United States Patent [19]
Camras

[11] **3,713,212**
[45] **Jan. 30, 1973**

[54] METHOD OF MAKING A TRANSDUCER HEAD

[75] Inventor: **Marvin Camras**, Glencoe, Ill.

[73] Assignee: **IIT Research Institute**, Chicago, Ill.

[22] Filed: **Nov. 18, 1970**

[21] Appl. No.: **90,773**

Related U.S. Application Data

[62] Division of Ser. No. 746,651, July 22, 1968, Pat. No. 3,582,572.

[52] **U.S. Cl.** ....**29/603,** 29/609, 148/112, 179/100.2 C
[51] **Int. Cl.** **G11b 5/42, H01f 7/06**
[58] **Field of Search** ....29/603, 609; 179/100.2 C; 340/174.1 F; 346/174 MC; 148/112

[56] **References Cited**

UNITED STATES PATENTS

3,542,971	11/1970	Willard	179/100.2 C
3,158,516	11/1964	Walter et al.	148/112 X
3,222,461	12/1965	Wood et al.	179/100.2 C
3,271,718	9/1966	Shaw	29/603 UX
3,454,728	7/1969	Siegemund	29/603 X
3,171,107	2/1965	Rogers, Jr.	340/174.1 F
3,311,711	3/1967	Maryatt et al.	179/100.2 C
2,694,754	11/1954	Connell	179/100.2 C
3,504,134	3/1970	Miyata	29/603 X
3,240,638	3/1966	Wiener et al.	148/112
2,736,776	2/1956	Camras	29/603 UX

Primary Examiner—Charles W. Lanham
Assistant Examiner—Carl E. Hall
Attorney—Hill, Sherman, Meroni, Gross & Simpson

[57] ABSTRACT

A method of making a magnetic transducer head or element thereof from a binary alloy of silicon and iron, preferably containing from about 3 percent to 7 percent of silicon by weight, including provision of a grain-oriented silicon-iron core, annealing the core at a temperature above the Curie point in a dry hydrogen atmosphere and during cooling from that temperature subjecting the core piece to a magnetic field applied in the direction of the working flux at the core. The annealed core piece is formed so as to provide a gap-defining face for coupling to a magnetic record medium, the gap being of the order of about 1 micron.

