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[54] TRANSDUCER HEAD WITH LAMINATED POLE TIPS FOR WIDEBAND TRANSDUCER SYSTEM

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[*] Notice: The portion of the term of this patent subsequent to Oct. 19, 1988, has been disclaimed.

[22] Filed: **July 30, 1970**

[21] Appl. No.: **59,511**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 23,157, Mar. 27, 1970, Pat. No. 3,614,339.

[52] **U.S. Cl.** ....**179/100.2 C,** 29/603, 340/174.1 F
[51] **Int. Cl.** **G11b 5/42,** G11b 5/22, G11b 5/40
[58] **Field of Search** ....179/100.2 C; 340/174.1 F; 346/74 MC; 29/603

[56] **References Cited**

UNITED STATES PATENTS

2,992,474	7/1961	Adams	179/100.2 C
3,417,209	12/1968	Schneider	179/100.2 C

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Assistant Examiner—Jay P. Lucas
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[57] ABSTRACT

A composite magnetic transducer head having laminated pole tips preferably formed of a special hot-pressed sintered iron-silicon-aluminum material with an electrical insulating layer isolating the pole tips from the ferrite core and having a thickness producing optimum high frequency response and signal to noise ratio.

9 Claims, 8 Drawing Figures

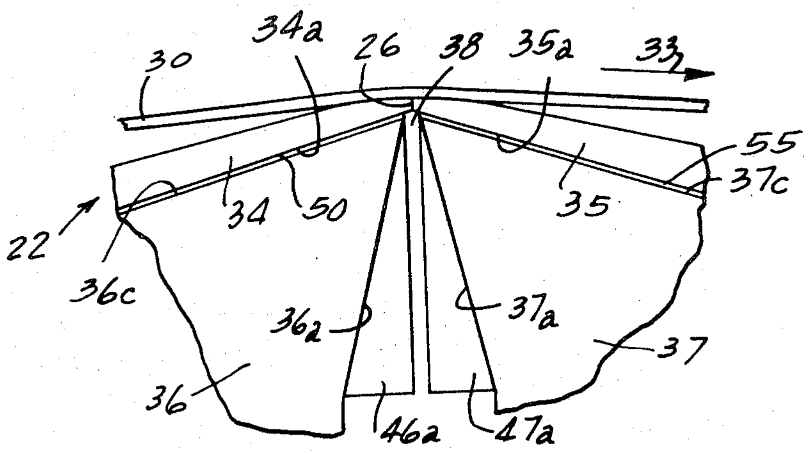


Fig. 1

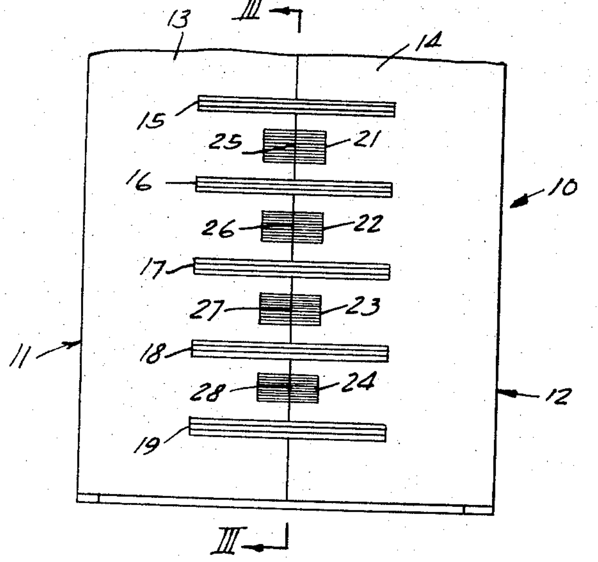


Fig. 2

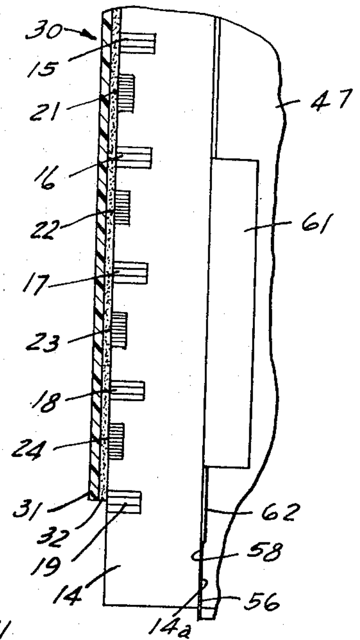
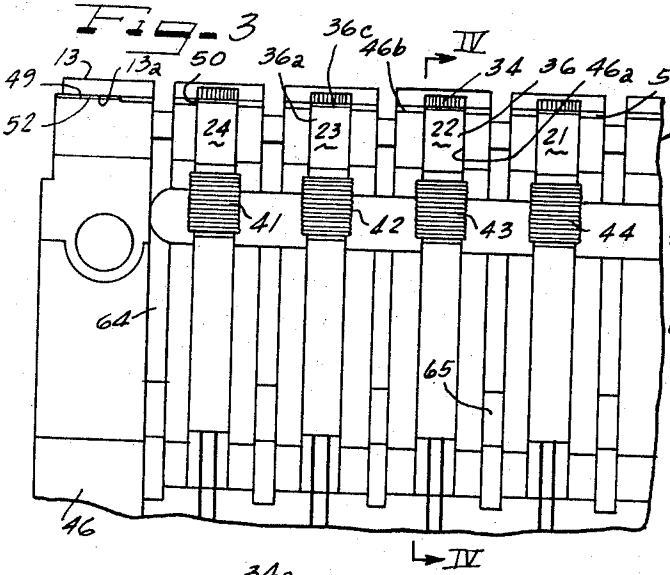


