

United States Patent

Romankiw et al.

[15] 3,662,119

[45] May 9, 1972

[54] THIN FILM MAGNETIC TRANSDUCER HEAD

[72] Inventors: Lubomyr T. Romankiw, Milwood; George A. Wardly, Yorktown Heights, both of N.Y.

[73] Assignee: International Business Machines Corporation, Armonk, N.Y.

[22] Filed: June 30, 1970

[21] Appl. No.: 51,186

[52] U.S. Cl. 179/100.2 C, 29/603, 117/212, 340/174.1 F

[51] Int. Cl. G11b 5/12, G11b 5/42

[58] Field of Search 179/100.2 C, 100.2 CH; 346/79 MC; 340/174.1 F; 336/200; 117/212; 29/603

[56] References Cited

UNITED STATES PATENTS

3,344,237	9/1967	Gregg.....	179/100.2 C
3,549,825	12/1970	Trimble.....	179/100.2 C
3,480,935	11/1969	Springer.....	179/100.2 C
2,933,721	4/1960	Hagopian.....	179/100.2 C

2,978,545	4/1961	Howling	179/100.2 CH
3,513,391	5/1970	Heinrich et al.	336/200

FOREIGN PATENTS OR APPLICATIONS

1,524,322	4/1968	France.....	336/200
-----------	--------	-------------	---------

Primary Examiner—Stanley M. Urynowicz, Jr.

Assistant Examiner—Jay P. Lucas

Attorney—Hanifin and Jancin and Graham S. Jones, III

[57]

ABSTRACT