4 Claims, 12 Drawing Figures

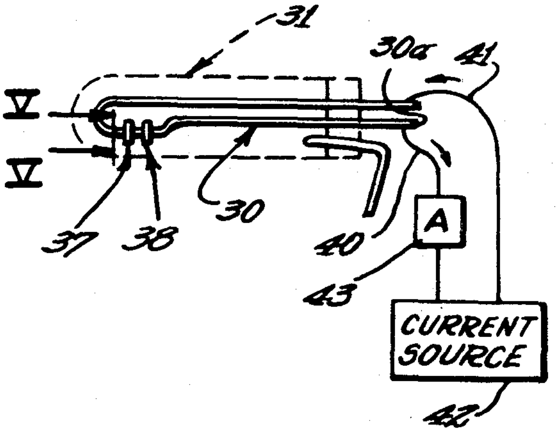


Fig. 1

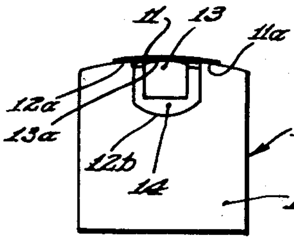


Fig. 2

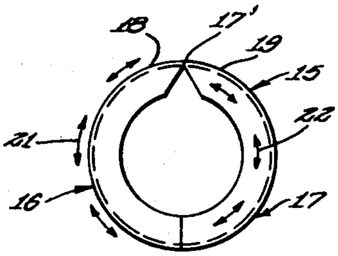


Fig. 3

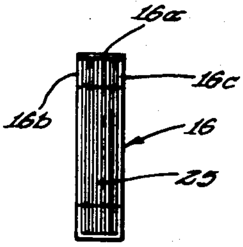


Fig. 4

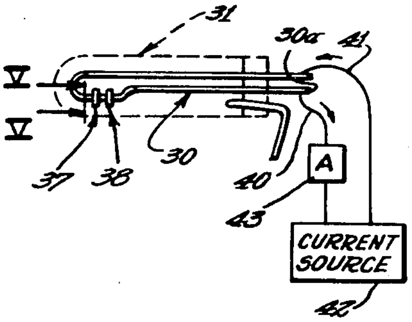


Fig. 6

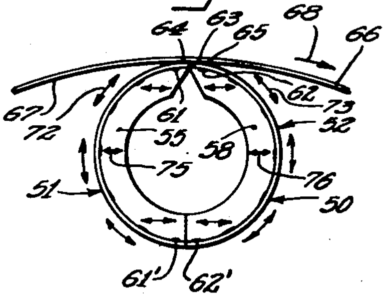


Fig. 7

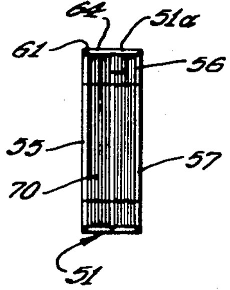


Fig. 5

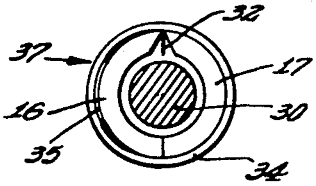


Fig. 8

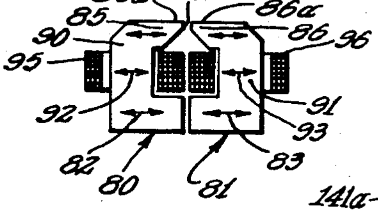


Fig. 9

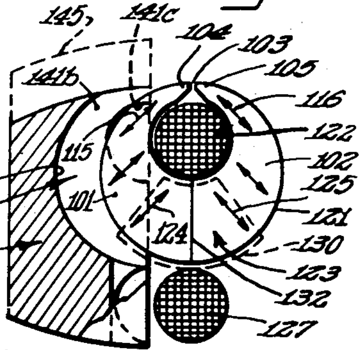


Fig. 12

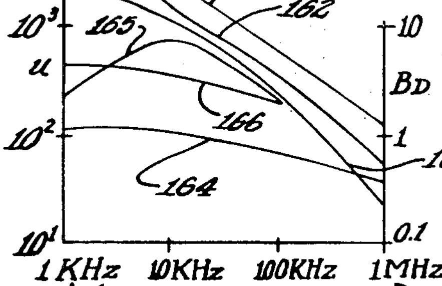


Fig. 10

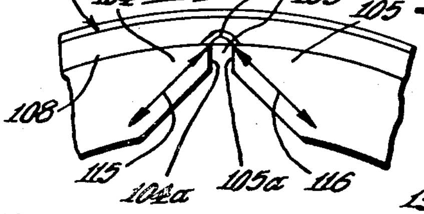
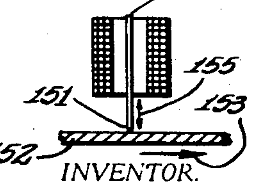


Fig. 11



INVENTOR.

Marvin Ca

BY

ATTORNEYS

METHOD OF MAKING A TRANSDUCER HEAD

CROSS REFERENCES TO RELATED APPLICATIONS

This application is a division of my co-pending application Ser. No. 746,651, filed July 22, 1968 now Pat. No. 3,582,572.

SUMMARY OF THE INVENTION

Contrary to earlier conclusions I have now found that superior heads can be made of binary alloys of silicon and iron, the silicon being preferably in the range from about 3 percent to 7 percent by weight, and the balance, except for the usual impurities, being essentially iron. In the fabrication of such binary alloys into pole pieces advantage is taken of the grain-orientation in the strips of silicon-iron alloy used. In accordance with my method, the grain-oriented strips of silicon-iron alloy are subjected to annealing at temperatures above the Curie point, and during cooling of the strips from the annealing temperature used they are subjected to a magnetic field at temperatures below the Curie point, with the direction of the magnetic lines of force in the same direction as the grain-orientation.

Heads such as disclosed herein give better defined gaps than obtained using "Permalloy" or the like when the gap size is below 100 microinches as for example 40 (1 micron), 20, or 10 microinches or even smaller. The gaps are maintained after long tape usage while gaps of "Permalloy" may smear across and become magnetically short circuited.

When the head pole pieces are of preferred material as taught herein and are mounted in a support made of material that wears more rapidly, the tape support area of the head acquires and maintains a laterally crowned contour with the pole pieces at the highest point. This insures excellent contact between head and tape at the gap, which is extremely important at short wave lengths. Wave lengths less than 0.000,025 inch long were recorded and played back with these heads.

The silicon-iron alloy poles remain clean after passage of tape across them and do not have an affinity for metallic and non-metallic accumulations that separate the tape from the gap.

Silicon-iron pole pieces have a longer life than those made of "Permalloy" by a factor of several times. They can be made with a lesser gap depth while the poles are still adequately supported because the metal is stronger, and will still have a long life before wearing through. The heads described herein may be made with a gap depth of 1 mil (.001 inch), increasing their efficiency especially at gap lengths of less than 40 microinches (1 micron), which is considered to be the microgap region of special interest in the present specification.

Magnetic saturation densities of 20 kilogauss or more are obtainable with silicon-iron alloys in the lower range of silicon content. Even at the higher limits of silicon-content the saturation density exceeds 10 kilogauss. By comparison, the saturation density is 5 to 8 kilogauss in "Mumetal" and "Permalloy," and with about 1.5 to 3 kilogauss in ferrites. A high saturation density did not prove advantageous in prior art heads and was therefore not considered important. In microgap heads which are to be used for recording it has been found that pole pieces according to this invention allow higher signal levels to be recorded than with prior art heads of the same microgap size.

The improved heads are especially suitable for economical video recorders of the fixed head longitudinal scan type, since they give high performance in the megahertz range, are economical to construct, and have a long life. A single head can be used for both recording and playback. At 60 inches per second tape-to-head speed, a response to 2.5 megahertz was obtained.