Fig. 3



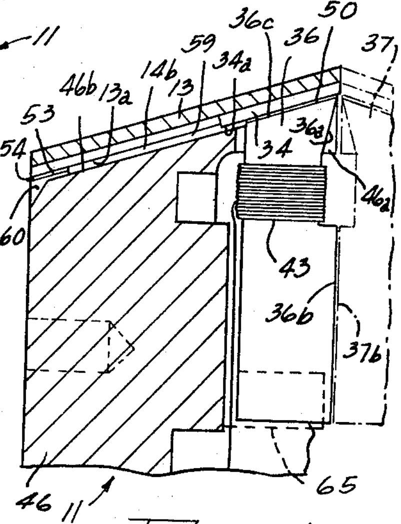


Fig. 4

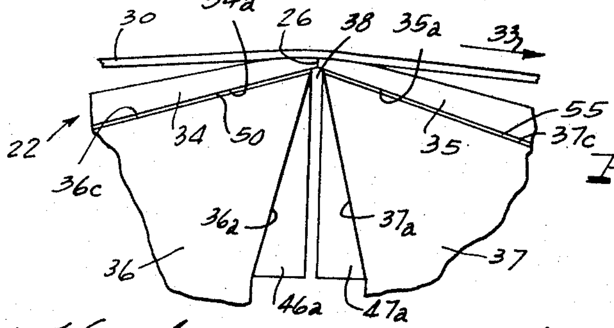


Fig. 5

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FIG. 6

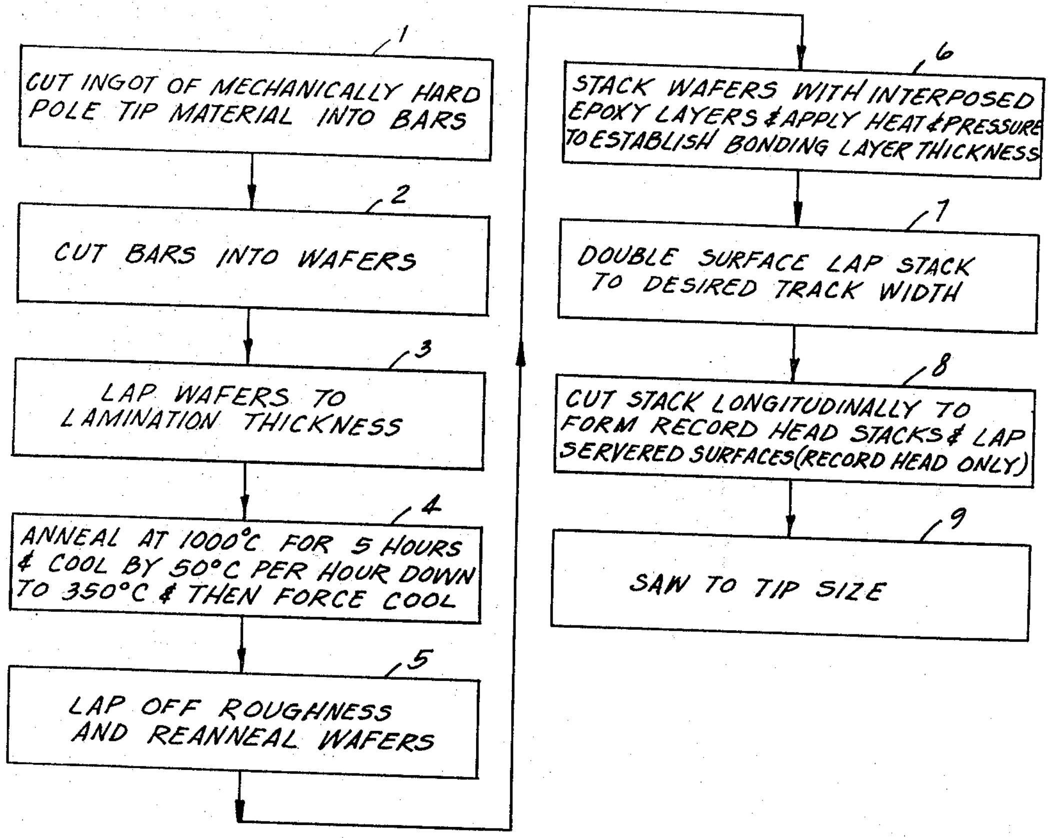


FIG. 7

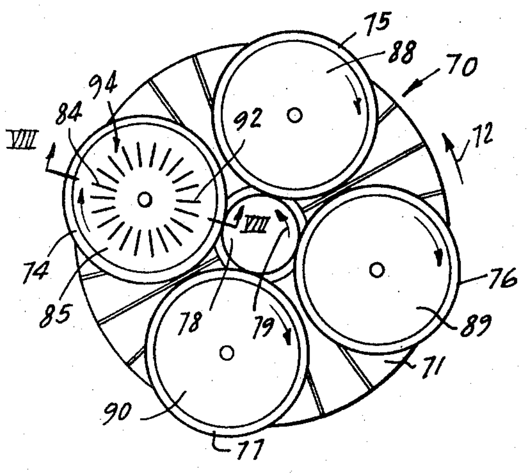
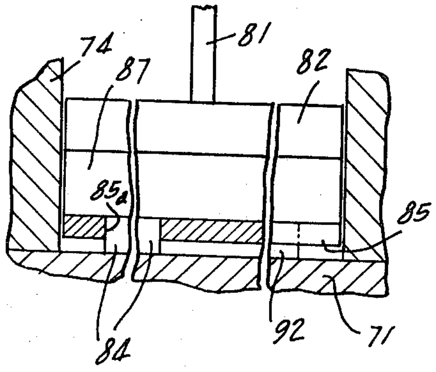


FIG. 8



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TRANSDUCER HEAD WITH LAMINATED POLE TIPS FOR WIDEBAND TRANSDUCER SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

The present application is a continuation-in-part of my copending application Ser. No. 23,157 filed Mar. 27, 1970, now U.S. Pat. No. 3,614,339 issued Oct. 19, 1971.

