Feb. 12, 1963 S. R. HOH 3,077,444

LAMINATED MAGNETIC MATERIALS AND METHODS

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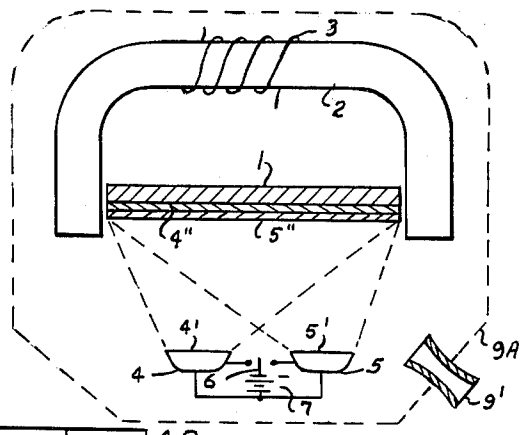


Fig-1A

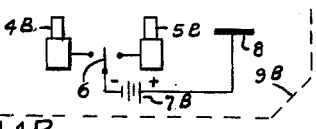


Fig-1B

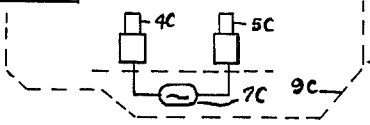


Fig-1C

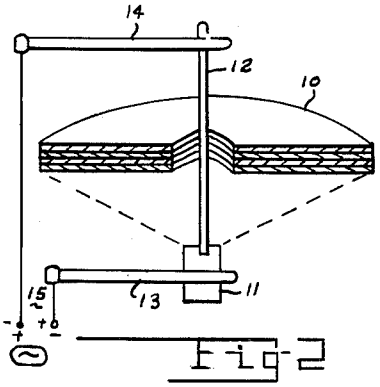


Fig-2

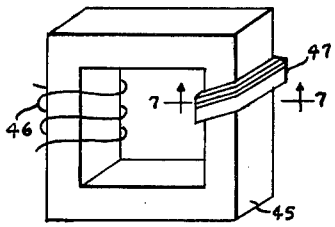


Fig-6

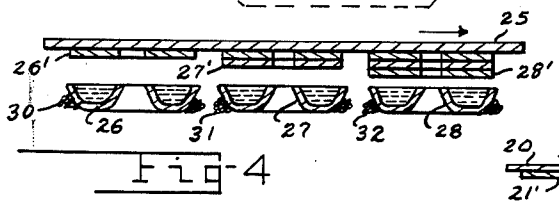


Fig-4

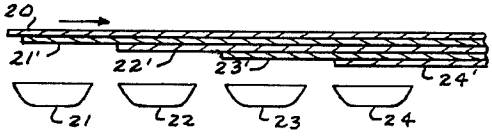


Fig-3

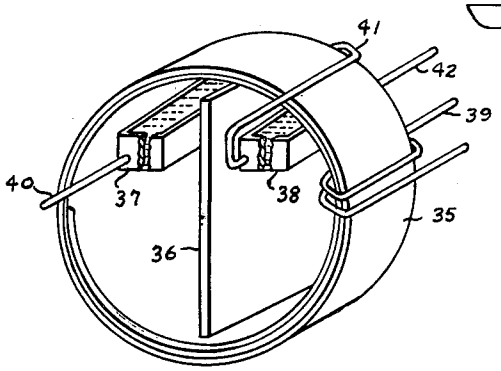


Fig-5

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LAMINATED MAGNETIC MATERIALS AND METHODS

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Fig-8

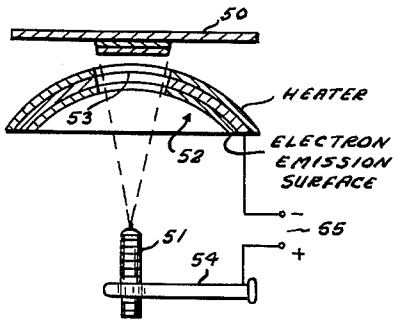
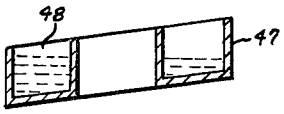