Other objects, features and advantages of the present invention will be apparent from the following detailed description taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a transverse view showing a magnetic head in accordance with the present invention in end elevation and indicating the tape record medium in cross-section;

FIG. 2 is a somewhat diagrammatic side elevational view illustrating a first magnetic core configuration in accordance with the present invention;

FIG. 3 is an end elevational view of a core piece for the core configuration of **FIG. 2**;

FIG. 4 illustrates apparatus for applying a magnetic field to a magnetic core part such as illustrated in FIG. 3 during the annealing of such core part;

FIG. 5 is a somewhat diagrammatic cross-sectional view taken generally along the line V—V of **FIG. 4**;

FIG. 6 is somewhat diagrammatic side elevational view of a second form of core configuration in accordance with the present invention;

FIG. 7 represents an end elevational view of one of the core parts of the core configuration of **FIG. 6**;

FIG. 8 illustrates a third form of core configuration in accordance with the present invention,

FIG. 9 illustrates a further form of magnetic transducer head in accordance with the present invention;

FIG. 10 is an enlarged somewhat diagrammatic detail view showing the gap region of the head of **FIG. 9**;

FIG. 11 illustrates a still further form of head construction in accordance with the present invention; and

FIG. 12 illustrates approximate comparative flux densities and permeabilities as a function of frequency for "Supermalloy," 6.5 percent silicon-iron and 3 percent oriented silicon-iron.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates a magnetic transducer head **10** having a tape record medium **11** with its magnetizable surface layer **11***a* in sliding contact with the head. The head is shown as comprising a housing **12** having tape contacting surfaces such as indicated at **12***a* and having an aperture **12***b* exposing a magnetic core **13**. As illustrated in FIG. 1, when the tape contacting surfaces **13***a* of the magnetic core **13** are made of my preferred silicon-iron alloy and the housing surface **12***a* is of a material that wears more rapidly, the tape support area of the head acquires and maintains a laterally crowned contour as shown in FIG. 1, with the tape engaging surface **13***a* at the highest point. This insures excellent contact between the head **10** and tape **11** at the gap (the plane of the gap being parallel to the plane of FIG.

1). Wavelengths less than 0.000,025 inch long were recorded and played back with a head construction such as shown in FIG. 1. In this embodiment, the head core 13 is embedded in insert blocks such as 15 of silver or other highly conductive material. The tape contacting surfaces 12*a* of housing 12 may be of silver, brass, "Mumetal," or other material that wears more rapidly than the silicon-iron alloy providing the tape engaging surface 13*a* of core 13.

FIGS. 2 and 3 illustrate a head core 15 including core pieces 16 and 17. As indicated in FIG. 3, each of the core pieces may have a gap defining face 16*a* and may have a generally channel cross-section with integral lateral flanges 16*b* and 16*c*. The gap defining faces such as 16*a* define a non-magnetic gap 17′ for coupling of the core with a magnetic record medium traveling successively across the polar surfaces 18 and 19, for example in the same way as contemplated in FIG. 1.

The core pieces 16 and 17 are made of a 3 percent grain-oriented silicon-iron sheet material having a thickness of about 2 to 4 mils (1 mil equals 0.001 inch) obtainable from Allegheny Ludlum Steel Company under the name "Silectron." The curved portions of the core pieces are in the direction of grain orientation with the preferred direction being indicated by arrows such as 21 and 22 in FIG. 2.

FIGS. 4 and 5 illustrate apparatus for applying a magnetic field to the core pieces 16 and 17 during annealing treatment. The core pieces 16 and 17 may be assembled on a loop 30 of non-magnetic stainless steel wire of about one-sixteenth inch diameter held inside a heat treatment chamber indicated at 31. As indicated in FIG. 5, a gap spacer 32 is inserted between the polar edge faces such as 16*a*, FIG. 3, and the C-shaped core pieces 16 and 17 are nested inside a ring 34 of non-magnetic material such as stainless steel, held securely by means of a wedge such as indicated at 35 if necessary. One or more of these nests are strung onto the loop 30 as indicated at 37 and 38 in FIG. 4 (the nest shown in FIG. 5 being designated by the reference numeral 37). The loop 30 is electrically connected by means of conductors 40 and 41 with an electrical current source 42 which may be capable of supplying an electrical current of 8 to 12 amperes as measured by an ammeter 43.

FIGS 6 and 7 illustrate a head core 50 made of 6½ percent silicon-iron of composition 6.5 percent silicon and the balance iron and minor impurities. Such material is too brittle to be formed as in FIGS. 2 and 3. It is therefore built up by bending strips of silicon-iron into C-shaped side pieces such as indicated at 55 and 58 in FIG. 6 and at 55, 56 and 57 in FIG. 7. The side pieces are spot welded to the generally arcuate interior surface of core pieces 51 and 52 as indicated at 61, 62, 61′ and 62′, for example, in FIG. 6. Good welds should be obtained as close to the gap 63 as possible. The core pieces 51 and 52 provide polar end faces such as indicated at 51*a* in FIG. 7 defining the opposite boundaries of the non-magnetic gap 63. Polar tape engaging surfaces are indicated at 64 and 65, and a tape record medium is indicated at 66 having a magnetizable oxide layer at 67 which is in sliding contact with surfaces 64 and 65 and moves in the direction indicated by arrow 68. The core pieces 51 and 52 may be of identical construction and are preferably filled with laminations 70, FIG. 7, whose configuration corresponds to that of the side pieces such as 55 and 58, FIG. 6. The laminations 70 are of high permeability material such as "Supermalloy" having a composition of 5percent molybdenum, 79 percent nickel and the remainder iron and minor constituents. The material of the laminations has the lowest possible coercive force and the laminations are insulated with magnesium oxide from each other and from the silicon-iron material.