BACKGROUND OF THE INVENTION

The fabrication of composite instrumentation heads is dealt with in my prior U. S. Pat. No. 3,417,209 issued Dec. 17, 1968. The teaching in this patent is that the sendust pole tips for composite heads should be in direct contact with the confronting surfaces of the ferrite core to minimize the reluctance of the magnetic circuit. Prior to may patent, it was common to tolerate a thin glue line between the solid pole tips and ferrite core since such glue line was required to hold the pole tips in place.

SUMMARY OF THE INVENTION

In the course of development of the present invention it has been discovered that laminated pole tips may be formed from a special hot pressed sintered iron-silicon-aluminum material to obtain increased density and hardness together with very favorable magnetic characteristics. Furthermore, means have been discovered for successfully fabricating a composite head using commercially available fusion cast iron-silicon-aluminum alloy in a laminated pole tip configuration. In each case, however, it is found that optimum high frequency performance unexpectedly requires that an electrical insulating layer of controlled thickness be interposed between the pole tip laminations and the confronting surface of the ferrite core, even through such layer is not required to secure the pole tips in place relative to the ferrite core.

This invention relates to an improved magnetic transducer head capable of handling frequencies in the megahertz range, and to special laminations and pole tip configurations for a magnetic transducer head, and to a method of manufacturing the same.

In the head construction of the present invention, the pole tips even though made of an extremely hard material of an iron-silicon-aluminum composition have been successfully formed into a laminated configuration suitable for the megahertz frequency range. A special lamination material has been developed which has resulted in a commercial head construction providing at least a 6-decibel improvement in signal to noise ratio at megahertz frequencies and a Vickers hardness of at least about 650. The present commercial head is considered a strikingly important advance in an already relatively highly developed field.

It is therefore an important object of the present invention to provide an improved composite multichannel magnetic transducer head construction providing substantially better high frequency response than the head of my prior patent.

It is a further object of the present invention to provide a magnetic transducer head with laminated pole pieces which exhibits greatly improved gap stability and uniformity during a substantially increased useful life.

Further objects and features of the present invention relate to an improved lamination material and improved laminated pole tip configurations for a composite transducer head, and to methods and techniques for fabricating the same.

The laminated tip head of the present invention provides a frequency response characteristic which is much less affected by head wear; also the head inductance is readily controlled to match any desired system requirements. With the solid sendust tip head the length of the front gap between the ferrite core parts is very critical and the frequency response characteristics of the head change drastically with wear (necessitating annoyingly frequent circuit adjustments in use of the head). With the present laminated tip head the ferrite front gap can be widened substantially (e.g. by 5 mils) without the head high frequency response falling below existing specifications.

Other objects, features and advantages of the invention will be readily apparent from the following description of certain preferred embodiments thereof, taken in conjunction with the accompanying drawings, although variations and modifications may be effected without departing from the spirit and scope of the novel concepts of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial somewhat diagrammatic top plan view of a head assembly in accordance with the present invention;

FIG. 2 is a partial side elevational view of the head of FIG. 1;

FIG. 3 is a somewhat diagrammatic vertical sectional view taken generally along the plane represented by the line III—III in FIG. 1 an looking in the direction of the arrows, but illustrating the head assembly prior to completion of certain of the fabricating steps;

FIG. 4 is a somewhat diagrammatic longitudinal sectional view taken generally along the line IV—IV of FIG. 3 and illustrating in detail only the left half of the partially fabricated head assembly, a portion of the right half of the head assembly being indicated in dot dash outline;

FIG. 5 is an enlarged somewhat diagrammatic longitudinal sectional view illustrating the pole region of the completed magnetic head assembly of FIG. 1 and 2 and showing the path of a tape record medium thereacross;

FIG. 6 is a flow diagram setting forth certain principal steps in the method of forming pole tips for the head of FIGS. 1–5 from a commercially available ingot of fusion cast iron-silicon-aluminum alloy;

FIG. 7 is a somewhat diagrammatic top plan view illustrating the arrangement for carrying out the lapping operation of step number 3 of FIG. 6; and

FIG. 8 is a somewhat diagrammatic vertical sectional view taken generally along the plane represented by the line VIII—VIII in FIG. 7.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIGS. 1 and 2 is illustrated a magnetic transducer head **10** formed of a pair of head sub-assemblies **11** and **12**. FIG. 1 shows a plan view of the tape confronting surface of the head which is formed by tip plates **13** and **14**, the top edges of shields **15–19** and the pole tips of transducer head units **21–24**. The coupling gaps for the respective head units are indicated at **25–28** and are arranged to coincide with the interface between the head sub-assemblies **11** and **12**.

For the sake of diagrammatic illustration, a magnetic tape record medium is indicated at **30** in FIGS. 2 and 5, having a flexible non-magnetic backing **31** and a magnetizable layer **32** which is in sliding contact with the surface of the head assembly **10** as represented in FIG. 5. As shown in FIG. 5, the magnetic tape record medium **30** moves in the direction of arrow **33** across the pole tips **34** and **35** of each of the head units. Ferrite core parts are partially indicated at **36** and **37** in FIG. 5, and a complete core part **36** is shown in FIG. 4. The core parts **36** and **37** have converging faces ***36a***, ***37a***, FIG. 5, which define a front non-magnetic gap **38**, and have parallel confronting faces ***36b***, ***37b***, FIG. 4, defining a back non-magnetic gap.

FIGS. 3 and 4 shown the head sub-assembly **11** prior to completion of certain of the fabricating steps. For ease of reference, however, corresponding reference numerals have been applied to the parts in FIGS. 3 and 4 which correspond to those in FIG. 1 and 2, even though certain of the parts such as the tip plate **13** as shown in FIGS. 3 and 4 will receive further machining operations prior to completion of the head **10** as shown in FIGS. 1 and 2. Referring to FIGS. 3 and 4, it will be observed that the core sections such as **36** receive respective transducer windings such as those shown at **41–44** in FIG. 3. The configuration of each of the head units **21–24** may be identical.