Fig-7



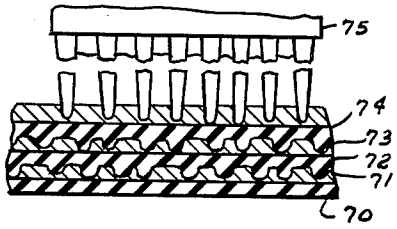


Fig-10

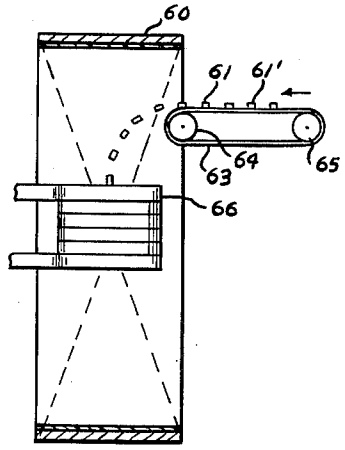


Fig-9

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United States Patent Office

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3,077,444
LAMINATED MAGNETIC MATERIALS AND METHODS

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Original application June 13, 1956, Ser. No. 591,250. Divided and this application Dec. 3, 1959, Ser. No. 857,236

9 Claims. (Cl. 204—192)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the United States Government for governmental purposes without payment to me of any royalty thereon.

This invention concerns laminated magnetic materials of both the soft core and the permanent magnet types and concerns also means and methods for making laminated structures by evaporation, sputtering and related techniques. This invention is a restriction from the parent application Serial No. 591,250, filed June 13, 1956.

As the terms are used herein: laminated materials are defined as heterogeneous solid bodies consisting of layers; a magnetically soft core is a core having a low coercive force, of a core characterized by low magnetic losses; and a permanent magnet is a magnet which retains its magnetism for an indefinite period of time. The magnetically soft cores contemplated hereby consist of a plurality of thin films of magnetic and of insulating materials, which may be alternately precipitated from their respective vapor phases. Metallic soft cores used for transformer applications and the like, involving alternating currents, have to be laminated in order to keep their eddy current losses low. Eddy current losses also may be reduced by the use of magnetic particles separately insulated from each other with a ceramic, a plastic or other form of electrical insulator. Previously made laminated cores have commonly consisted of rolled laminations or strips. Limitations which characterize these earlier forms of laminated magnetic cores are avoided in the devices which are contemplated by the present invention.

As a background for insuring a sufficient understanding of the present invention as claimed, in past practices laminated electrically conductor and electrically insulator bodies have been produced on a horizontal metal disk which is rotated in an evacuated compartment over two crucibles which give off different metal and insulator vapors. The metal and the insulator vapors are deposited successively in laminations of a thinness which is controlled by the speed of the disk rotation and by the temperature at which the vapors are released. The depositions of successive film laminations from the vapor phase upon a colder body is applicable to most elements and to most inorganic materials.

Metals, alloys, insulators and the like have been applied to a substrate or a base metal also as a fine spray in the formation of successive laminations thereon.

The thinness of the resultant laminations is of importance to the performance of the resultant article. The resultant product consists of stratified layers of different metals, alloys, insulators and the like. The resultant laminated bodies are used as electrical elements in circuitry assemblages of which radio frequency conductors, light diffraction gratings; capacitors, rectifiers, etc. are illustrative.

A general statement of the nature and of the substance of the present invention as claimed comprises in nature the provision of new and improved laminated structures. In substance the present invention comprises laminated articles, apparatus and methods involving evaporation, sputtering, electron bombardment, etc., for making laminated structures. The present invention is inclusive of the deposition of laminations within a magnetic field of ample strength to accomplish the desired orientation of magnetic domains.

A general statement object of the present invention, as claimed, is the provision of a new and a useful family of laminated bodies and methods for the production of the bodies by making use of different physical states of solid, liquid and gas which are accomplished by differences in temperature levels of elements, metals, alloys, insulators and the like, within an inclosure which has a controlled atmosphere, and to methods described hereinafter for accomplishing lamination depositions of controlled thicknesses, shapes and magnetic characteristics.