A rectangular thin film transducer head includes a magnetic core composed of overlapping laminations of permalloy film joined together magnetically and electrically, near an air gap, at one end of the rectangle, between the two laminations, which gap couples flux to the magnetic recording medium. Two electrically parallel insulated thin film copper windings starting at the end opposite the gap are deposited about the core joining electrically at the end adjacent to the gap to a conductor coupled to both permalloy laminations which conduct return current through the legs of the core inside of the windings. Alternatively, a single series winding passes around the core and through the gap. The head is manufactured by means of photolithographic, vacuum, and thin film techniques.

9 Claims, 31 Drawing Figures

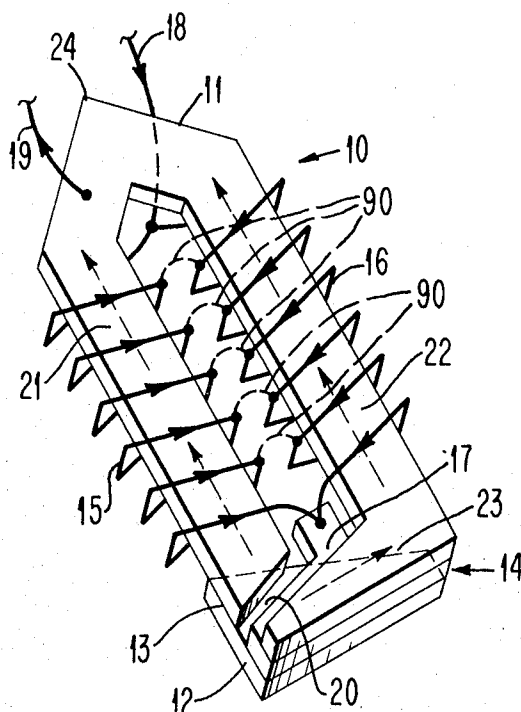


FIG. 1

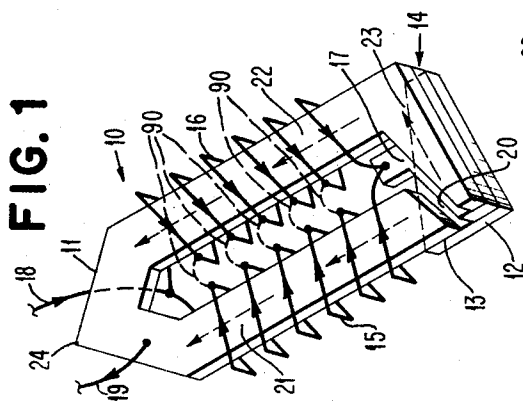
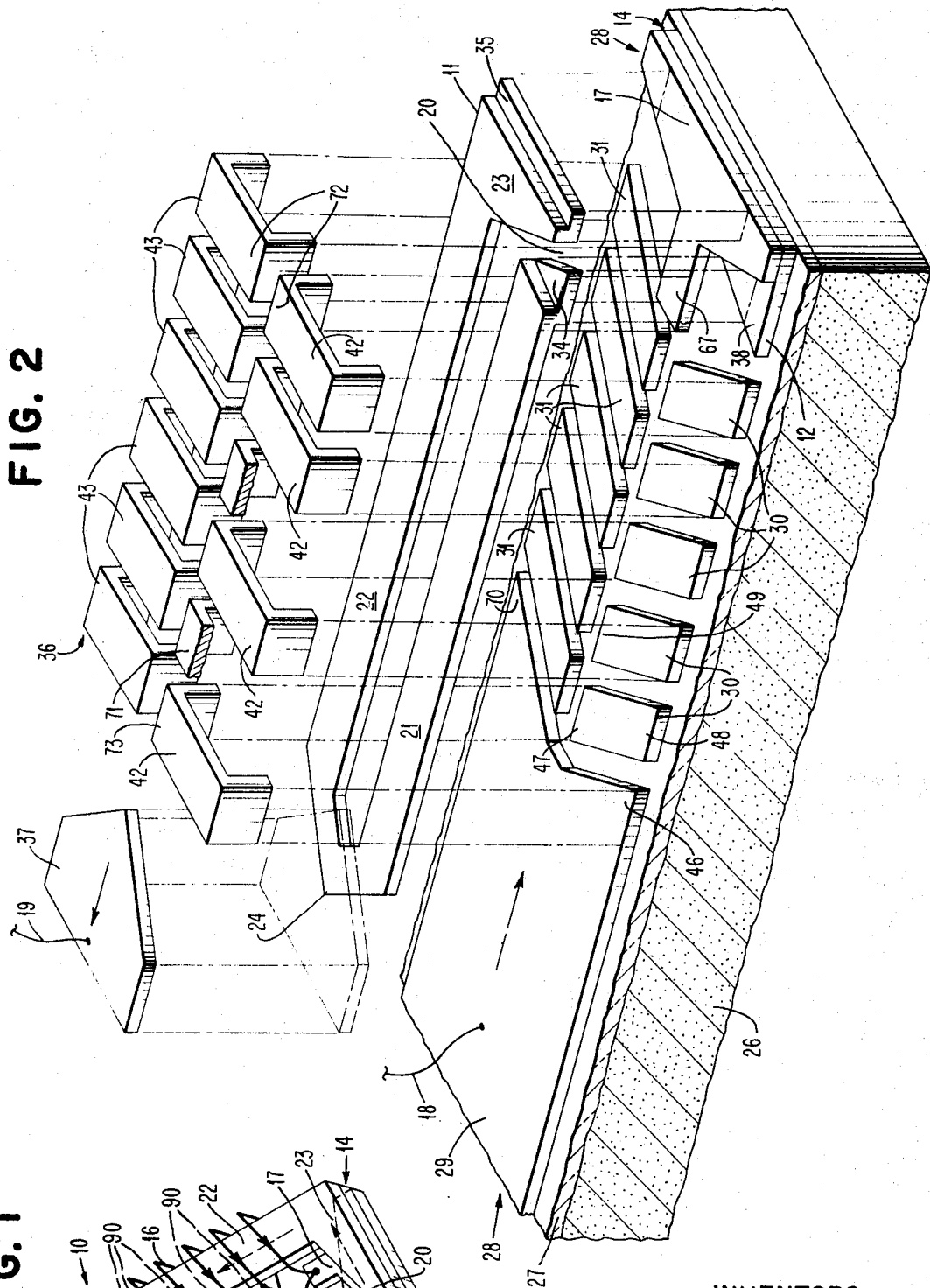
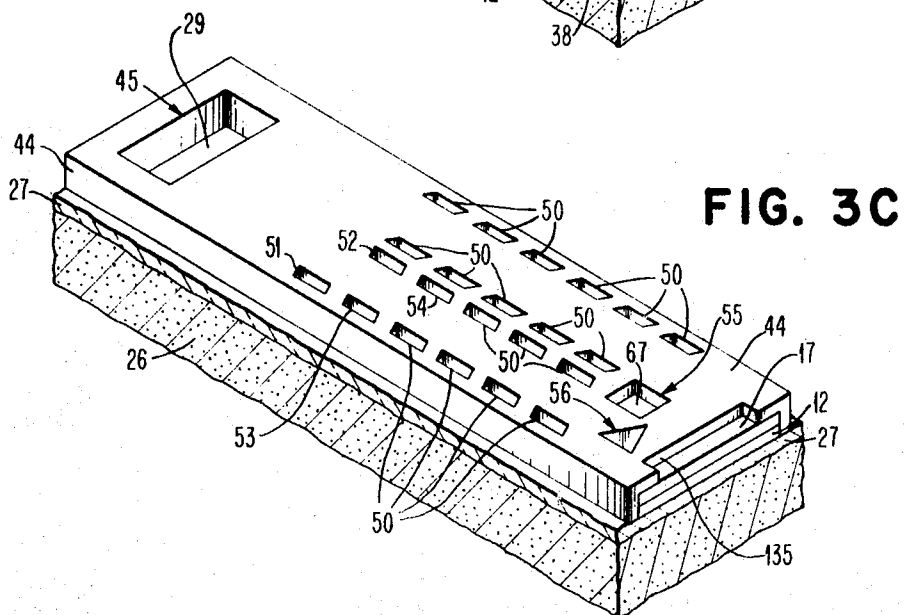
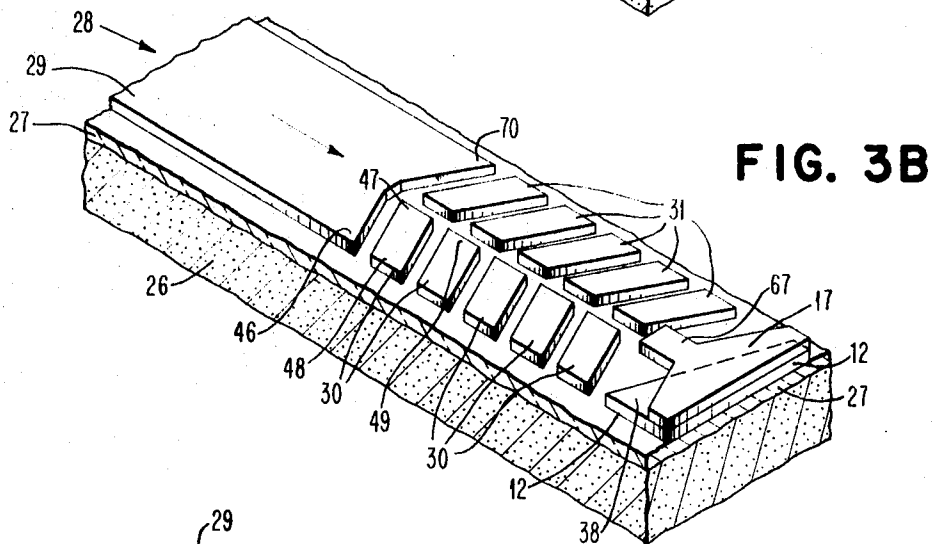
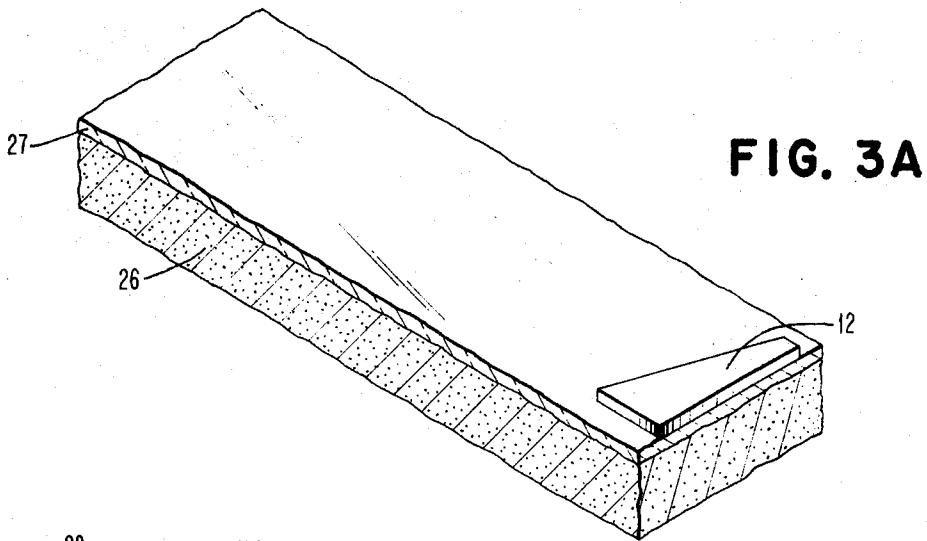