A mounting means for the ferrite core parts and shields comprises mounting brackets **46** (FIGS. 3 and 4) and **47** (FIG. 2), having interior walls such as **46***a*, **47***a*, FIG. 5, defining mounting slots for receiving the ferrite core parts **36** and **37**. In forming the sub-assembly **11** of FIGS. 3 and 4, the core parts **36** are secured in the recesses of the associated bracket **46** by a suitable cement. The edge faces **36***c* of ferrite core parts **36** are lapped flat with lands such as indicated at **49**, FIG. 3, at each side of bracket **46**.

A coating of cement is then applied to each ferrite core edge face **36***c*, and to each bracket land area as **58**, FIG. 2, **49**, FIG. 3, and **53**, FIG. 4. The tip plate **13** is applied with sufficient pressure such that the cement bonds to the lower edges of the pole tip laminations and forms an electrical insulating layer **50** of controlled thickness, for example about **20** to **40** microinches. The excess cement is squeezed out from between the confronting surfaces of the ferrite core parts and the respective pole tips and into the intervening spaces such as indicated at **51**. The bracket **46** is shown with the land areas **49**, FIG. 3, and **53**, FIG. 4, spaced from the tip plate **13** by cement layers **52** and **54** which are substantially equal in thickness to the layer **50**. The insulating and bonding layers **50**, **52** and **54** appearing in FIGS. 3, 4 and 5, and corresponding layers such as **55**, FIG. 5, and **56**, FIG. 2, of the other head sub-assembly **12** are shown with exaggerated thickness in the drawings for the sake of clarity. The pressure and/or temperature applied to the bonding layers such as **50**, **52**, **54**, **55** and **56** during the formation thereof may be selected to control their thickness dimension.

It has been found that the bonding layers **50** and **55**, being electrically non-conductive in comparison to the conductivity of the ferrite edge faces **36***c* and **37***c*, provide electrical isolation of the laminations of each pole tip assembly, and result in improved high frequency response where the core parts **36** and **37** are of a manganese zinc ferrite having a resistivity of the order of 1,000 ohm-centimeters or less.

The interior spaces as **51**, FIG. 3, and **59**, FIG. 4, between the undersurface **13a** of the tip plate **13** and an upper surface **46***b* of bracket **46** may be filled with a suitable epoxy supplied at apertures such as **60**, FIG. 4, as described in my U.S. Pat. No. 3,417,209. The head sub-assembly **12** is provided with similar apertures such as **61**, FIG. 2, so that spaces such as **62**, FIG. 2, are likewise filled with epoxy which secures tip plates **14** to bracket **47**. The further processing steps of the head sub-assemblies may conform with those disclosed in my prior patent.

The shields **15–19** are seated in recesses such as indicated at **64**, FIG. 3, and may be bottomed against shield stops such as **65**, FIGS. 3 and 4, for convenient positioning thereof during mating of the sub-assemblies **11** and **12**. After the parts **11** and **12** are assembled, the empty spaces within the assembly are filled with a suitable potting compound, and the tape contacting surface is formed as indicated in FIGS. 1, 2 and 5.

By way of example, the gaps **25–28** between pole tips such as **34** and **35**, FIG. 5, of head units **21–24**, may each have a length dimension of about **30** microinches for use as playback head, and may have a length dimension of about **80** microinches for use as a record head. The confronting polar faces of pole tips **34** and **35** may have a depth or vertical dimension as viewed in FIG. 5 of about 3 ½ mils, (1 mil equals 0.001 inch), and the pole tips may each have a length of about .32 inch for a playback head and about .15 inch for a record head. The front gap **38** between the ferrite core parts may have a length dimension of the order of three mils. (In each case the length dimension is generally parallel to the direction of movement of the tape record medium.)

EXAMPLES OF LAMINATION FABRICATION TECHNIQUES

Referring to FIG. 6, the basic steps in an exemplary method for fabricating laminations from the commercially available fusion cast material known as sendust are identified by numerals **1–9**. The following numbered sections will refer to these respective basic steps.

1. Sendust is commercially available in ingots, for example of 1 ½ inch diameter and six inches long. A typical example of such commercial alloy has a composition of 84.5% iron, 6% aluminum and 9.5% silicon and a mechanical hardness of Rockwell C–42. The stated characteristics are as follows: density 7.1 grams per cubic centimeter, and electrical resistivity 80 micro-ohm centimeters.

The ingots are cut into bars 1 inch wide and 0.350 inches thick, and as long as possible, for example by an abrasive grinding technique using a silicon carbide wheel.

2. It is found that such bar material can be sliced into wafers having a thickness of 8 mils (0.008 inch) by means of a Norton Wafering Machine, which is known per se in the semiconductor art. For the present application, an aluminum oxide slurry is flowed over the blades of the machine which operate to progressively wear away material during a very large number of successive passes adjacent an edge of the bar. Thus, each bar is progressively sliced into a large number of wafers which when viewed in side elevation are of rectangular configuration with a length dimension of 1.00 inch and a height dimension of 0.350 inch. When viewed in a particular orientation, each wafer may be provided with a beveled upper left hand edge which serves to provide a reference mark during subsequent processing. The bars formed in step number 1 may be provided with a suitable 45° chamfer along one of the long edges thereof so that the wafers are then formed with the beveled edge. (As an example, a bar of pole tip material as formed in step number 1 may have a long dimension of 4 inches).

3. The wafers as formed in step number 2 are then subjected to a single surface lapping operation which serves to reduce the thickness of the wafers to the desired ultimate lamination thickness, for example between five and six mils. It is found that such lapping can be effected utilizing aluminum oxide as the lapping compound and utilizing a Meehenite cast iron plate or a hard steel plate. Further details of the lapping procedure are given hereinafter having reference to FIGS. 7 and 8 of the drawings.