Additional objects of the present invention are the production of bodies consisting of laminations of alternated conductive and insulating material of sufficient thinness to minimize core losses when the material is so used; laminated bodies wherein the laminations consist of magnetic alloys which, because of their brittleness, lack of cohesion or the like, can not be successfully mechanically rolled to desired degrees of thinness; to laminated bodies which are protectively coated from the atmosphere by insulating films or the like; to laminated bodies characterized by controlled magnetic domains which are oriented during the deposition of films of materials which form the laminations; to laminated bodies characterized by the elimination of voids or air spaces between the films or laminations, which facilitates the miniaturization of cores and reduces the corrosion of the materials making up the laminations of the resultant body, and the provision of new and unique methods and processes which are well adapted for use in the production of printed circuits and related techniques applicable to the field of electronic equipment.

Another object of the present invention is the deposition of magnetic films within a magnetic field, thereby achieving an alignment of magnetic domains within the structure of the films as they are being deposited. A domain may contain from 10^{12} to 10^{15} atoms. The domains are magnetized to saturation with the magnetic moments of all of the spinning electrons within each domain parallel to one another. A rectangular shaped magnetic hysteresis loop is obtained in the performance of a magnetic core which embodies this invention if the direction of the lines of force of the applied constant magnetic field coincides with the direction of magnetization to which the finished core is subjected. This method of the deposition of material within a magnetic field permits domain alignment even in materials with low Curie temperature, inclusive of materials which do not respond to the method of domain alignment by annealing the materials in a magnetic field.

Another object of the present invention is to produce and to provide a method of making a permanent magnet which is characterized by thin laminations, by a flaky lamination structure, or by the existence of stresses within the laminations. The production methods described herein for making thinly laminated permanent magnets are in some respects the same as for soft magnetic cores. The greatly increased coercive force which characterizes permanent magnets is due mainly to; first the greater thinness of the permanent magnet laminations, in comparison to the laminations of soft magnetic cores; and secondly to the presence of stresses within the films of the permanent magnets which stresses are desirable.

The high coercive force of a magnetic film of a certain critical thickness is believed to be due to the fact that such films become single magnetic domains and that domain rotation is the predominant mechanism of magnetization. Coercive force is increased by stress and by

crystal anisotropy. These factors determine the optimum film thickness at which the highest possible coercive force can be obtained. Theoretical work on the magnetic domain structure and on the coercive force of films and small particles is illustratively presented in "Theory of Structure of Ferromagnetic Domains," by C. Kittel, published in the Physics Review, volume 70 at pages 965 to 971, in 1946.

In the field of permanent magnets, illustrative film thicknesses of iron laminations are in the order of several hundred angstrom units. Thinner laminations are obtained by shortening the time periods during which the lamination material is evaporated; by a reduction in the rate of evaporation of lamination material by using decreased voltages or power; by the dimensions of the stock from which the lamination material is evaporated; etc. Stresses in laminations are induced by reductions in the temperature of the substrate during the period of deposition; by using an insulating film between magnetic laminations which insulating film has a materially different coefficient of thermal expansion than the magnetic laminations have; and the like.

Another object of the present invention is the provision of domain oriented laminated magnets wherein the magnetic lamination material is characterized by high crystalline anisotropy, of which magnesium bismuth may be taken as being illustrative.

Illustrative embodiments of the present invention of magnetic cores and of equipment used in methods by which the cores are produced, are illustrated in the accompanying drawings of equipment positioned within an inclosure which may be evacuated or which may be filled with a low pressure gas atmosphere, in the order illustratively of about one tenth of one atmosphere.