The core pieces 51 and 52 may be formed from grain oriented sheet material such as the silicon-iron binary alloy above described, having a thickness of 4 mils and having a rolling direction as indicated by the arrows such at 72 and 73 (FIG. 6), so that when the core pieces are bent into the generally arcuate shape the preferred direction follows the circumference of the core (which is in conformity with the direction of the working magnetic flux path in the core). The side pieces such as 55 and 58 (FIGS. 6 and 7) may also be formed from oriented sheet material with a preferred direction as indicated by arrows such as 75 and 76.

FIG. 8 illustrates a head construction wherein core pieces 80 and 81 are formed from the above-mentioned oriented silicon-iron sheet material with preferred directions as indicated by arrows such as 82 and 83. The core pieces 80 and 81 may be built up from a series of C-shaped laminations of identical configuration having respective extremities such as indicated at 85 and 86 defining a gap 87 across which a tape record medium moves in sliding contact with surfaces such as indicated at 85*a* and 86*a* as in the previous embodiments. The polar portions 85 and 86 have a width dimension (in the vertical direction as viewed in FIG. 8) which progressively increases in the direction away from the gap 87. The core pieces have intermediate portions as indicated at 90 and 91 which are of substantially greater width (here measured in the horizontal direction as viewed in FIG. 8) in comparison with the width dimension of the extremities 85 and 86. At the intermediate portions 90 and 91, the preferred direction as indicated by arrows 92 and 93 is cross-wise to the direction of the working magnetic flux path of the core, and electric windings 95 and 96 are preferably located on the intermediate portions 90 and 91 of the core pieces 80 and 81.

FIGS. 9 and 10 illustrate a further head construction wherein core pieces 101 and 102 define a coupling gap 103 and have pole pieces 104 and 105, FIG. 10, across which a tape record medium 107 moves in the direction of arrow 108′. As in each of the other embodiments, the tape 107 has a magnetizable layer 108 which is in sliding contact with polar surfaces of the pole pieces 104 and 105 in the vicinity of the gap 103. In each of the embodiments, the layer 108 may be formed of iron oxide particles in a non-magnetic binder and exhibiting a coercivity of at least 200 oersteds. In each of the embodiments, the tape may move in the direction of the arrow 108′ at a speed of 30 inches per second or at a speed of 60 inches per second. The gap 103 is considered to have a depth which is measured in the vertical direction as viewed in FIG. 10 and is determined by the vertical dimension of the gap defining faces 104*a* and 105*a* of the pole pieces 104 and 105. The direction of the working magnetic flux path of the core in the gap region is indicated by the flux line 110, FIG. 10.

The core pieces **101** and **102** (FIG. 9) may be formed from a series of generally C-shaped laminations which are stamped from grain oriented flat sheet silicon-iron material. In this embodiment, the preferred direction of magnetization is at an oblique angle, for example about 45° to the horizontal as viewed in FIG. 9, and pointed toward the gap edges as indicated by arrows **115** and **116**, for example. As shown in FIG. **10**, the working magnetic flux path in the pole tips **104** and **105** generally conforms with the preferred direction of magnetization as indicated by arrows **115** and **116**, and the direction of arrows **115** and **116** is in close conformity with the magnetic field direction inside the record medium as indicated by flux line **110** (FIG. **10**).

In FIGS. **9** and **10**, the core pieces **101** and **102** may be made of 3 percent grain oriented silicon-iron and may comprise a stack of identical laminations 1 mil thick with the direction of orientation as indicated by the arrows **115** and **116**. The exterior perimeter of the core formed by the assembly of core pieces **101** and **102** may have an outer perimeter **121** which is circular, and may have an inner perimeter as indicated at **122** which is also circular that is offset in the direction towards the gap **103** relative to the circle defined by the outer perimeter **121**. The result is a configuration with a base region **123** of substantially greater cross-sectional area and flux carrying capacity than other portions of the core, the preferred direction as indicated by arrows **124** and **125** in the base region being generally transverse to the direction of the working magnetic flux path. The circular window defined by inner perimeter **122** accommodates a doughnut-shaped winding **127** which is of larger volume at the region thereof within the inner perimeter **122** than the volume of the pole pieces **104** and **105** considering the volume of the pole pieces which is directly above the cross-section of the winding **127** as viewed in FIG. **9**.

To reduce the reluctance of the base portion **123** of the core of FIG. **9** still further, a channel-shaped piece may be added as indicated in dash-outline at **130** in FIG. **9**. In the embodiment of FIG. **9**, the channel-shaped piece **130** would have a bight portion conforming in contour to the external perimeter **121**, and would have respective planar portions extending vertically as viewed in FIG. **9** at opposite sides of the core and in contacting relation with the outer faces of the respective end laminations forming the core pieces **101** and **102**. The channel-shaped piece **130** may bridge across the back gap **132** between core pieces **101** and **102**, or it may be cut and lapped so as to provide a gap corresponding in configuration with the back gap **132** of the core.

As indicated in FIG. **9**, the core pieces **101** and **102** may each be mounted in a cavity such as indicated at **140** in an electrically conductive mounting block **141**. The generally arcuate face **141*a*** of the block **141** has the same radius of curvature as the outer perimeter of **121** so as to provide a layer of electrically conductive material in close conforming relation to the exterior perimeter of the core piece **101**, the core surface being insulated to avoid excessive eddy current loss. The lateral surfaces such as **141*b*** may also be disposed in close conforming relation with the core particularly at the upper portion thereof at each lateral side of the core piece **101**. The mounting block **141** may be suitably recessed as indicated at **141*c*** to accommodate the winding **127** and the channel-shaped piece **130**. The portion of the mounting block **141** indicated at **145** may be removed during the final finishing operation so as to expose the tape engaging surfaces of the pole pieces **104** and **105**.