FIG. 2



INVENTORS
LUBOMYR T. ROMANKIW
GEORGE A. WARDLY

BY *Graham S. Jones, II*
ATTORNEY



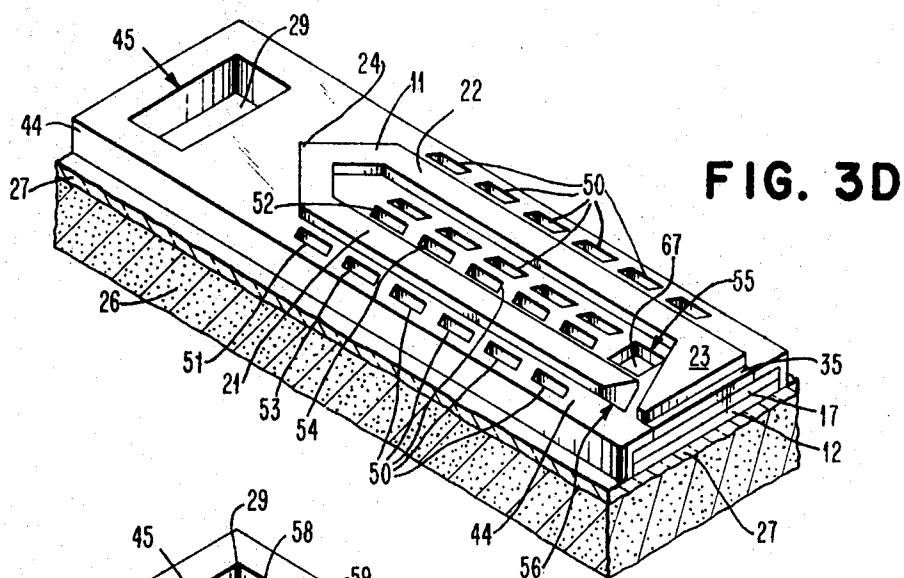


FIG. 3D

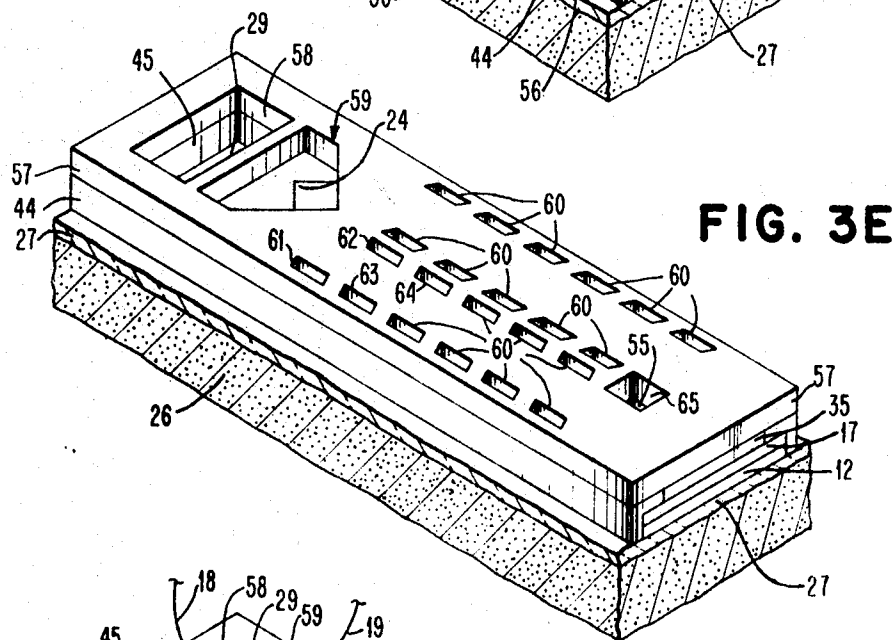


FIG. 3E

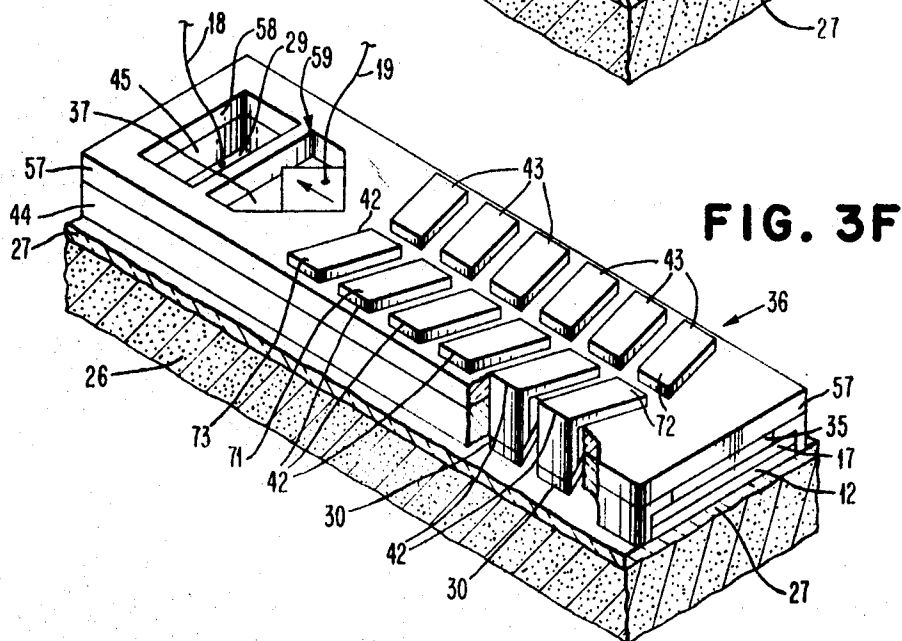


FIG. 3F

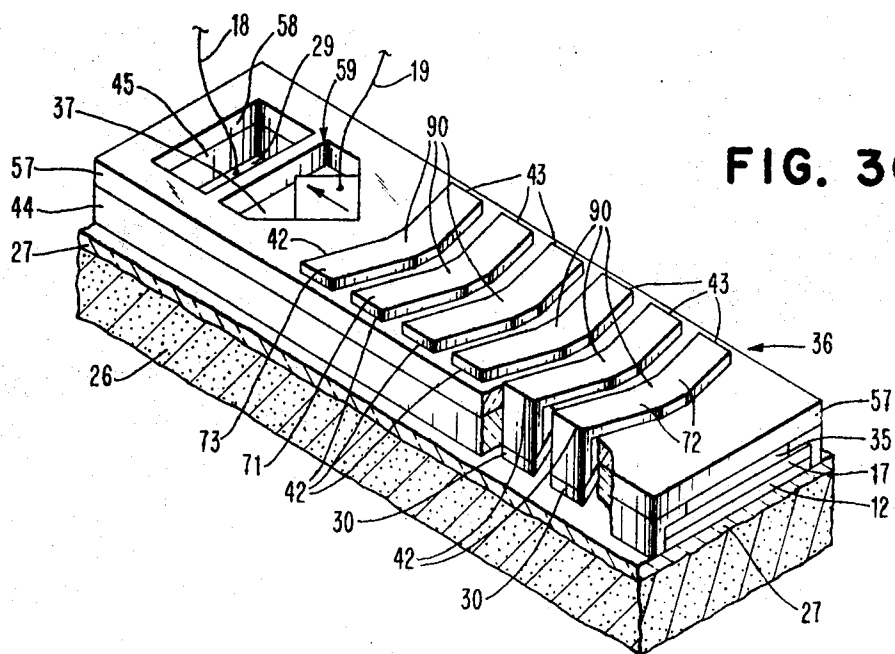


FIG. 3G

FIG. 4G

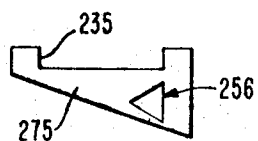


FIG. 4H

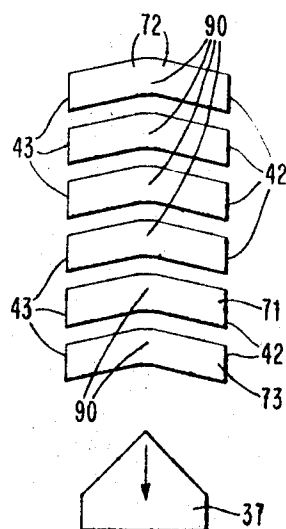


FIG. 4A FIG. 4B FIG. 4C FIG. 4D FIG. 4E FIG. 4F

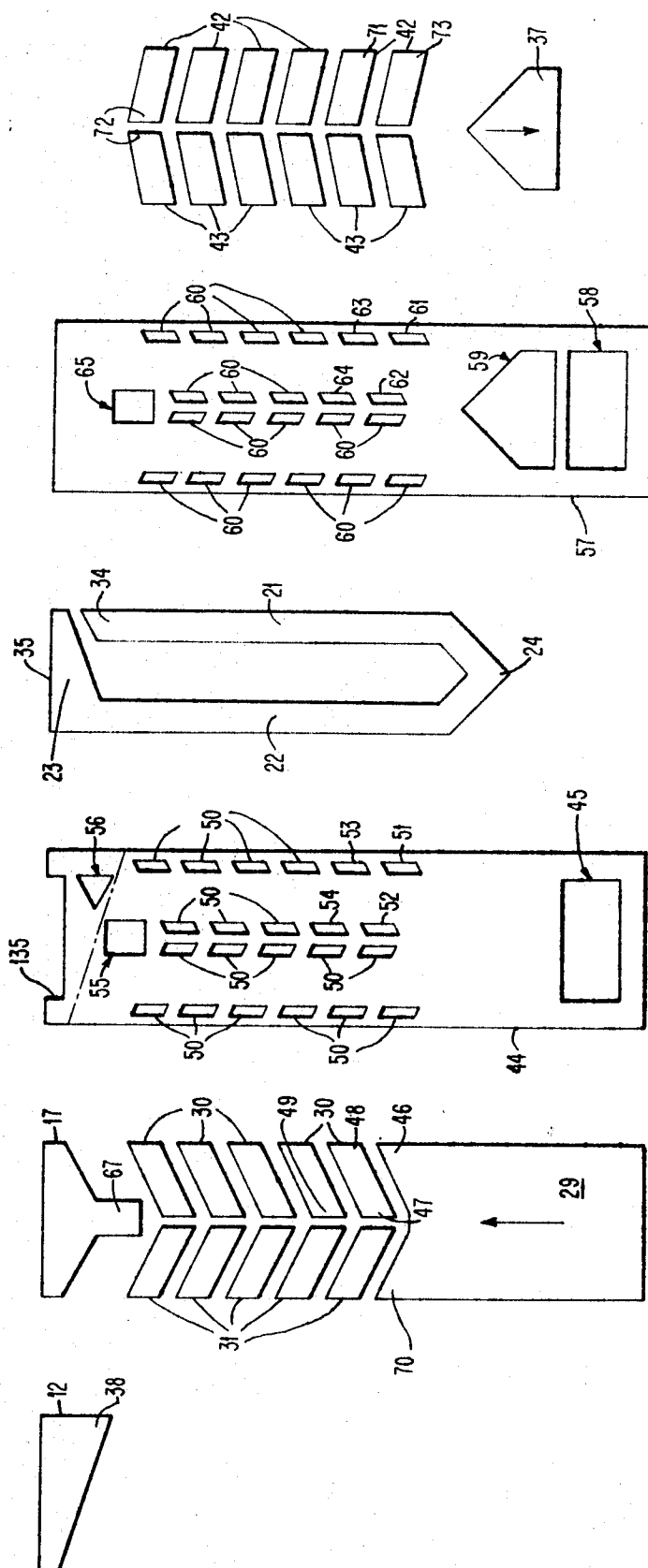


FIG. 5A

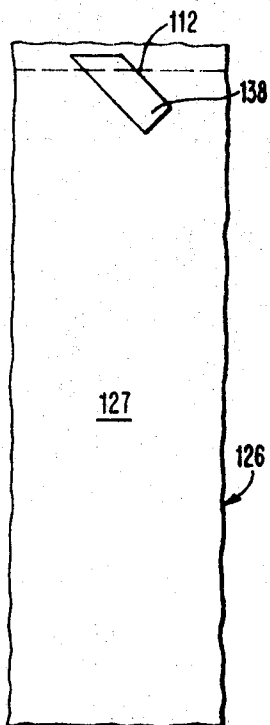


FIG. 5B

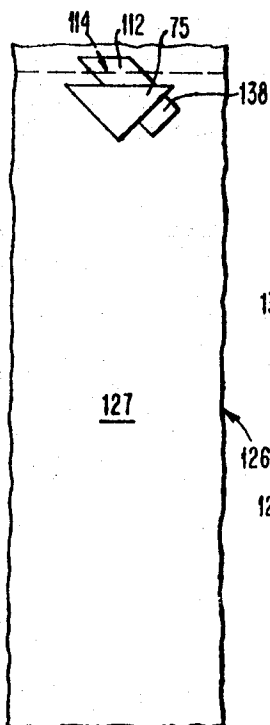


FIG. 5C

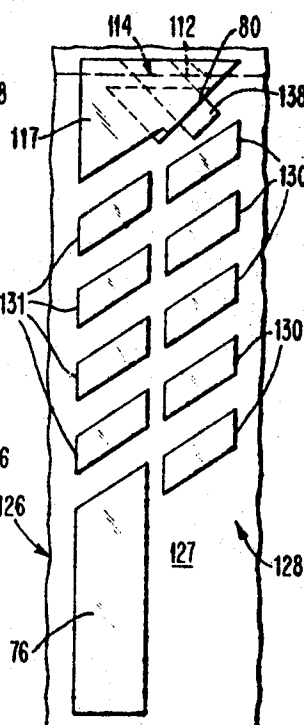


FIG. 5D

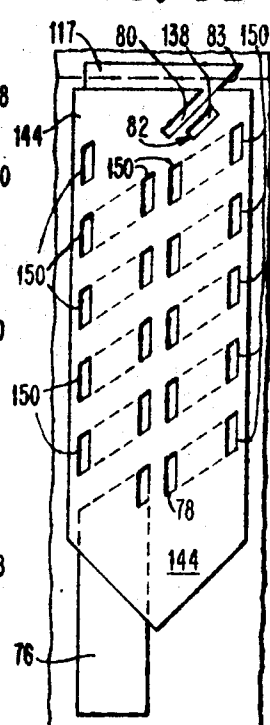


FIG. 5E

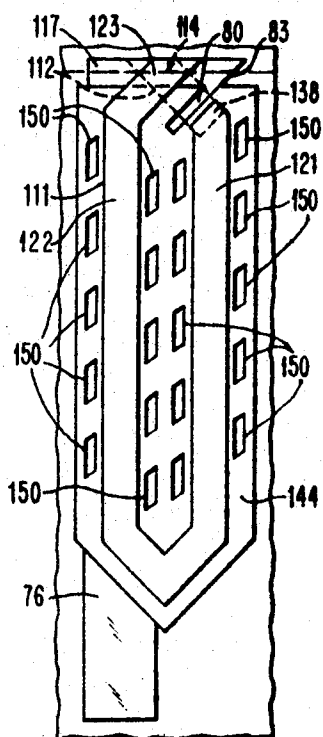


FIG. 5F

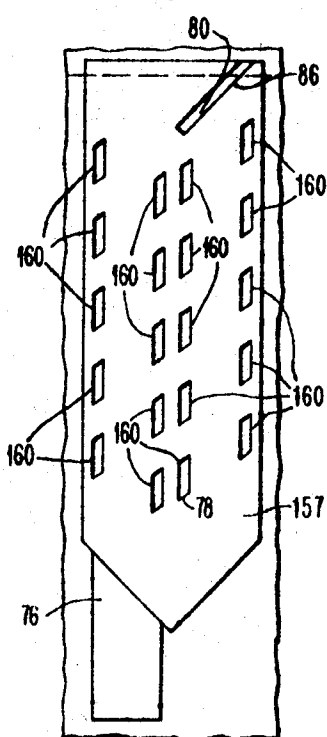


FIG. 5G

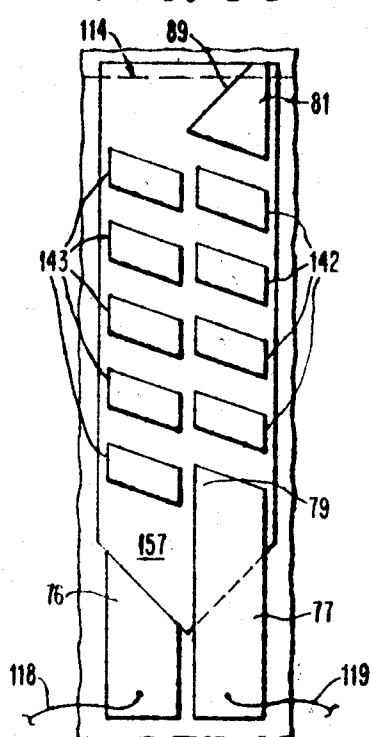


FIG. 6A