In the accompanying drawings of equipment for practicing the present invention:

FIG. 1 is a diagrammatic fragmentary illustration of an inclosure containing a substrate to which laminations are applied; in FIG. 1A from heated crucibles; in FIG. 1B from sputtering cathode rods; and in FIG. 1C from sputtering electrode rods to which alternating current is applied;

FIG. 2 is a fragmentary diagrammatic illustration of a base metal or a substrate to which laminations are applied from one electrode or from desired alternations of electrodes of an electrical arc;

FIG. 3 is a fragmentary diagrammatic illustration partly in section of a continuously moving base strip to which desired laminations are supplied from fixed crucibles;

FIG. 4 is a diagrammatic fragmentary sectional illustration of a periodically moving base strip passed over heated lamination supplying fixed crucibles;

FIG. 5 is an end elevational view of a rotating cylindrical substrate with lamination material vaporizing boats on opposite sides of a partition of a cylinder;

FIG. 6 is a perspective elevational view of a transformer with a secondary which is an open top ceramic shell containing a material to be vaporized;

FIG. 7 is a sectional view taken along the line 7—7 of FIG. 6 of the ceramic shell therein;

FIG. 8 is a diagrammatic view, partly in section, of a centrally apertured concave cathode shaped to focus emitted electrons upon a target from which vapors are emitted for solidification upon a substrate;

FIG. 9 is a side, elevational view, partly in section of particles dropped into an induction heating coil within which the particles are vaporized for deposition upon a substrate; and

FIG. 10 is a fragmentary sectional view of a lamination grooved permanent magnet.

In the accompanying drawings FIG. 1 illustrates a substrate 1 mounted in a magnetic field suitably provided, as by a magnet 2 energized by a winding 3, by a permanent magnet or the like. The use of the magnet accomplishes domain alignment and crystallographic orientation within the resultant magnetic laminations deposited upon the substrate, if the substrate temperature is below the Curie temperature of the magnetic material being solidified. In FIG. 1A a pair of containers, such as crucibles 4 and 5 are separately energized by a switch 6 from a power source 7. The substrate 1 and the crucibles 4 and 5 are positioned within an inclosure, indicated by a dash line 9. If preferred the magnet 2, the switch 6 and the power source 7 may be positioned outside of the compartment 9.

Current from the power source 7 vaporizes the contents of the crucibles 4 or 5, which then solidifies on the substrate 1 with the compartment 9 evacuated. Vapor from the crucible 4 may be a ferromagnetic material, such as iron, and vapor from the crucible 5 may be an electrically insulating material, such as magnesium fluoride or the like. As the crucible temperature is increased, vapor from that crucible solidifies as a film or a lamination, upon the substrate 1. The crucibles 4 and 5 may be of greater number, if preferred. The crucibles may be heated separately or together for alloys and thereby caused to give off vapors 4', 5', etc. which deposit as liminations 4", 5", etc. on the substrate 1. The crucibles may be resistance heated, inductance heated, heated by electron bombardment, or by similar methods.

The equipment shown in FIG. 1, which is inclusive of sub-FIGURES 1A, 1B and 1C, is applicable to crucible heating and to sputtering from holder supported rods 4B and 5B in FIG. 1B and holder supported rods 4C and 5C in FIG. 1C. In the sputtering process the compartments 9B and 9C are filled with an inert gas, such as argon maintained at a low pressure. In FIG. 1B the power source 7B is of sufficiently high voltage to maintain a gas discharge and is connected to a counter electrode 8 within the inclosure 9B. During sputtering in FIG. 1B a gas discharge is maintained between the material sources 4B or 5B and the counter electrode 8. The laminations may be deposited from a desired plurality of material sources acting as cathodes consecutively connected to a suitable power source.

A modified sputtering method concerns the use of the material sources 4 and 5 as electrodes connected to an alternating current source 7C shown in FIG. 1C.

Laminations of most magnetic substances can be made by the equipment and the method described above, using the apparatus shown in FIG. 1, as well as other apparatus to be described hereinafter. The sputtering of the lamination material is particularly advantageous with iron alloys which contain embrittling amounts of silicon, aluminum, cobalt and the like.