FIG. **11** illustrates diagrammatically a single pole piece **150** having a polar extremity **151** for coupling with a magnetic tape record medium **152** moving in the direction of arrow **153**. The pole extremity **151** has a polar tape-engaging surface in sliding contact with the surface of the magnetizable layer of the record medium **152**. The core piece **150** may be made of a flat strip of oriented silicon-iron, the preferred direction of orientation being in the direction of arrow **155**. The properties may be further enhanced by heat treatment in a linear magnetic field also in the direction of arrow **155** using an alternating current magnetic field with a frequency of 60 cycles per second and providing an r.m.s. value of magnetizing force of about 15 oersteds. Substantially higher frequencies may be used instead, or direct current magnetic field may be applied to provide a direct current of magnetizing force of about 15 oersteds.

FIG. **12** compares typical magnetic characteristics of "supermalloy"6.5 percent silicon-iron, and 3 percent oriented silicon-iron, at various frequencies useful in magnetic heads. The measurements were taken using flat washer-like samples of the material which were stamped from flat sheet material having a thickness of 4 mils. The permeability (*u*) measurements were taken at a field of 0.1 oersted r.m.s. in all cases, and the B_D readings represent the highest level (in kilogauss) where an undistorted output was obtained. The oriented 3 percent silicon-iron sample had an orientation somewhat analagous to that indicated by the arrows associated with side pieces **55** and **58** in FIG. **6**. A curve **161** shows the permeability variation of the "Supermallov" sample; curve **162** shows the permeability variation for 6.5 percent silicon-iron; and curve **163** shows the permeability variation for 3 percent oriented silicon-iron. Curve **164** shows the B_D variation for "Supermalloy"; curve **165** shows the B_D variation for 6.5 percent silicon-iron; and curve **166** shows the B_D variation for 3 percent oriented silicon-iron.

Although "Supermalloy" has the highest permeability, the lower permeability of the silicon irons has proved to be adequate in actual heads. It will be noted that the B_D values for the silicon-iron materials are much better than are those for the "Supermalloy." The readings for the oriented silicon-iron in FIG. **12** are for a sample having all directions of orientation with respect to the working flux path of the sample, so that these readings would be higher if taken for a sample where the preferred direction conformed with the direction of the working magnetic flux path throughout the sample.

Apparently the silicon-iron heads having a relatively high magnetic saturation are of best advantage when used with high coercive record materials as represented by modern magnetic oxide surfaces with coercive forces above 200 oersteds, for example 225 oersteds or higher, and make it possible to record efficiently on record materials with coercive forces above 350 oersteds which have not been practical except in very thin coatings.

Iron-cobalt alloys of 50 percent iron and 50 percent cobalt composition, and improved versions containing 49 percent iron, 49 percent cobalt, and 2 percent of vanadium also have exceptionally high magnetic saturation, but are more expensive and difficult to produce than are silicon-iron alloys.

The following Table I gives some properties of silicon-iron alloys, the values being intended to be typical for the percentages of silicon indicated. It is notable that the resistivity is a maximum at about 11 percent silicon content; a high resistivity being advantageous for low eddy current losses. The Curie point is useful in specifying the temperature below which the magnetic field must be applied, for example with the apparatus of FIGS. **4** and **5** during the magnetic anneal process; for example 1,380° F. for 3 percent silicon material, and 1,270° F. for 6½ percent silicon material. Also the annealing temperature should be above the Curie point for the material. Saturation magnetization (for an applied direct current magnetizing force) decreases with increasing silicon content, but is high in all cases compared to previously used 79 percent nickel material such as "Permalloy." Values not specified in Table I can be interpolated.

TABLE I

Typical Characteristics of Silicon Iron Materials

% Si	Resistivity microhm cms	Curie Point °F.	(D.C.) B sat.	Hardness Rockwell (B2 Scale)
0	10	1420	22 000	
0.25	15	1420		
0.5	18			38
1.0	23		21 500	50
2.0	34			
2.5	40			
3.0	45	1380	20 500	79
4.25	58		19 500	86
4.75	65		19 000	
6.5	82	1270	18 000	
8.0	92		17 000	
10	99			
11	102		15 000	
12	92			
14	52			
15	42	990		

By way of comparison, typical values for "permalloy" are a resistivity of 55 microhm-centimeters, a Curie point of 1,100° F., a $B_{sat.}$ of 7,300 gauss and a Rockwell Hardness of 30.

It has been found that at frequencies of 100 kilohertz and above there is a marked skin effect in the pole pieces, with only the outer layers carrying the magnetic flux. Advantage has been taken of this effect in the illustrated head designs where the high saturation capability of the silicon iron material increases the high frequency flux at the tape surface. These heads operate at high megahertz frequencies which were previously considered possible only with ferrite cores.

While oriented materials as for example American Iron and Steel Institute M-4 through M-10 silicon irons are preferred, successful experiments have also been made with non-oriented silicon irons. Examples of non-oriented silicon irons are AISI types M-15, M-19 , M-22, M-27 and M-36.