4. The pole tip wafers are then placed between aluminum oxide plates (0.1 inch thick) with weights on top of the aluminum oxide plates to tend to prevent curling or the "potato chip" effect during an annealing operation. As indicated in FIG. 6, the annealing operation may take place at 1,000°C for 5 hours, with cooling thereafter at the rate of 50°C per hour until the temperature is reduced to 350°C or 400°C, (which is below the Curie temperature of 482°C). The material can then be forced cooled.

It is found that the pole tip wafers after annealing developed very substantial surface roughness, which is believed to be due to crystal shift during the annealing process.

5. It is found possible to effectively remove this surface roughness by subjecting the pole tip wafers to a further lapping operation to remove surface irregularities, and then subjecting the pole tip wafers to a second annealing operation which may be identical to the first annealing operation just described. It is found that the surface roughness does not again develop after the second annealing operation, and that the pole tip wafers now remain essentially flat and smooth with 100 microinch overall flatness and a surface finish of 4 microinches r.m.s.

With the resultant pole tip wafer arranged with the beveled edge at the upper left as before, the opposite surfaces of the wafer are inspected over a zone between 20 and 60 mils below the upper edge to insure that this critical zone is free of pits greater than 0.0002 inch diameter (except adjacent the opposite vertical edges of the pole tip wafter).

Without the second annealing operation, it was found that the commercially available material developed such roughness that a stack of laminations with spacing of 200 microinches developed short circuits because of the surface roughness.

6. The flat and smooth pole tip wafers as formed in step number 5 are then stacked to form a wafer lamination assembly having a length dimension of 1.00 inch, and a height dimension of 0.35 inch and having, for example nine laminations with interposed cement layers. By way of example, the pole tip wafers may be sprayed or coated with a semi-rigid epoxy system and stacked in a fixture with accurate spacing. A hydraulic press with heated platens then compresses the stack to the proper width dimension with the excess epoxy being squeezed out from between the laminations and a strong mechanical bond being formed between the successive laminations of the stack to form a unitary structure, the bonding layers having a thickness of about 0.0002 inch (200 microinches) and less than 0.0003 inch (300 microinches).

7. The stack as formed in step number 6 is then double surface lapped to provide the desired stack width, for example 0.0503 inches plus or minus 0.0001 inch where the pole tip wafers had a thickness of 0.0056 plus or minus 0.0002 inch.

The wafer lamination assembly as thus formed is edge lapped along the long (1.00 inch) upper edge face to remove edge roughness.

8. Where recording pole tips are to be formed, the wafer lamination assembly with the orientation just described is cut horizontally and the cut edges lapped to provide two wafer lamination assemblies each having a height dimension of 0.155 inch and a lapped edge face which is perpendicular to the side surfaces thereof.

9. The wafer lamination assemblies are then cut into pole tip sections having a depth dimension of 0.014 inch plus or minus 0.002 inch, with an edge face having a width dimension of 0.0505 inch and depth dimension of 0.014 inch being formed from the lapped surface of the wafer lamination assembly so as to provide a gap defining face of the pole tip. Each pole tip section is inspected for a distance of 0.06 inch from the lapped gap defining edge face to be certain that no voids or pits greater than 0.0002 inch diameter can be seen at the side surfaces of the pole tip section.

FIGS. 7 and 8 illustrate a suitable lapping apparatus **70** for carrying out step Nos. 3 and 5. The lapping plate **71** is shown as rotating in the direction of arrow **72** on a central vertical axis. Four retaining rings **74–77** have external gear teeth (not shown) meshing with a central gear **78** which is selectively engageable to rotate with the lapping plate **71** as indicated by arrow **79**. When the gear **73** is engaged, the retaining rings are driven clockwise, while when the gear **78** is disengaged, frictional contact of the rings **74–77** with the surface of the lapping plate **71** drives the rings in the counterclockwise direction. The reversing of the direction of rotation of the rings **74–77** is effected as necessary to maintain the surface of the lapping plate substantially flat.

The four retaining rings such as **74** are held in place on the lapping plate **71** during a lapping operation by means of four air cylinders (not shown) fixed to the upper frame of the apparatus and having respective piston rods such as indicated at **81**, FIG. **8**, carrying universally mounted pressure plates such as **82** which fit within the respective rings such as **74**.

In the illustrated embodiment, the wafers such as **84** are carried in conforming apertures such as **85*a*** of circular work holders such as **85**. Circular disks **87–90** are secured to the top surfaces of the respective work holders. The weight of the disks plus the pressure exerted by the cylinders may be such as to produce a pressure on the surfaces of the wafers such as **84** and **92** which engage the lapping plate of 6 pounds per square inch.

As indicated in FIG. **8**, the thickness of the holder plate **85** may be 4 mils, in comparison to an original thickness dimension of the wafers of 8 mils. There may be **22** apertures such as **85*a*** disposed in a radial pattern as indicated diagrammatically at **94** in FIG. **7**.

The wafers can be loaded into each work holder while the work holders are inverted. If the wafers are wetted with the slurry used during lapping prior to insertion thereof into the apertures of the work holder, surface tension will retain the wafers in the apertures as the holders are placed on the lapping plate **71**.

The slurry may comprise aluminum oxide particles with a size of **25** microns. One pound of the particles is mixed with one gallon of a suitable lapping oil such as Speedfam lapping oil supplied by Speedfam Corp., North Third Avenue, Des Plaines, Ill. The slurry is supplied in advance of each retaining ring at a rate of a couple of drips per second.

The wafers are lapped for about 2 minutes on one side and then inverted. This cycle is repeated about three times so that the total processing time for each group of 88 wafers is about 12 minutes.

The lapping plate **71** may be rotated at about **50** revolutions per minute.

In the double surface lapping operation of step No. 7, lapping plates engage the stacks on each side of the work holders. A slurry may be formed using aluminum oxide particles of three microns, and a mixture of 1 pound of particles per gallon of the same lapping oil as before. About ten minutes is required for this lapping operation.