Electrically and magnetically poor conductor and nonconductor lamination materials illustratively are oxides, nitrides, halides, borides and related compounds of iron, silicon, aluminum and the like, which form relatively insulating films on previously deposited laminations. The iron oxides and the iron nitrides permit a simplification in the operation of the apparatus in FIG. 1A. As a modification in the use of the apparatus in FIG. 1A of the accompanying drawing, instead of two lamination material sources a single source of iron or an iron alloy, is adequate and the single source remains permanently connected across the power supply 7.

In the practice of this modification of the present invention a lamination such as 4" may consist of iron or iron alloys permanently heated in a single crucible of the assembly. The lamination 4" of iron may be followed by a successive lamination 5" of iron oxide by the admission of oxygen into the continuously evacuated inclosure 9. A venturi nozzle 9' intermittently directs a high velocity stream of oxygen toward the iron lamination. The oxygen molecules have a kinetic energy which speeds up the rate of reaction between the iron and the oxygen. The venturi nozzle 9' also causes the oxygen to avoid contaminating the lamination material source. The compartment 9 is again evacuated and a third lamination of

iron is deposited. Repetitions of the process provide consecutive depositions of iron and iron oxide which then comprise the laminations on the substrate 1. The substitution of nitrogen for oxygen in the above described process permits the building up upon the substrate 1 of laminations of iron alternated with iron nitride, where preferred. In a similar manner laminations of different compounds from a greater or lesser number of sources may be built up upon the substrate 1 with the equipment shown in FIG. 1. If desired the laminations so built up may be peeled away from the substrate 1 in many of the constructions described herein.

In FIG. 2 of the accompanying drawing is shown a centrally apertured circular substrate 10 to one surface of which laminations are applied. The laminations may come from electrodes 11 and 12 connected through supports 13 and 14 to a power source 15. When an arc is struck between the electrodes 11 and 12, vapor from either or both of the electrodes solidifies as a lamination upon the substrate.

A desired rate of electrode vaporization and a desired alloy deposit can be obtained by a proper composition of electrode materials; by the diameter of the electrodes 11 and 12; by the current density of the arc; by the type and polarity of current; and by the time duration of its application.

Illustratively, the electrode 11 may be made of iron and the electrode 12 may be made of nickel, in which case the laminations on the substrate 10 would be alternately iron and nickel or an iron-nickel alloy, depending upon whether the potential from the power source 15 is direct current or is alternating current respectively.

If desired nonmetallic laminations can be alternated with metallic laminations by intermittently admitting oxygen or nitrogen through a venturi nozzle, as in FIG. 1A, to oxidize or to nitride a metallic lamination. Magnetic domain orientation within the laminations deposited upon the substrate 10 is accomplished by the magnetic field surrounding the electrode 12. This equipment is particularly desirable in the production of ring-shaped cores used in magnetic amplifiers, computers and the like.

FIG. 3 of the accompanying drawing represents a base strip 20 which moves in the direction indicated by the arrow, either continuously or intermittently, as preferred, over one or more rows of a desired number of continuously heated crucibles 21, 22, etc. which individually give off the vapors of their contents. As the strip 20 moves along over the crucibles 21, 22, etc. the strip 20 has applied thereto successive laminations 21', 22'', etc. until a desired plurality of laminations is carried by the strip. The resulting laminated strip is provided with a desired plurality of laminations depending upon the number of applications of vaporized crucible contents over which the strip 20 passes. The equipment illustrated in FIG. 3 of the drawing may be operated within an evacuated container, or it may pass through a plurality of atmospheres, if preferred, and has the advantage of being a continuous laminated strip producing apparatus. The lamination depositions may be accomplished within a magnetic field for the purpose of aligning magnetic domains therein, if desired.

In FIG. 4 of the accompanying drawing a base strip 25 is caused to move intermittently over a desired plurality of crucibles 26, 27, etc. The crucibles illustratively may be of open topped shape, and may be inductively heated by coils 30, 31, etc. or the like. The travelling strip 25 is stopped for predetermined periods of time in order that each crucible may apply its contents as a lamination of a predetermined thickness on the strip 25. The equipment represented in FIG. 4 may be caused to operate within an inclosed furnace or within a furnace having a regulated atmosphere. It will be apparent that the shape and the contour of the ring laminations applied to the underside of the intermittently moving strip 25 may, if desired, be other than apertured circles to meet a particular demand.