Filler laminations such as indicated at **25** in FIG. **3**, and at **70** in FIG. **7** may range from 0.5 to 4 mils in thickness and are helpful in reducing residual magnetization and improving the flux carrying capacity. They may be omitted for economy.

It has been considered that a high initial permeability is essential for pole pieces used in magnetic heads. Heads described herein have given excellent results, however, although the initial permeability was not especially good. The reasons for this may relate to local effects due to illustrated head constructions including skin effects at high frequencies, and to other properties inherent in the head configurations herein specifically disclosed.

When annealing the illustrated core constructions in a magnetic field, for example as represented in FIGS. **4** and **5**, it is desirable to place the core pieces in a magnetic circuit configuration similar to that of the final assembly and to include a gap spacer as indicated at **32** in FIG. **5** so that the field during annealing follows the direction of the working magnetic flux path of the head in actual use even down to the fine details as at the gap. The gap spacer may be of a non-magnetic stainless steel or of platinum, or of "Inconel" (which has a composition of approximately 80 percent nickel, 14 percent chromium, and 6 percent iron), so as to withstand the high annealing temperatures.

For the recommended anneals to be effective, it is important that the silicon iron having a low carbon content of less than 0.05 percent, and preferably about 0.02 percent or below.

A typical winding for the illustrated core constructions would have a top portion with 50 turns of No. 40 AWG wire, and a bottom portion of 150 turns of No. 42 AWG wire, both wound together in a doughnut shape such as shown at **127** in FIG. **9**.

As illustrated in the Table I, magnetic saturation densities of 20 kilogauss or more are obtainable with silicon-iron in the lower range of silicon content. Even at the higher limits of silicon content the saturation density exceeds 10 kilogauss. These values compare with saturation densities of 5 to 8 kilogauss in "Mumetal" and 79 percent material such as "Permalloy" and with saturation densities of about 1.5 to 3 kilogauss in ferrites. A high saturation density did not prove advantageous in prior art heads and was therefore not considered important. In microgap heads (where the gap dimension is of the order of 1 micron or less) which are to be used for recording, it has been found that pole pieces formed according to this invention allow higher signal levels to be recorded than with prior art heads of the same microgap size.

The improved heads are especially suitable for economical video recorders of the fixed head longitudinal scan type, since they give high performance in the megahertz range, are economical to construct, and have a long life. A single head such as those illustrated in any of the embodiments herein, can be used for both recording and playback. At 60 inches per second tape to head speed, a response to 2.5 megahertz was obtained.

Heads made according to the following examples give better defined gaps than "Permalloy" when the gap size is below 100 microinches as for example 40, 20 or 10 microinches or even smaller. The gaps are maintained after long tape usage while gaps of "Permalloy" may smear across the gap so as to provide a magnetic short circuit between the pole pieces. Wavelengths less than 0.000,025 inch (25 microinches) long were recorded and played back with the heads described herein.

The following examples illustrate preferred practice; features of the various examples may be combined or used separately if desired.

EXAMPLE 1 (FIGS. 2 and 3)

The core **15** comprises core pieces **16** and **17** of a 3 percent grain-oriented silicon-iron alloy 4 mils thick obtainable from Allegheny Ludlum Steel Company under the name "Silectron." The curved portions of the core pieces **16** and **17** are in the direction of grain orientation with the preferred direction as indicated by arrows **21** and **22** and have an outer diameter of 110 mils and an inner diameter of 70 mils. The 3 percent silicon material is quite malleable and is readily shaped to the channel cross section as shown in FIG. 3. The inner portion of the channel is filled with crescents of "Supermalloy," as indicated at **25** of 1 mil thickness insulated from each other by thin layers of magnesium oxide. In the same way the channels themselves are also insulated on all surfaces. The filled core pieces **16** and **17** are then annealed in an atmosphere of dry hydrogen, holding at a temperature of 2,000° F. for 15 minutes or more, and cooled slowly over a period of several hours. The core pieces **16** and **17** are cemented into close fitting cavities such as indicated at **140** in FIG. **9** provided by insert blocks such as indicated at **141** in FIG. **9** made of silver. The silver insert blocks may in turn fit into recesses in mating mounting blocks of brass which in turn may be enclosed within a one-piece housing shell of magnetic material similar to that indicated at **12** in FIG. **1** with a separate bottom closure part. As indicated in FIG. **1**, the silver insert blocks corresponding to the material **14** in FIG. **1** may be recessed below the tape engaging surfaces **12***a* and **13***a*. In this construction, the core pieces **16** and **17** are secured in separate mounting blocks with the mating faces lapped to an optical finish, then assembled with a beryllium copper gap spacer at **17**, FIG. **2**, having a thickness of approximately 18 microinches and placed between the upper gap defining faces such as indicated at **16***a*, FIG. **3**, with a coil of 200 turns placed around the lower extremities of the core pieces **16** and **17** generally as indicated for the winding **127** in FIG. **9**. The assembly is mounted in a casing which may be of "-Mumetal" corresponding to casing **12**, FIG. **1**, the projecting tape engaging surfaces **18** and **19** of the pole pieces being lapped to expose the gap **17**′ to the active surface such as indicated at **11***a* of the tape record medium **11** indicated in FIG. **1**.