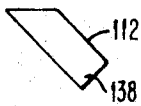


FIG. 6B

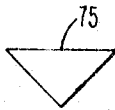


FIG. 6C

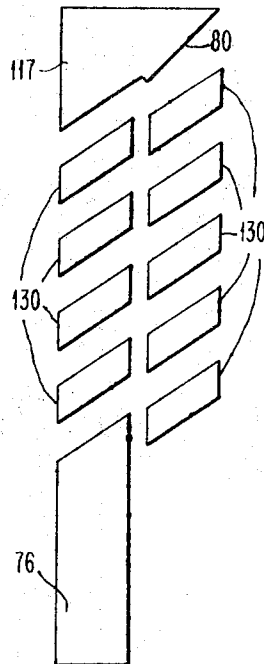


FIG. 6D

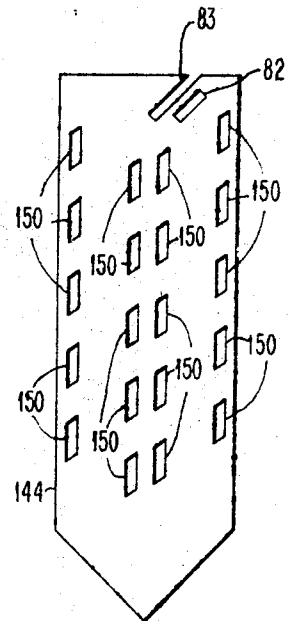


FIG. 6E

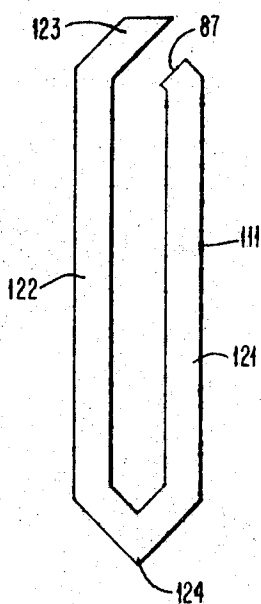


FIG. 6F

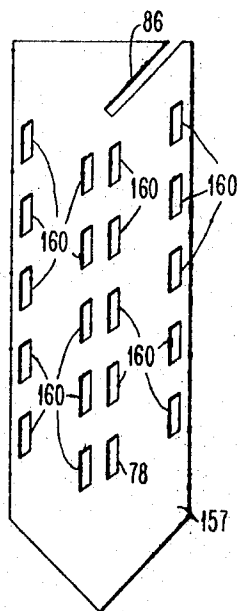
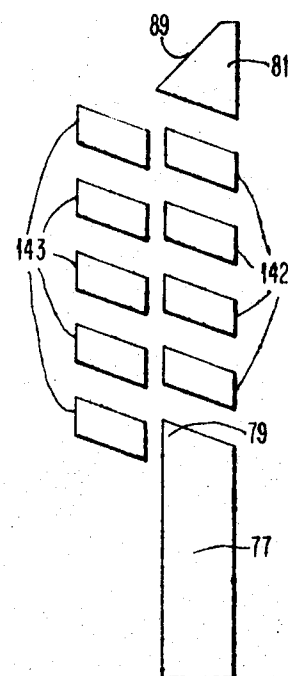


FIG. 6G



THIN FILM MAGNETIC TRANSDUCER HEAD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an electromagnetic head for providing an electrical to magnetic transducing action to write and read information in relation to a magnetic medium such as a tape in response to or for producing electrical signals. This invention also relates to thin film techniques of manufacture including sputtering and vacuum deposition, electroless deposition or plating (i.e. deposition by chemical rather than by electrical means) and electroplating, and photolithography.