In FIG. 5 of the accompanying drawing is shown a substrate or a base cylinder 35 which is adapted for rotation around a stationary axially extending divider 36. The divider 36 separates vapors from a desired plurality of stationary boats 37, 38, etc. Additional dividers may be positioned within the cylinder 35 and may provide lamination material vapor deposition compartments for additional stationary boats, if preferred, within the scope of the present invention. Vapors rising from the boats within the rotating cylinder 35 supply successive laminations to the cylinder, as the rotation of the cylinder 35 leaves one compartment to which vapor is applied from a first crucible and enters a second compartment supplied by vapors from a second crucible. A stationary winding 39 provides a magnetic field for magnetic domain alignment within the magnetic laminations which are successively applied to the inside of the rotating cylinder 35.

Continuous films or laminations of magnetic and insulating materials may be deposited by this method on the inside of the cylinder 35. The contents of the crucibles may be evaporated or may be sputtered, if preferred, to form a desired number of successive laminations. In this installation, as well as in others described herein, the crucibles or boats 37, 38 or the like, are fixed in position and when provided with separate electrical circuits their temperatures and their times of functioning are separately controlled so that the laminations which are applied thereby are of controlled thicknesses or are of different combinations of materials, within the scope of the present invention. The circuit heating the crucibles or boats 37, 38, etc. may be wired in series by leads 40, 41 and 42, as shown, to also supply a magnetic field and thereby in part orient the magnetic domains within the laminations, if preferred.

The crucibles or boats which are discussed herein and are intended for the melting therein of iron, iron ores or the like, may be made of electrically conductive oxides and hydrides of titanium, zirconium and the like, if the resistance heating through the crucibles or the boats is to be employed.

FIG. 6 of the accompanying drawing is a transformer consisting of a magnetic core 45, a primary winding 46 and a closed loop secondary 47. The transformer secondary 47 consists of a closed loop, open top ceramic shell which illustratively contains a metal 48 in its molten state. FIG. 7 is a sectional view of the ceramic shell transformer secondary 47 which is designed to reduce the current carrying cross section of a part of the molten metal 48 within the transformer secondary. The reduced molten metal cross section increases its resistance and its temperature at the more shallow part of the secondary winding. The molten metal reduced cross section preferably is outside of the magnetic core 45, so that the vapor stream from the more shallow portion of the molten metal 48 is not obstructed by other parts of the transformer primary core 45. The lateral dimension between the walls of the shell may be reduced locally to achieve the same result of a decreased cross section of molten metal.

FIG. 8 of the accompanying drawing is a substrate or a base metal 50 to which successive laminations of different materials are applied from a lamination source material 51 which may consist of a metal alternated with an insulator, or it may be of a uniform composition, or of a desired number of compositions, as preferred. The source material 51 shown is a rod which is continuously fed for vaporization, such that its end to be melted or vaporized is at a predetermined proximity to a cathode 52 which is apertured centrally at 53. Vaporized laminations of the rod 51 pass through the cathode aperture 53 in approaching the substrate 50 for adherence to the substrate or to laminations previously applied thereto. The rod 51 is adjustably positioned within a support

54. The material of the rod 51 is heated and is evaporated only locally at the tip of the rod by the concentration of fast electrons given off from the concave surface of the cathode and directed to the tip of the rod 51. The cathode 53 and the rod 51 are supplied a potential from a power source 55 which is adequate to accomplish the vaporization of the lamination forming materials comprising the rod 51.

In FIG. 9 of the accompanying drawings is shown an apparatus for accomplishing the deposition of laminations upon the inner surface of an illustratively rotating cylindrical substrate 60. Pellets 61, 61' etc. of desired lamination materials preferably are preheated and then are carried by a suitable device such as a conveyor belt 63 and are discharged into an electromagnetic field of an induction heating coil 66 or the like, where the particles are evaporated. The conveyor belt 63 moves in the direction shown by the arrow on wheels 64 and 65. The induction coil 66 may, if preferred, be replaced by a capacitor, a crucible or the like. A magnetic field within which the laminations solidify with magnetic domain alignment may be provided where desired, as in FIG. 5.