A head made with two side-by-side cores each 21 mils wide, to provide a 42 mil wide track has an inductance of about 2 millihenries with a 200 turn coil when measured at a frequency of 1 kilohertz. This is one-half the inductance of a similar head made of "Supermalloy," yet the output of this head equals or exceeds that of the "Supermalloy" head under conditions of bias signal optimized for "Supermalloy." More turns can thus be used on the silicon-iron head for increased output without exceeding limitations caused by head resonance. A high saturation value is noted, with permeability as a function of magnetizing force still rising at an excitation of 4 ampere-turns.

For video recording, the above head with a 50 turn tap on the 200 turn winding to provide a 50 turn recording winding, gives excellent response to signal frequencies up to 2 megahertz and up to bias frequencies of 7 megahertz using quarter inch tape at 60 inches per second tape-to-head velocity.

EXAMPLE II (FIGS. 6 and 7)

A head of overall dimensions the same as in Example I is made of an alloy of 6.5 percent silicon, and 93.5 percent iron and minor constituents, which is 4 mils thick, obtainable from Westinghouse Electric Corp. This material is not malleable enough to bend into a form such as that illustrated in FIG. 3. It is therefore built up by welding as described in connection with FIGS. **6** and **7** heretofore. The rolling direction of the core pieces **51** and **52** is as indicated by the arrows such as **72** and **73**, the core pieces being bent to their curvature with the preferred direction following the circumference. The inner C-shaped side pieces such as indicated at **55** and **58** in FIG. **6** are cut or punched from a flat sheet and are oriented with a preferred direction favoring the gap flux as indicated by the arrows such as **75** and **76**. Other directions, however, are operative. Spot welds such as those indicated at **61** and **62**, FIG. **6**, fasten the side pieces such as **55–58** to the respective core pieces **51** and **52**. This silicon-iron material welds very easily using miniature equipment such as is common for transistors and integrated circuits. Welds close to the top and bottom of the side pieces are important, welds near the base of the core of FIG. **6** being indicated at **61′** and **62′**. More sides pieces can be welded in positions between the side pieces such as indicated at **55**, **56** and **57** in FIG. **7** to improve the strength and magnetic efficiency of the head. The pockets between the side pieces **55–58** are filled with laminations **70** of "Supermalloy,"and the core configuration is heat treated in hydrogen as in Example I. Other details of finishing are also as in Example I.

The inductance of this head is higher and its saturation flux density lower than that of Example I, but still considerably better than for a comparable head of "Supermalloy." High resistivity improves the loss factor at high frequencies. The extra hardness improves gap definition and wear resistance. Response is to 2.5 megahertz at 60 inches per second head-to-tape velocity.

In each of the examples, the various forming operations are preferably carried out before annealing, except for the final polishing or lapping. Good welds should be obtained as close to the gap **63** as possible, so as to give maximum support to the gap defining surfaces such as indicated at **51***a*, FIG. **7**. the laminations **70** for Example II preferably have the lowest possible coercive force, for example, as provided by "Supermalloy" material. The gap spacer providing the gap **63** is of beryllium copper having a thickness from 60 microinches down to 12 microinches or less in Example II.

The permeability of this silicon-iron material is close enough to that of "Supermalloy" so that performance of the Example II silicon-iron head in the video range is completely satisfacotry. The head gives better results than "Supermalloy" when extremely small gap spacers are used. This is attributed to the freedom from mushrooming or smearing of the core material at the defining faces, causing the gap to be bridged where the tap rides over it. Soft materials such as "Permalloy" are susceptible to this effect when the gap is very small. Microscopic observation confirmed these effects.

Another reason for better operation with extra small gap dimension is that the saturation flux density of the 6.5 percent silicon-iron (approximately 10 kilogauss or more) is considerably higher than with the "Supermalloy" material, so that higher recording fields are achieved for very small gap sizes where the leakage flux directly between the confronting gap defining faces causes the core to saturate at relatively modest fields during recording. The high resistivity of 6.5 percent silicon-iron (approximately 80 microhm-centimeters) reduces eddy current losses at high frequencies.

The above advantages are most evident with small gap heads of a gap thickness of 100 microinches or below, and especially with microgap heads with gap dimensions, according to Example II, below 40 microinches (1 micron). An experimental head, according to Example II, with a 14 microinch gap of beryllium copper gives excellent results for video recording at 30 inches per second and at 60 inches per second head-to-tape velocity, using a bias frequency of 6.5 megahertz and video frequencies up to 2.5 megahertz.

A range of heat treatment temperatures was tried for the materials of Example II, above and below the specific temperature of 2,000° F. but the results were optimum at 2,000° F. It is advantageous to cool the core while a magnetic field is applied to it in the direction of magnetization of the working flux as described in connection with FIGS. **4** and **5**. This may be accomplished by supplying a direct current of about 10 amperes to conductor loop **30**, FIG. **4**, while the core cools from 1,500° F. in a hydrogen atmosphere.

Examples I and II utilize the magnetic tapes with oxide surface layers having a coercive force on the order of 225 oersteds.

EXAMPLE III

The pole piece material and procedure are the same as in Example II, except that for the annealing of the core parts they are nested inside a ring of non-magnetic stainless steel as indicated at **34** in FIG. **5**, and held securely with a wedge **35**, if necessary. The stainless steel is type 302 (18 percent chromium, 8 percent nickel and the balance iron). The loop of stainless steel wire has a cross-section about one-sixteenth inch in diameter and is held within the heat treatment chamber **31** as illustrated in FIG. **4**. Sixty cycle per second alternating current having an r.m.s. value of 8 to 12 amperes as measured by ammeter **43** passes through the loop **30**, especially during the cooling cycle until the core parts have cooled to below 500° F. This gives a magnetizing force of about 15 oersteds r.m.s. in the pole pieces, the exact value being non-critical.