The teachings of the present invention are also applicable to ingots of hot-pressed sintered silicon-aluminum-iron alloy having a thickness initially of at least about twenty mils and having a mechanical hardness of at least about Vickers 650 (measured at a 300 gram load). The concept in the prior art has been to sinter compacted masses of such alloys having essentially the desired ultimate thickness. Following the teachings of the present invention, blocks or bars of the hot-pressed sintered material can be formed and then wafered and lapped as taught herein to provide laminations with a thickness of not more than about eight mils (0.008 inch), and having much greater density and better magnetic properties than laminations heretofore available from this material.

In the case of the preferred sintered alloy, an ingot having a volume of about four cubic inches is formed, having a Vickers hardness of at least about 650 (with 300 gram loading) in comparison to a Vickers hardness for a fusion casting of the conventional sendust material of about 560. The preferred sintered alloy has a resistivity of about 100 to 110 micro-ohm-centimeters and is wafered and lapped as taught herein to provide a lamination thickness of about 5 ½ mils. The wafers are annealed in a vacuum furnace by raising the temperature of the heating chamber from room temperature to 800°C in from ½ hour to 1 hour, and then shutting off the furnace and allowing the heating chamber to cool back to room temperature at an unforced rate (with the chamber remaining closed).

In this case the annealed wafers are briefly dipped (for about 5 seconds) into a viscous hydrofluoric acid solution to etch the surfaces thereof. This rapid dip acid treatment step removes any silicon which may have diffused to the surface of the wafers without weakening the wafers by excessive etching at the grain boundaries. The resulting surface is found to be chemically clean as verified by a water break test.

With this preferred sintered alloy the wafering procedure is the same as for the fusion cast material, but it is found that the wafers do not develop the severe degree of roughness after annealing experienced with the cast material, and consequently the reannealing step can be omitted. It is theorized that a sintering operation introduces less stress in the material than fusion casting, so that the annealing induces markedly less crystal shift.

The preparation of the preferred hot-pressed sintered material is described in detail in a commonly owned pending application of Jean Berchtold entitled "Material for Magnetic Transducer Heads and Method for Preparing the Same," filed July 30, 1970 Ser. No. 59512, and the disclosure of this application is incorporated herein by reference.

Specifically, the preferred hot-pressed sintered material is prepared as follows:

The starting material may include an iron-silicon-aluminum alloy containing by weight from 4% to 9% and preferably about 5.6% of aluminum; from 6% to 12% and preferably about 9.6% of silicon and the balance essentially iron, viz.

about 84.8% iron. Minor amounts of other constituents can be included as impurities or as conventional additives but are not essential to impart thereto the properties that are desired in my magnetic alloy. As will be explained later, however, in preparing the preferred magnetic alloy composition after a suitable alloy powder has been formed, the alloy powder is nitrided, or provided with a nitride layer.

As a first general step in the preparation of my magnetic material, a powder of the above-described starting alloy, having a composition of 5.6% Al, 9.6% Si and 84.8% Fe, is produced if not already in the form of a powder. The powder preferably is of a particle size somewhat coarser than **325** mesh (Tyler Standard Screen Scale) or coarser than about **40** microns maximum dimension, and, in general between +325 and −250 mesh, the latter mesh size representing a particle size of about **60** microns maximum dimension. The mesh size can be anywhere between about **10** microns as a practical minimum and 500 microns as a practical maximum dimension but for best results in the processing of any given batch of the starting alloy, the particle size for that batch should be within a rather narrow range of from 50 percent either way of the mean particle size.

In forming this initial alloy powder, it is preferable to melt the individual elements in their relative ratio, as for instance, in an induction furnace having an inert gas or hydrogen atmosphere, and then run the molten alloy from the furnace into water to produce granules of the alloy and then subdivide the granules to the desired particle size by impact milling.

The powdered initial alloy, after nitriding as hereinafter described, is then mixed with iron, silicon and aluminum as elemental powders in portions by weight of 80% initial alloy and 20% elemental powders, and thoroughly blended to provide a homogeneous mixture of the desired final composition. No binder, such as a resin, agglutinate or other adhesive material is added to the mixture, and the composition of the final mixture is kept substantially within the ranges for Al, Si and Fe above-given in this preferred example. The particle sizes of the initial alloy, and of the elemental silicon, aluminum and iron can all be with the same close size ranges specified above but the alloy powder is most preferably within a range of about 40 to 60 microns, while the silicon and aluminum can suitable be finer than about 150 microns maximum dimension. Iron is preferably of a fine particle size such as less than about 325 mesh (less than about 40 microns maximum dimension), because of its slow rate of diffusion during hot-pressing.

As to the purities of constituents, the iron is preferably 99.5 percent pure; and therefore low in carbon, sulfur and phosphorus; the silicon is typically of 99.9 percent purity and the aluminum typically of 99 percent purity.

The powdered mixture of the initial alloy and about 20 percent by weight of elemental iron, silicon and aluminum, as a homogeneous blend of the powders within the particle size ranges specified, is charged to the chamber of a mold assembly. The mold assembly comprises an open-ended cylinder made of aluminum oxide that has been cold compacted isostatically and then sintered to give a dense alumina wall of about 99.5 percent pure alumina. The blend of powders to be sintered and hot-pressed therein should be free of any binder. Porous, high strength ceramic disks carried on upper and lower ram assemblies serve to apply mechanical pressure to the powder in the assembly. After the powder mixture is in the mold, the upper ram assembly is positioned in place, the charge in the mold assembly is subjected to the required temperature and mechanical pressure to effect the combined hot-pressing and sintering of the powered charge into a high density compact of high surface hardness, low porosity and high resistivity.