2. Description of the Prior Art

It has been suggested heretofore to manufacture a thin film multitrack head including a permalloy core surrounded by silicon dioxide and having several thin film deposited turns provided around the permalloy core. The permalloy is deposited in layers, with the windings wound about only one of those layers.

In thin film transducer heads known heretofore sensitivity has been limited because of the core configuration employed. As a result the number of efficient turns which could be wound upon a core was limited because of the proximity of the totally overlapping legs of the core which led to considerable leakage of the magnetic field from one leg to the other which short circuits the magnetic circuit to a degree. The reluctance of the core at an increasing distance from the gap for a given core configuration becomes so high relative to the reluctance of the space separating the legs, that additional turns at greater distance produce smaller magnetic fields at the gap and have lesser coupling to magnetic fields passing the gap relative to turns which are closer to the gap.

In thin film technology, the number of process steps required to manufacture a completed device determines the cost as well as the overall efficiency of the manufacturing process in view of the fact that the percentages of yield are less than unity and, in general, similar reductions of overall yield result from added steps.

In cases of multiple track heads wherein cores are spaced in close proximity, there is a possibility for flux from one winding to thread through adjacent windings thereby leading to false response, referred to as cross-talk, or requiring use of measures to avoid such false response, or cross-talk, such as spacing the heads more widely, which will greatly reduce the quantity of data stored on a given quantity of magnetic recording medium.

SUMMARY

In accordance with this invention, a thin film transducer head is provided comprising a ramp shaped core of magnetic material forming a gap between its overlapping segments. The core includes a central spacer made of non-magnetic material and thin film windings about the core.

In another aspect of this invention, electrically parallel windings are made along two legs of the core and the return currents are connected back through the core.

A further aspect of this invention is that windings are provided about the ramp core wound in an electrical series around the ramp core.

In still another aspect of this invention, an electrical winding turn passes between the two portions of the core forming the magnetic gap. In still another aspect, current flows through the core from the windings. In a further aspect of this invention, redundancy of windings is provided and thereby fabrication yield is increased, higher linear bit density, higher speed, and greater track density.

An object of this invention is to produce a head with improved sensitivity consistent with thin film technology.

Another object of this invention is to minimize the number of fabrication steps required to produce a thin film head having all the above optimum features.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a partially schematic perspective view of a thin film ramp shaped core with a pair of electrically parallel windings connected to the core as an electrical return. A plurality of turns is indicated. The number of turns can greatly exceed the number of turns shown in the figure.

FIG. 2 shows an exploded view of a head including a ramp shaped core, and a pair of electrically parallel windings about the core having a current return path through the core. Extraneous portions of the substrate on which the core is produced have been omitted and the head appears here to be built on a rectangular parallelepiped.

FIGS. 3A-3F show the thin film head of FIG. 2 manufactured in accordance with the process of this invention in successive stages of fabrication. Undulations in the successive layers, caused by lower layer structures, have been omitted for facility of illustration.

FIG. 3G shows an alternative structure with parallel redundancy.

FIGS. 4A-4F show the patterns of masks for manufacture of the thin film head of FIGS. 2 and 3A-3F.

FIGS. 4A-4F represent a set of masks for an individual recording transducer. In actuality the masks consist of a plurality of such heads packed in rows as closely, side by side, as the pattern permits.

FIGS. 4G and 4H show alternative patterns of masks to be used as explained in combination with those of FIGS. 4A-4E with FIG. 4H replacing FIG. 4E.

FIGS. 5A-5G show the successive layers applied to form a thin film head with a ramp shaped core wherein the windings are wound in series about the two legs of the core.

FIGS. 6A-6G show the corresponding pattern masks employed for manufacturing a thin film head corresponding to the successive steps illustrated by FIGS. 5A-5G.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 shows a ramp shaped core 10 having an upper lamination 11 generally rectangularly shaped with a base 23 and including a left leg 21 and a right leg 22. There is a break 20 in lamination 11 between the left leg 21 and the base 23. Beneath the base 23, break 20 and the lower end of the left leg 21 is a lower lamination 12 which has a contact 38 that contacts the segment 34 of left leg 21 magnetically and electrically, but which is spaced by a copper terminal 17 from the base 23. Thus a magnetic gap 14 is formed between the base 23 and the lower lamination 12. The wire 18 is connected to a left winding 15 wound about left leg 21 and a right winding 16 wound about right leg 22. The windings 15 and 16 connect together at copper terminal 17. Copper terminal 17 is electrically connected to both the base 23 and the lower lamination 12 and the lower lamination 12 is electrically connected to the left leg 21 so that the return current path passes through left leg 21 and right leg 22 as indicated by dotted lines.

While the current arrows in FIG. 1 show the direction of current for input of current on line 18 and withdrawal of current from line 19 secured to the ramp core 10 near its apex 24, it will be understood that current will reverse periodically and the arrows are shown merely for convenience of explanation as to what the current path would be for flow of current in only one direction.

The FIGS. 1-6G make no attempt to show the transmission lines which supply current to the heads or receive signals from the heads. Neither do they show possible adjacent heads. Electrical contact pads are shown to which contact can be made by wires, however, transmission lines can be fabricated concurrently with the head. The figures would then be modified in obvious ways to show twin line, strip line or twisted pair trans-

mission lines. In these cases the contact pads would then be integral with the chosen transmission line and insulation patterns would be modified.

By way of example, referring to FIG. 2, a typical recording head is fabricated with a track width along magnetic gap 14 of between 1 and 10 mils, gap 14 thickness defined by a copper layer 28 of between 1 and 4μ meters, the magnetic ramp core 10 is, in part, comprised of legs 21 and 22 between 5 and 50 mils long, each leg 0.5 to 4 mils wide and copper conductors 31, 30, etc. between 0.1 and 0.5 mil wide. The number of chevrons 15, 16 or barber poles (turns) around the magnetic ramp core 10 is determined by the width of the copper conductors and by the length of the legs 21 and 22. The gap thickness and track width are dependent on the ultimate application of the head which may be used with storage devices such as a disk, drum, strip file, tape, or other equivalent storage device. The selected gap thickness and track width determine all other lateral dimensions as well as the individual layer thicknesses. They are usually chosen to result in maximum efficiency of the head based on its final intended application.

Although FIG. 2 shows two individual cores forming chevron stripes, the cores can be formed by connecting opposite bars 42 and 43 and 30 and 31. The current divides equally around cores 21 and 22 by virtue of equal impedance characteristics of the geometrically opposing cores. This provides redundancy with respect to random failure of individual windings.

Referring to FIG. 2 an exploded perspective view of a magnetic head incorporating the features of FIG. 1 is shown. A cutout portion of a silicon substrate 26 includes a thin film of silicon dioxide 27 upon which the lower lamination 12 of the ramp core 10 is deposited. Over lamination 12 is deposited a copper layer 28 including a lower terminal 29. A plurality of lower halves of windings 30 and 31 are combined with the upper halves of windings 42 and 43 discussed below to provide entire helical windings and the copper terminal 17 which lies in electrical contact with and above the lower permalloy lamination 12 leaving overlapping magnetic contact 38 uncovered. It will be noted again that the copper film of terminal 17 also provides the minimum spacing between the lower lamination 12 and the base 23 forming the magnetic gap 14. Above the copper layer 28 is the upper lamination 11 of the ramp core 10 which is comprised of permalloy. The left leg 21, the apex 24, the right leg 22 and the base 23 of lamination 11 are shown. The base 23 has end 35 which electrically contacts terminal 17, otherwise base 23 is spaced from terminal 17 by insulation layer 44 shown in FIG. 3C, etc. which is provided between the copper and permalloy layers except below segment 34 and end 35 which are in electrical and physical contact with the permalloy lower lamination 12 at contact 38 on the one hand and the copper terminal 17 on the other hand.

At the top level is a layer of copper 36 composed of an end terminal 37 and copper sections 42 and 43 comprising upper half windings which are of U-shaped cross sections and which connect between the lower terminal 29 and the lower halves of windings 31 to the copper terminal 17 by means of helical windings about the legs 21 and 22, respectively, on the permalloy ramp core 10. All of the windings are formed about the upper lamination 11 of core 10.

It should be understood, that the actual elevations and formations of the layers of the materials used will vary slightly from what is shown here which is simplified for convenience of illustration and for convenience of drawing. For example, the terminal layer 17 would have a slightly different shape from that which is shown. It is shown as being flat on its entire surface but actually would be bent down over the lower lamination 12.

