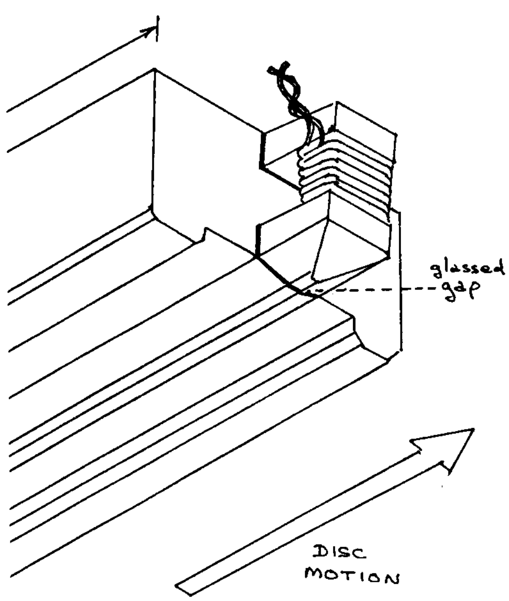
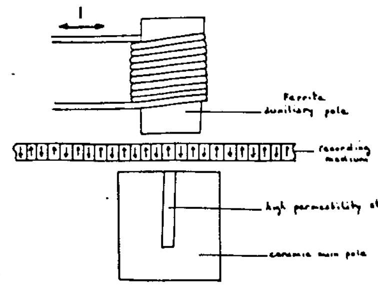
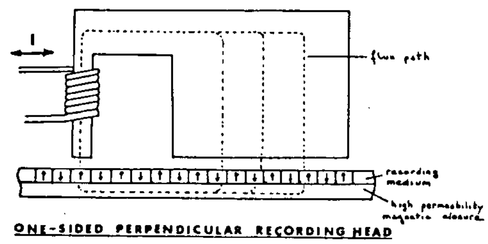


Figure 2



TWO-SIDED VERTICAL RECORDING HEAD

Figure 3



ONE-SIDED PERPENDICULAR RECORDING HEAD

Figure 4

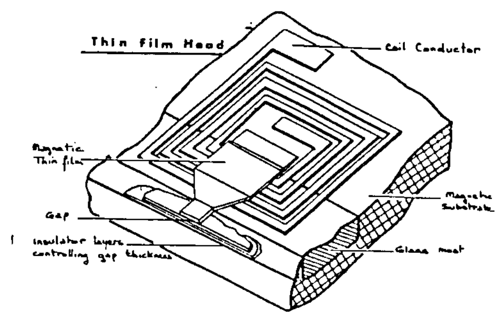


Figure 5

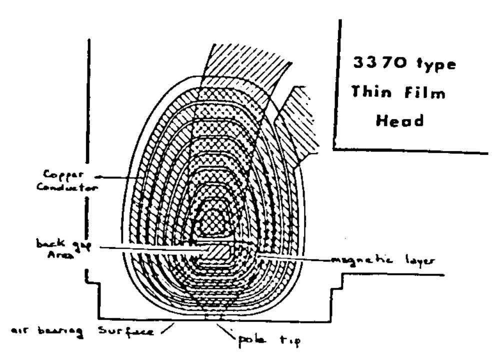


Figure 6