During the sintering and hot-pressing, the powder mix in the mold chamber is subjected to a mechanical pressure of about 1,000 pounds per square inch or more, as for instance 1,200 p.s.i. The volume of the powder decreases by about 55 percent as the sintering temperature is reached, as measured by a thermocouple positioned in the underside of the porous ceramic disk forming the head of the lower ram assembly. In general the sintering temperature will be about 15°C. to 30°C. below the actual melting point of the alloy, which if of the composition herein set forth, is typically about 1,235°C. Thus, to achieve minimum porosity the temperature should be above 1,205°C. and preferably about 1,220°C. as measured by the thermocouple 50.

A mechanical pressure of about 1,000 pounds per square inch is applied, and the temperature is increased to about 1,220°C. and is maintained over a period of about 6 to 12 hours after the porous ceramic disks forming the piston heads have reached substantially their maximum relative displacement toward each other. The mold assembly is allowed to cool while mechanical pressure is maintained and the hot-pressed sintered mass in the form of a dense compact is removed and processed as described above. The provision of a metal foil lining the mold chamber with a layer of a refractory powder between the foil and the cylindrical ceramic wall of the mold assembly facilitates the removal of the compact.

In addition to providing a slow flow of about 1 liter per minute of an inert gas, such as argon, through the mold assembly via the hollow upper and lower ram assemblies to sweep out oxygen and/or moisture, a getter of titanium powder can optionally be provided in the mold chamber to react with and reduce the amount of oxygen and/or moisture trapped in the system. Fired alumina particles in layers covering the titanium powder inhibit any alloying of the getter with the powder in the mix undergoing sintering and hot-pressing. It is found, however, that where care is exercised in minimizing the presence of oxygen and water, the results explained herein can be achieved without the use of the getter particles.

The nitriding of the final magnetic alloy can be best accomplished by a preliminary nitriding of the initial alloy in finely divided form employing a nitriding atmosphere of nitrogen and hydrogen such as a mixture of 82 vol. % of nitrogen and 18 vol. % of hydrogen. Nitriding is thus preferably carried out as a separate step ahead of the hot-pressing and sintering operation. In the nitriding operation, the alloy powder is subjected to an atmosphere of $N_2 + H_2$, of low dew point, and at a suitable nitriding temperature such as about 640°C. Heating is continued at about 640°C. in the nitriding atmosphere for at least about 4 hours or until an appreciable nitride layer is formed on the alloy powder.

The pre-nitrided alloy particles are then blended with approximately 20 percent by weight of powders in their elemental, unnitrided state and in proportions such as to maintain the previously given percentages of Al, Si and Fe. The nitride layer on the alloy powder effectively isolates the particles from one another to increase the resistivity of the powder compressed between electrodes almost a million times, or from about 40 Ohm-centimeters in the non-nitrided state, to 30×10^6 Ohm-centimeters in the nitrided state.

It may be noted that the alloy powder prior to nitriding has a metallic gray color, while after nitriding the powder has a yellowish tint. It is found that the nitriding step not only causes a virtual absence of growth in grain size during sintering, but also, most fortunately, does not interfere with the desirable magnetic qualities which render the material highly suitable for the pole tips of magnetic recording heads and magnetic playback heads.

The preferred material exhibits a smaller and more uniformly fine grain size as a result of the inhibiting effect upon grain growth of the nitridation of the alloy powder; a higher hardness of the final hot-pressed sintered compact in the neighborhood of a Vickers hardness of about 650 kg/mm^2 for a 300 gram loading (as compared with a Vickers hardness of only about 560 kg/mm^2 for an ingot of commercial cast "-sendust"); and a resistivity of about **110** micro-Ohm-centimeters (versus a resistivity of about 80 micro-Ohm-centimeters for a cast alloy of the same composition). Thus, nitriding is effective in preventing grain growth during hot-pressing and sintering and in increasing electrical resistivity and hardness, while yet providing a magnetic material with an initial permeability of at least about 15,000.

Also, where nitridation is carried out, the final sintered and hot-pressed compact is almost void-free, having a porosity of considerably less than 1 vol. % and most generally of not over 0.1 vol %. The method of determining porosity is explained below under the heading "Definitions."

DEFINITIONS

Porosity and Density

The ratio of pore area to total area visible on a polished surface of a sample region of a material under consideration may be obtained by microscopic inspection. (It is known that the area porosity value so obtained is essentially identical to the value of volume porosity for the same sample region.) The term "porosity" as used herein with respect to a given body of sintered material is expressed as a percentage value and is obtained by determining the proportion of pore area to total area for a number of sample areas of the material adequate to provide a reliable indication of the volume porosity for the entire body.

Typical densities for the preferred hot-pressed sintered material whose composition is given herein (about 5.6% by weight aluminum, 9.6% by weight silicon and 84.8% by weight iron) are between about 6.97 and 7.01 grams per cubic centimeter. In general, the preferred hot-pressed sintered materials will have densities greater than the density of a fusion-cast ingot of the same composition and volume. A typical density for a preferred hot-pressed sintered compact would be at least 99.9 percent, corresponding to a porosity of below about 0.1 percent. Such porosities which are substantially less than the porosity of the presently commercially available fusion-cast ingot of the same composition and volume are herein termed "negligible."

Uniform Grain Size

The term "grain size of a substantially constant dimension" or of a "substantially uniform dimension" is used herein to refer to the preferred sintered material and is intended to refer to the relatively markedly improved uniformity of grain size thereof which grain size does not vary by more than plus and minus 50 percent from the mean grain size. Preferably with a mean grain size of about 50 microns, the grain size does not vary by more than about plus and minus 20 percent, that is from about 40 microns to about 60 microns. Essentially, for the preferred material, there is a virtual absence of growth in grain size during sintering from that corresponding to the size of the original alloy particles. Thus, the grain size of the preferred sintered material is virtually identical to that of the original alloy particles over the entire volume of the hot-pressed sintered compact. (A convenient size for the compact is about 4 cubic inches). The rectangular bar formed the compact in accordance with the process of the present invention, would also have a grain size of substantially uniform dimension throughout its volume.