The end terminal 37 is in electrical and mechanical contact with the apex 24 of the upper lamination 11. Thus the end terminal 37 may conduct current passing through the legs 21 and 22 of the upper lamination out to the second wire 19 for connection to the circuit controlling the head.

It will be understood also that, in general, insulation is provided between the copper windings and the permalloy core, on both levels, as will be shown hereinafter except at the points where it is indicated that there is actual mechanical and electrical contact between the segments of the ramp core 10 and the electrical circuit.

It will also be noted that the formation of the conductors by the segments 30 and 31 as well as 42 and 43 is in the form of sets of chevron stripes. This will be seen particularly clearly with reference to FIGS. 3B and 3F which will be described in greater detail hereinafter.

Referring to FIG. 3A, a portion of the substrate 26 is shown with the silicon dioxide coating 27 thereon coated with the permalloy lower lamination 12. It will be seen by reference to the mask in FIG. 4A that the shape of the lower lamination 12 is nearly identical to that of the mask of FIG. 4A. The masks of FIGS. 4A-4F are somewhat extended beyond the final desired gap location in order to provide for final polishing of the substrate and to a desired flushness. The method employed to form the permalloy lower lamination 12 is a photolithographic method in which the entire surface 27 is coated with permalloy after additional preparatory coatings described below in detail. Then, by photolithography, the unwanted permalloy is removed leaving the lower permalloy lamination 12.

FIG. 3B shows the product of FIG. 3A with the addition of a copper layer 28 in the form of the mask of FIG. 4B including the lower terminal 29, the left and right lower halves of windings 30, 31 and the copper terminal 17.

One corner 46 of lower terminal 29 in FIGS. 2, 3B and 4B is connected by a left, upper half winding 73, one of the windings 42, to the first end 47 of the first chevron 30 on the left side. The second end 48 of the first chevron 30 is connected by a second upper half winding 71 to the first end 49 of the second chevron 30.

We note again that overlapping magnetic contact 38 on the top of lamination 12 is the surface of lamination 12 which is not covered by copper terminal 17 in FIGS. 2 and 3B.

FIG. 3C shows the product of FIG. 3B with the addition of an insulating layer 44 in the form of the mask in FIG. 4C including a window 45 for the lower terminal 29, and windows 50 for corners 46 and 70 of the terminal 29 and the ends of the chevron lower halves of the windings 30 and 31 such as ends 47, 48 and 49. Window 51 is provided for the corner 46 of the terminal 29. Window 52 is provided for the first end 47 of the first chevron 30. Window 53 is provided for the second end 48 of the first chevron 30. Window 54 is provided for the first end 49 of the second chevron 30. Window 55 above segments 67 of the terminal 17 is provided for connection of the upper halves 42, 43 of the last turns 72 of the windings to the segment 67 of terminal 17. Window 56 is provided for connection of the upper permalloy segment 34 to the magnetic contact 38 as will be described in connection with FIG. 3D.

Referring to FIG. 3D, the permalloy, upper lamination 11 of core 10 is shown with the apex 24 directed towards the terminal 29, and the base 23 overlying the terminal 17, with the end 35 of base 23 extending down into electrical contact with the copper terminal 17. The left leg 21 of permalloy lamination 11 extends between the windows 51, 53 and 52, 54, respectively, and the other lefthand windows 50 so that the upper half windings 42 will pass over it. Winding 73 passes from window 51 to window 52 over the left leg 21 and winding 71 passes from window 53 to window 54 over the left leg 21 also. Similarly, all of the remaining windows 50 will be connected in like fashion by upper half windings 42, 43, about legs 21 and 22, respectively. The segment 34 extends downwardly into the window 56 for electrical and magnetic connection of the upper permalloy segment 34 to the magnetic contact 38 of FIG. 3B to provide both electrical and magnetic continuity. The lower permalloy lamination 12 and the upper permalloy lamination 11 are thereby formed into one continuous ramp core 10 which has magnetic continuity and which provides the return path for the electrical currents as was described in connection with FIG. 1 as will be shown

in greater detail in connection with FIG. 3F. It will be seen by reference to FIG. 4D that the mask shown therein is of the same configuration as the upper permalloy layer although the elevations provided by the lower layers alter the three dimensional form of the shape.

Referring to FIG. 3E, the second insulating layer 57, a mask for which is shown in FIG. 4E, is deposited upon the product of FIG. 3D. A window 58 is provided and is coextensive with window 45 above the lower terminal 29. A window 59 is provided for a second contact terminal 37 (deposited in FIG. 3F) with a segment of the apex 24 of the upper permalloy lamination 11 of the core 10 extending into the space defined by the window 59. Windows 60, corresponding to windows 50, are provided above and in alignment with windows 50, with windows 61, 62, 63 and 64 above, and corresponding to, and in alignment with windows 51, 52, 53, and 54. Window 65 overlies and is in alignment with windows 55 above the segment 67 of terminal 17 which is adapted to be connected to windings 42 and 43 of the last turns 72.

FIG. 3F shows the topmost, copper layer deposited upon the product of FIG. 3E in the form shown in FIG. 4F with a terminal 37 in window 59 electrically connected to the underlying apex 24 of lamination 11 of core 10. The wire 19 is connected to terminal 37. The upper half windings 42 are shown with a portion of the structure partially cut away to show the entire connection to left lower halves 30. Upper half winding 73 connects corner 46 of lower terminal 29 and the first end 47 of chevron lower half winding 30. Upper half winding 71 connects second end 48 of the first lower half winding 30 and first end 49 shown in FIG. 3B. The last turns 72 are connected through windows 55 and 65 to the segment 67 of copper terminal 17 in order to connect the windings about legs 21 and 22 to a common point, electrically. It will be noted that terminal 17 is connected directly to lower lamination 12 and upper lamination 11 and, as described in FIG. 1, provides return current paths therethrough. Wire 18 is connected through windows 58 and 45 down to terminal 29 to connect the opposite ends of the windings 15 and 16 to an outside source as shown in FIGS. 1 and 2.

In another variation of the structure one can protect the chevron wired transducer against random faulty contacts between the upper copper "Chevron" half windings 42-43 and the lower half windings 30-31 in FIGS. 3B-3F, by adding shorting bars 90 in FIG. 1 which are shown there as dashed connections between geometrically opposing windings. This is accomplished by taking the product of FIG. 3E and depositing the layer of copper 36 and etching or electroforming it by use of the mask in FIG. 4H in place of the mask in FIG. 4F which yields the product in FIG. 3F. Additional copper 90 in FIG. 3G is deposited between geometrically opposing upper half windings 42, 43. The connections 90 between geometrically opposing windings 30-42 and 31-43 have no effect on the electrically parallel current in the windings around core legs 21 and 22 unless there is a fault in an upper or lower half winding 42-43-30-31 or a fault in the electrical connections between some half winding pairs 40-42 and 31-43. The interconnections areas 90 lend a redundancy of electrical connection which is used to increase the yield of the fabrication processes. Thus, if an open circuit fault occurs in one half winding pair 30-42 or 31-43, the complementary or geometrically opposing half winding pair 31-43 or 30-42, respectively, will conduct current for both of the geometrically opposing or complementary winding pairs 30-42 and 31-43.

Referring to FIG. 5A, a portion of a substrate 126 is shown which may be composed of a material such as silicon molybdenum, or other metal with a thin film of silicon dioxide or other insulating film 127 covering the entire surface of the wafer. Alternatively, the substrate 126 may be made of sapphire, glass, alumina or other insulating material. Deposited above the insulative surface 127 is the lower permalloy lamination 112 having an overlapping magnetic contact area 138 at the end thereof distal from the upper end of the wafer 126. The mask shown in FIG. 6A is employed for the purpose

of photolithographically selecting the permalloy 112 to be retained during etching away of the surplus permalloy.

Referring to FIG. 5B, the product of FIG. 5A is overlaid with an insulating layer 75 employing the photolithographic mask shown in FIG. 6B.