Annealing by this procedure gives a higher magnetic permeability than in Example II where the magnetic field treatment is omitted. High frequencies may also be used for the current source **42** with beneficial results.

EXAMPLE IV

The same process is used as in Example III but with a direct current having a value of the order of 8 to 12 amperes. A higher magnetic permeability is also obtained, in comparison to the results in Example II without the magnetic field treatment.

EXAMPLE V

A head structure is made having laminations of configuration corresponding to that of side pieces **55** and **58** in FIG. **6**, with the preferred directions of magnetization in successive laminations arranged generally at right angles to each other, such that preferred directions as illustrated by arrows **75** and **76** in FIG. **6** for one lamination are generally horizontal, while the preferred directions for the adjacent laminations on either side are generally vertical, so that the permeability of the overall assembly is improved at the intermediate portion of the core parts where the orientations **75** and **76** are crosswise to the direction of the working magnetic flux path. The laminated head of this Example is similar to the head of FIG. **9** except for the exact configuration of the laminations. Twenty laminations of 2 mil thickness are used to form each core piece.

The laminations are of 6.5 percent silicon-iron and have a thin surface layer of magnesium oxide for insulation and are annealed in hydrogen at 2,050° F. When cool they are transferred to a block such as indicated at **141**, FIG. **9**, having a close fitting cavity such as **140** of high electrical conductivity, the cavity being coated on its surface with a thin layer of epoxy resin, such that the laminations are held at their outer edge and are not subjected to stresses that occur when the sides of the laminations are adhered together. A pair of blocks such as **141** are finished as indicated previously, using an 18 microinch gap spacer. The head made in this way is very efficient at high bias frequencies exceeding 7 megahertz, and gives excellent signal response at 2 megahertz.

Where oriented material is used with the preferred direction lined up as illustrated in FIG. **8**, the overall permeability is improved by increasing the cross-section of the core pieces at the intermediate regions **90** and **91**. The coils **95** and **96** are preferably associated with the core pieces at the intermediate regions **90** and **91** where the direction of orientation as indicated by arrows **92** and **93** is transverse to the working magnetic flux path of the core, so that the magnetomotive force loss of these poorer regions **90** and **91** is supplied by the immediate source of magnetomotive force; while the best permeability portions are used at the pole pieces **85** and **86** so as to channel the magnetic flux to the working gap **87** with minimum loss.

The directional properties are used to advantage in the construction of FIG. **9** where the preferred direction of magnetization is at an oblique angle (as for example about 45°) **as indicated by arrows** 115 **and** 116 **which as indicated in FIG.** 10 **are pointed toward the gap edges of pole pieces** 104 **and** 105. **As shown in FIG.** 10 **the arrows** 115 **and** 116 **have direction which is in close conformity with the magnetic flux path** 110 **inside the magnetizable layer** 108.

EXAMPLE VI

The head core pieces are made of 3 percent grain oriented siliconairon (Silectron) in laminations 1 mil thick, with the direction of orientation as indicated in FIGS. **9** and **10**. The procedure is generally as in Example V. The result is a head with exceptionally good resolution at short wavelengths, and with superior efficiency at megacycle frequencies. Annealing is effected with the direct current magnetic field applied to the core as described in Example IV.

Referring to FIG. **4**, the nested assemblies such as **37** may be removed and replaced from the loop **30** by disconnecting the leads **40** and **41** from the ends of the loop **30**, and removing the ends of the loop **30** from the end seal indicated at the right-hand end of chamber **31**. The seal also has a duct extending therethrough to provide an atmosphere inlet and outlet.

Although in the past silicon-iron has been noted as a possible head material, to applicant's knowledge no commercially successful head has been made of such material, presumably because if tried the performance was found to be unsatisfactory.

Transducer heads made of other materials may also benefit by a magnetic anneal as taught herein. Such heads may be made of ferrites, the various materials such as "Permalloy," and cobalt iron materials such as "Supermendur."In each instance, there is usually a preferred composition that responds best to such treatment. For the materials such as "Permalloy" this is the 65 percent nickel, 35 percent iron range. For cobalt iron an alloy of 49 percent cobalt, 49 iron and 2 vanadium is optimum. For silicon-iron a preferred composition is 6.5 percent silicon, and the balance iron and minor impurities.

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

I claim as my invention:

1. The method of making a magnetic transducer head of the type having two opposed pole pieces defining a gap therebetween, and of the type wherein an electrically conductive winding is magnetically linked with said magnetic head which comprises forming a core of magnetically permeable material into a shape defining at least said pole pieces and said gap, energizing said shape with a magnetic field corresponding in shape and direction to the field associated with said winding during use in a magnetic recording system, and annealing said shape while exposed to said magnetic field.

2. The method of claim **1** in which said magnetic field is established by linking said shape with an electric current.

3. The method of claim **1** in which said core is formed of relatively brittle material by combining a section of magnetic material having its grain oriented in the direction of the said field of said winding section of magnetic material and another with its grain not oriented in such direction.

4. The method of claim **3** in which said sections are combined by welding.

* * * * *