Resistivity of the Bulk Alloy Powder

The reference to the resistivity of the alloy powders after the treatment in the nitrogen atmosphere is herein defined as the resistivity of the powder when compressed between electrodes under a pressure of 2 atmospheres, that is 29.4 pounds per square inch. By way of example, where the iron-silicon-aluminum alloy powder, with a composition of 5.6% by weight aluminum, 9.6% by weight silicon and 84.8% by weight iron, had a resistivity as so measured of 40 Ohm-centimeters, the same alloy powder after the treatment in the nitrogen atmosphere exhibited a resistivity of 30×10^6 Ohm-centimeters (30 megohm-centimeters), when compressed between electrodes with a pressure of 2 atmospheres.

Sintering Temperature

The term "sintering temperature" refers to a temperature close to but below the melting point of the alloy being formed. For example, in the case of an alloy having a melting point of 1,235°C., the sintering temperature is in the range from about 1,205°C. to about 1,220°C.

Ingot

The term "ingot" is used herein to refer to the product of a conventional fusion casting process and to the analogous product formed by compacting and sintering of powdered alloy material. The term denotes a product having a typical density of the fusion cast material or a product formed by sintering but having comparable or even greater density. The term "ingot" as used herein requires an iron-silicon-aluminum alloy mass having a density at least substantially equal to that of fusion cast sendust and a Rockwell hardness of at least C-40. The term "ingot" requires a density of a sintered material of about sendust composition of at least 6.5 grams per cubic centimeter.

Initial Permeability

Sintered materials of a density of at least 6.5 grams per cubic centimeter as contemplated herein may have a direct current permeability (measured with ΔH equals 0.02 oersted on a ring sample with a thickness of 0.350 inch) of at least 6,000, this permeability being defined as "initial permeability" herein.

For examples of sintered magnetic materials which, while not preferred, could be fabricated in accordance with the teachings of the present invention, reference is made to the book *Magnetic Materials* by Tebble and Craik, published in 1969, Table 13. 19 at page 542.

It will be apparent that many modifications and variations may be effected without departing from the scope of the novel concepts and teachings of the present invention.

I claim as my invention:

1. In a magnetic transducer head including a ferrite magnetic core and a pair of magnetic pole tips forming a magnetic circuit with said magnetic core and having a magnetic record medium engaging surface for sliding contact with a magnetic record medium moving successively across said pole tips, the pole tips defining therebetween a coupling gap for coupling of the magnetic circuit with said magnetic record medium, the improvement comprising:

said pole tips being formed of stacks of laminations, said laminations having been machined from an ingot of sintered magnetic material having a composition by weight of from 6% to 12% silicon, 4% to 9% aluminum and the remainder essentially iron, and having a thickness of not more than about 0.008 inch.

2. A magnetic transducer head according to claim 1 with said laminations being formed of hot-pressed sintered magnetic material having a porosity of less than one percent.

3. A magnetic transducer head according to claim 1 with the laminations having been machined from hot-pressed sintered magnetic material exhibiting an initial permeability of about 15,000, and a porosity of less than 1 percent.

4. A composite magnetic transducer head comprising a ferrite magnetic core having magnetic pole tips defining a coupling gap for coupling of the core with a record medium, characterized in that at least one of the pole tips comprises laminations machined from an ingot of hot-pressed sintered iron-silicon-aluminum alloy, said laminations having a mechanical hardness of about Vickers 650 (measured at a 300 gram load) and a thickness of about five to six mils, said laminations having substantially smooth side surfaces, and a bonding layer between the successive laminations and mechanically bonding the laminations as a unitary structure, said laminations having a porosity of less than about 0.1 percent and an initial permeability of about 15,000.

5. A magnetic head comprising a magnetic core having magnetic pole tips defining a coupling gap for coupling of the core with a record medium, characterized in that the pole tips comprise laminations machined from a hot-pressed sintered iron-silicon-aluminum alloy, said laminations having a mechanical hardness of about Vickers 650 (measured at a 300-gram load) and a thickness of less than eight mils, said laminations having lapped side surfaces which are substantially flat and smooth, and a bonding layer between successive laminations mechanically bonding the laminations as a unitary structure and having a thickness of less than 300 microinches, said laminations having an initial permeability of about 15,000.

6. A magnetic head according to claim **5** with said laminations of said alloy having been annealed in a vacuum furnace by raising the temperature of the heating chamber thereof from about room temperature to a temperature of about 800°C. in from about ½ hour to about **1** hour and then allowing the heating chamber to cool back to room temperature at an unforced rate.

7. A magnetic head in accordance with claim **6** wherein the laminations of said hot-pressed sintered iron-silicon-aluminum alloy have been given a rapid dip acid treatment subsequent to the annealing thereof.

8. A composite multitrack magnetic transducer head assembly comprising

a support bracket having a series of ferrite magnetic cores therein, the cores having respective pairs of edge faces all lying substantially in a common plane,

a pole tip assembly comprising a plate secured to said bracket and having secured thereto a series of pairs of pole tips with undersurfaces lying in closely spaced confronting relation to the respective edge faces to define respective head units for cooperation with respective channels of a magnetizable layer of a magnetic record medium,

said pole tips each comprising a series of laminations machined from an ingot of iron-silicon-aluminum alloy having a hardness of at least about Rockwell C–40, and

means providing an electrically insulating layer between said undersurfaces of said pole tips and the edge faces of said ferrite magnetic cores.

9. A multitrack magnetic transducer head assembly according to claim **8** with said laminations having been machined from hot-pressed sintered magnetic material and having been annealed and then etched with a viscous acid solution subsequent to annealing, the laminations of each pole tip assembly having successive bonding layers therebetween mechanically bonding the laminations as a unitary structure and providing a substantially uniform spacing between the successive laminations of less than 300 microinches.

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