Subsequently as shown in FIG. 5C a layer 128 of conducting material which may be copper or other conductive material is deposited upon the product of FIG. 5B. Copper terminal 117 overlies the insulating layer 75 and the lower permalloy lamination 112 with the overlapping magnetic contact 138 extending beyond the end of the terminal 117. The magnetic gap will, eventually after polishing and lapping, occur along the dashed line 114 near one end of substrate portion 126 which has been isolated for drawing purposes. The gap will exist where permalloy 111 and permalloy 112 totally overlap and are spaced by copper terminal 117. One set of lower half windings 130 are shown along with the other set of half windings 131 and arranged in a "barber pole" fashion instead of the "chevron" arrangement which was shown in the previous embodiment. The two sets of windings are to be connected in series rather than in parallel, in this case. A terminal segment 76 is shown in the lower left hand corner in FIG. 5C. In the manufacture of this layer, first the entire surface is coated with copper. The mask shown in FIG. 6C then is used to provide photolithographic resist techniques for etching away the surplus copper or for additively forming the copper conductors in order to produce the configuration shown in FIG. 6C.

The product of FIG. 5C is shown in FIG. 5D with the addition of insulating layer 144 of silicon dioxide or resist which has been etched away in accordance with the mask of FIG. 6D to provide coupling window 83 for area 80 of the terminal 117 for coupling a turn including terminal segment 117 and coupling segment 81 in FIG. 56 through the core at end 89. Window 82 is provided for the overlapping magnetic contact 138 of the lower permalloy lamination 112. Windows 150 are provided for connection of the upper half windings 142 and 143 in FIG. 5G, down to the lower half windings 130 and 131. FIG. 6D shows the mask which was employed in providing the product of FIG. 5D by photolithographic resist techniques. The product of FIG. 5D is further modified as shown in FIG. 5E by the addition of an upper permalloy lamination 111 so that the end 123 of the lamination 111 overlaps the end of lower lamination 112, thereby providing a magnetic gap of a head ultimately along the dotted line 114 of the gap in FIG. 5 which will be a real substrate edge after polishing away excess substrate and head material above line 114. Then as can be seen the legs 122 and 121 extend between the windows 150 and as can be visualized the legs 121 and 122 extend between the ends of lower windings 130 and 131, respectively. The upper permalloy layer 111 is insulated from electrical and magnetic contact except through the window 82 whereby it makes magnetic and electrical contact with the lower lamination 112 overlapping magnetic contact 138 which is shown in phantom along with the lower lamination 112 and except for contact with the copper lamination, 111 adjacent to the final dotted line 114 of the magnetic gap 114. Thus, copper lamination 117 provides the minimum spacing between permalloy legs 122 in the vicinity of the gap 114. Manifestly the mask of FIG. 6E is employed to make the upper permalloy lamination 111.

The product of FIG. 5E is further modified employing the mask of FIG. 6F to provide an additional insulation layer 157 which provides an additional window 86 which overlies window 83 so that the contact areas 80 for coupling the turn through the core is capable of making electrical contact with the next layer. Similarly, windows 160 are provided overlying windows 150 in order to permit contact to be made with the lower half windings 130 and 131 and the terminal 117. One of the windows 78 will connect to the corner 79 of an upper right terminal segment 77 composed of copper, for example. This upper insulating layer 157 may also be composed of silicon dioxide, an insulating photoresist or some other organic or inorganic insulation.

The product of FIG. 5F is further processed as shown in FIG. 5G employing the mask configuration of FIG. 6G to provide an upper coupling segment 81 having an end 89 extending down through the windows 86 and 83 into contact with the end 80 of lower terminal 117. The upper half windings 142 and 143 are shown with the respective ends thereof extending down through windows 160 to contact the lower half windings 130 and 131 as will be understood particularly with reference to the procedure employed in the previous embodiment. Also, as will be understood, the windings are electrically in series. The upper terminal segment 77 connects to the first lower winding on the lower level through end 79 and window 78. Assuming that current enters terminal segment 76, it will then move upwardly towards the right and then will flow into the winding 143 in the lower left hand corner of FIG. 5G at its right end towards its upper end and then down into the first winding 131 shown in FIG. 5C up to the right hand corner of that winding and then back up into FIG. 5G in the lower right hand corner of the second winding 143 shown in FIG. 5G, etc. A helical current flow is produced. Thus, employing the right hand rule to this circulating current one would place his hand around the enclosed leg 122 shown in FIG. 5E with his thumb extending downwardly. This downward direction being that of the induced magnetic field in the core leg 122. At the top of FIG. 5G, the current would then pass through the winding of the left hand corner down into winding 117 and then to edges 80 and 89 up to segment 81 and from 81 down through the window 160 in the upper right hand corner in FIG. 5F and rise back through the window 160 to the left and a little below the upper rightmost window 160 and would travel across the upper right hand winding 142 from left to right, etc. A helical current flow then surrounds core leg 120 so that employing the right hand rule, the induced magnetic field would be directed upwardly towards the top of the page in FIG. 5G in core leg 121. Thus, with the above sign conventions, a counterclockwise magnetic flux is induced in the core 111 in FIG. 5E by the current. The current then passes from the first winding 130 through window 78 into the edge 79 of the upper terminal 77. Current would be taken to/from lower terminal 76 and from/to upper terminal 77 by means of wires connected to them shown in FIG. 5G as wires 118 and 119, respectively.

Again, wires 118 and 119 may take the form of twin lead, strip line or twisted pair transmission line fabricated simultaneously with the head. And again, the terminals 76 and 77 would be continuous with and leading into the transmission line. The masks for copper and insulation layers would then be extended and modified in ways that are known to produce the desired transmission line.

The "barber pole" embodiment is more susceptible to interference from closely spaced adjacent heads because it contains an open current loop whereby current approaches the gap line 114 via conductors 131-143 and recedes via the conductors 130-142. The resulting "cross-talk" of this embodiment can be nulled by a compensating transmission line. The insulating layer 25 provides additional separation of the composite leg 121-112 and leg 122 where they overlap until they are adjacent to the location of the magnetic gap to be formed by polishing the completed structure in FIG. 5G to the gap line 114.

This extra insulating layer was not used in the description of the chevron striped head so that both approaches could be demonstrated. When additional spacing of legs 121 and 122 is not mandatory, insulating layer 75 may be removed entirely from the above discussion. Likewise, when additional spacing is required, layer 75 is used. The "chevron striped" embodiment does not consider similar additional spacing between the permalloy lamination and the terminal layer 17 in FIG. 3B. This additional spacing can be achieved by interposing an additional insulator lamination between the laminations 12 and 17 shown deposited in FIG. 3A and FIG. 3B. Thus, a photolithographic deposition of insulator 275 is masked by the mask in FIG. 4G. The mask windows 256 and 235 in FIG. 4G are thus positioned beneath the mask windows 56 and 135 in FIG. 4C.

The process steps for the fabrication of the preferred embodiments are described below. The two processes basically differ in that steps 4 and 5 for the series wound head deposit the insulation layer 75 in FIG. 5B, whereas these steps are omitted in the fabrication of the "chevron head." Thus, step 6 of the "barber pole" head fabrication process (the second-described process below) is essentially the same as step 4 of the "chevron head" fabrication process (the first one below).

As mentioned above, insulation layer 75 of the "barber pole" head can be eliminated. Also, the insulation layer 275 photolithographically deposited with the use of the mask in FIG. 4G can be included in the "chevron" head. Steps 4 and 5 of the "barber pole" head fabrication process are then interposed between steps 3 and 4 of the "chevron" head fabrication process with the substitution by the words "seventh mask shown in FIG. 4G" in place of the words "...second mask shown in FIG. 5B."

In fabrication of the head in accordance with the first preferred embodiment of FIGS. 2, 3A-3F, and 4A-4F, a number of steps are required as follows:

1. Deposit a titanium or a chromium film as an adhesion layer either in vacuum or by sputtering or any other acceptable metallization technique to the thickness of 150-500A and a copper or permalloy film of approximately 300-500A are both placed upon a silicon dioxide surface upon a silicon wafer or other similar substrate.

2. Electroplate permalloy (or deposit it using any equivalent technique) upon the entire surface of the metallized film coatings to the thickness of from 1.5-5 microns.

3. Apply a photoresist coating to the entire surface of the permalloy. Employ the first mask shown in FIG. 4A, and expose the photoresist through it and etch with ferric chloride or any other suitable etchant to yield the first permalloy lamination in the shape of FIG. 4A. Etch the titanium underlayer using 1% HF solution.

4. Evaporate approximately 150-500 A of titanium and 300-500A of copper all over the wafer as in step (1).

5. Apply Shipley* (*Shipley Co. Inc., Wellesley, Mass.) positive photoresist everywhere with a thickness of 2-4 microns and then use the second mask shown in FIG. 4B to remove resist where it is desired to apply a plurality of copper chevrons, etc., over what remains of the permalloy and the metallized silicon dioxide surface.

6. Electroplate 1 to 3 microns of copper through the apertures formed by the second mask.

7. Electrolessly plate or electroplate 1,000-2000A of gold on top of the copper.

8. Remove the Shipley mask using acetone or other acceptable technique.

9. Etch the underlying copper with ammonium per sulphate and underlying titanium with 1% HF in order to separate the chevron segments which would be connected by the copper applied in step (1).

10. Deposit a new layer of insulation composed of SiO₂, KTRF** (**Eastman Kodak Co., Rochester, New York) (negative) photoresist or Shipley photoresist to a thickness of 1-3 microns. When using KTRF or Shipley bake resist at a temperature greater than 170° C to thermally stabilize and polymerize the resist.

11. Etch holes in the insulation with the third mask in FIG. 4C using hydrogen fluoride for silicon dioxide insulation (solution may be buffered with ammonium hydroxide) and if KTRF or Shipley is used, expose and develop the photoresist using an appropriate developer.

12. Evaporate a very thin layer of titanium 150-500A and then evaporate a very thin layer of permalloy 400-500A, or metallize the entire surface using any other acceptable means.

13. Electroplate 2-4 microns of permalloy on the very thin metallized layer (plating it in a sheet form).

14. Apply Shipley or KTRF expose and develop resist and etch both parts of the second layer of permalloy after using the fourth mask, in FIG. 4D. Etch Ti underlayer as described in step (9).

15. Apply KTFR or Shipley photoresist or apply SiO_2 and bake the photoresist, if used, to form a second insulator. Expose the fifth mask shown in FIG. 4E and etch using buffered hydrogen fluoride if SiO_2 has been used in the preceding step, or expose and develop if KTFR or Shipley photoresist has been used. This opens the connections to the contacts.

16. Evaporate a thin film of titanium and a thin film of copper as in step (4) upon the areas exposed by the fifth mask in FIG. 4E and all other areas of the coated wafer.

17. Apply Shipley photoresist.

18. Expose the sixth mask pattern shown in FIG. 4F.

19. Plate copper through the mask as in step (6).

20. Electroplate or electrolessly plate copper with 1,000–2,000 thick layer of gold as in step (7).

21. Remove the Shipley photoresist mask and etch the copper and titanium underlayers as in steps (8) and (9).

22. Connect wires to the pads in the structure, polish head structure and substrate to make the substrate edge flush with the desired magnetic gap position 14 in FIG. 2.

In fabrication of the head shown in FIGS. 5A–5G a similar set of steps is required as follows:

1. Deposit a titanium or a chromium film as an adhesion layer either in vacuum or by sputtering or any other acceptable metallization technique to the thickness of 150–500 Å and a copper or permalloy film of approximately 300–500 Å are both placed upon a silicon dioxide surface upon a silicon wafer or other similar substrate.

2. Electroplate permalloy (or deposit it using any equivalent technique) upon the entire surface of the metallized film coatings to the thickness of from 1.5–5 microns.

3. Apply a photoresist coating to the entire surface of the permalloy. Employ the first mask shown in FIG. 5A, and expose the photoresist through it and etch with ferric chloride or any other suitable etchant to yield the first permalloy lamination in the shape of FIG. 5A. Etch the titanium underlayer using 1% HF solution.

4. Deposit a layer of insulation composed of SiO_2 , KTFR etc (same as 12 below).

5. Etch the insulation with the second mask shown in FIG. 5B using hydrogen fluoride for silicon dioxide insulator (solution may be buffered with ammonia) and if KTFR of Shipley is used, expose and develop the photoresist using an appropriate developer.

6. Evaporate approximately 150–500 Å of titanium and 300–500 Å of copper all over the wafer as in step (1).

7. Apply Shipley* (*Shipley Co., Inc., Wellesley, Mass.) positive photoresist everywhere with a thickness of 2–4 microns and then use the second mask shown in FIG. 5C to remove resist where it is desired to apply a plurality of copper stripes, etc., over what remains of the permalloy and the metallized silicon dioxide surface.

8. Electroplate 1 to 3 microns of copper through the apertures formed by the mask.

9. Electrolessly plate or electroplate 1,000–2,000 Å of gold on top of the copper.

10. Remove the Shipley mask using acetone or other acceptable technique.

11. Etch the underlying copper with ammonium persulphate and underlying titanium with 1% HF in order to separate the copper segments which would be connected by the copper applied in step (1).

12. Deposit a new layer of insulation composed of SiO_2 , KTER** (**Eastman Kodak Co., Rochester, N. Y.) (negative) photoresist or Shipley photoresist to a thickness of 1–3 microns. When using KTFR or Shipley bake the resist at a temperature greater than 170° C to thermally stabilize the resist.

13. Etch holes in the insulation with the fourth mask in FIG. 5D using hydrogen fluoride for silicon dioxide insulation (solution may be buffered with ammonium hydroxide) and if KTFR or Shipley is used, expose and develop the photoresist using an appropriate developer.

14. Evaporate a very thin layer of titanium 150–500 Å and then evaporate a very thin layer of permalloy 400–500 Å, or metallize the entire surface using any other acceptable means.

15. Electroplate 2–4 microns of permalloy on the very thin metallized layer (plating it in a sheet form).

16. Apply Shipley or KTFR expose and develop resist and etch both parts of the second layer of permalloy after using the fifth mask, in FIG. 5E. Etch Ti underlayer as described in step (9).

17. Apply KTFR or Shipley photoresist or apply SiO_2 and bake the photoresist, if used, to form a second insulator. Expose the fifth mask shown in FIG. 4E and etch using buffered hydrogen fluoride if SiO_2 has been used in the preceding step, or expose and develop if KTFR or Shipley photoresist has been used. This opens the connections to the contacts.

18. Evaporate a thin film of titanium and a thin film of copper as in step (4) upon the areas exposed by the sixth mask in FIG. 5F and all other areas of the coated wafer.

19. Apply Shipley photoresist.

20. Expose the seventh mask pattern shown in FIG. 5G.

21. Plate copper through the mask as in step (8).

22. Electroplate or electrolessly plate copper with 1,000–2,000 thickness of gold as in step (9).

23. Remove the Shipley photoresist mask and etch the copper and titanium underlayers as in steps (10) and (11).

24. Connect wires to the pads in the structure, polish head structure and wafer to form the magnetic gap at the proper location (line 114 in FIGS. 5A–G) and make the substrate edge flush with the desired gap location.

What is claimed is:

1. A thin film transducer head comprising a plural layer integral core of magnetic material forming a gap between overlapping segments thereof, said core including a central space without magnetic material and thin film windings about said core, said windings being electrically connected to said core adjacent to said gap, to form an electrical circuit with said windings and said core in series with each other.

2. Apparatus in accordance with claim 1 wherein said windings are formed on separate layers and are generally in complementary chevron shaped patterns with one half of each chevron stripe on a separate layer.

3. A thin film transducer head comprising a plural layer integral core of magnetic material forming a gap between overlapping segments thereof, said core including a central space without magnetic material and thin film windings about said core, and current from said windings passing through said core.

4. A thin film transducer head comprising a plural layer integral core of magnetic material forming a gap between overlapping segments thereof, said core including a central space without magnetic material and thin film windings about said core, said windings being electrically connected in parallel, and said windings being connected in series with said core.

5. A head in accordance with claim 4 wherein current through said windings passes through said gap.

6. A thin film transducer head comprising a plural layer integral core of magnetic material forming a gap between overlapping segments thereof, said core including a central space without magnetic material and thin film windings about said core said windings being electrically connected in parallel, and electrical return current passing from the windings returns through the core passing through a winding for current flowing through an electrical circuit including the windings of the coil and the core in series.

7. A magnetic head comprising a magnetic core formed in a plurality of layers and joined at one point to form a unitary magnetic core having a gap,

a plurality of windings electrically in parallel about said core connected to said core as an electrical return path for current flowing through an electrical circuit including said windings and said core connected in series.

8. A transducer head comprising a core of magnetic material including two arms with parallel windings about both of said

11

12

arms with bridging connections between respective loops of the windings on each arm so as to provide alternate electrical paths around the core for improved reliability in the event of failure of at least one loop.

9. A transducer head in accordance with claim 8 wherein 5 said core comprises a plural layer integral core.

* * * * *

10

15

20

25

30

35

40

45

50

55

60

65

70

75