An outstanding advantage of the electron bombardment equipment represented in FIG. 8 of the drawing and of the use of inductive and dielectric heating using the equipment shown in FIG. 9, is complete freedom from contamination of the lamination material by avoiding contact with other materials.

In FIG. 10 of the accompanying drawings is shown a substrate 70 upon which is deposited a first magnetic lamination 71, which has been scraped by a steel wire brush 75 or the like. The brush scraping provides a plurality of ribs extending along and partly or all of the way through the thickness of the lamination. The lamination so modified has bonded thereto a nonmagnetic second lamination 72. A desired plurality of additional scraped magnetic and nonmagnetic laminations 73 and 74, respectively, may be bonded to the first pair of laminations.

Improved permanent magnet characteristics are obtained if magnetic laminations of proper thickness are broken up or are divided into narrow strips or flakes. The strips or flakes then become single magnetic domains, according to magnetic theory, and display extremely high coercive force. The direction of the magnetic field during the production and in later use as permanent magnets is parallel to the strips and laminations. A preferred method of producing improved permanent magnets of the narrow strip or flake construction is accomplished by applying grooves to the magnetic films on the inside of the cylinders in FIG. 5 and in FIG. 9, such as the film 71 preferably immediately after the film is formed. The film may be flat, curved or of other contour. The grooves may be applied to a film by scratching it with a fine wire brush or other tool, to make the striations extend substantially in a single direction. The wire brush 75 shown enlarged in FIG. 10 of the accompanying drawings preferably may be removably positioned within the cylinder 35 of FIG. 5 so that it scratches striations or grooves in the magnetic films as they are being deposited on the inner surface of the hollow cylinder 35 during its revolution. In a similar manner the wire bristle brush 75 shown in FIG. 10 may be correspondingly mounted to impart striations in the magnetic films or laminations in the continuous process shown in FIGS. 3, 8 and 9.

In FIGS. 3 and 8 the deposits of laminations occur, preferably although not necessarily, within a magnetic field provided by a magnet, such as the magnet 2 in FIG. 1 or the like, which is omitted from the FIGS. 3 and 8 for purposes of clarity of presentation. The width of the strips of the magnetic film as scratched need not be uniform. Striated strips may be deposited during the production of the lamination by positioning a screen or a stencil, not shown, between the vapor source and the successive laminations applied to the substrate, within the scope of this invention.

The open tapped ceramic shell transformer secondary 47, shown in FIGS. 6 and 7 of the drawings, illustratively is shown as a step-down transformer, since the secondary has a single winding, and is shown as a means for evaporating lamination material and as such is adapted to replace corresponding lamination material vaporizing means shown elsewhere in the drawings where such substitution is desirable.

The nonferromagnetic laminations may be made as thin as possible consistant with their insulating functions. A high ratio of ferromagnetic material to nonferromagnetic material is thus obtained. This characteristic results in optimum magnetic properties for the magnetic cores and the permanent magnets, the making of which are primary objects of the present invention. The thicknesses of ferromagnetic laminations in magnetic cores and in permanent magnets is in the order of about from 10^{-3} to 10^{-7} inch. The thicknesses of nonferromagnetic laminations are maintained at a minimum consistent with needed insulating characteristics, whether the insulator be nonmagnetic or electrically nonconductive. Ferromagnetic metals cannot be rolled successfully to a thinness below 10^{-4} inches. The deposits from vapor of laminations of ferromagnetic materials is accomplished by the vaporizing equipment and by the methods which are disclosed herein making laminations of thicknesses below 10^{-4} inches.

In practicing the processes disclosed herein and in passing oxygen or nitrogen through the nozzle 9', the substrates and the laminations deposited thereon are at a desired high temperature from heat energy radiated from the crucibles or from another source, as required.

It is to be understood that the equipment that is disclosed herein and the described methods for its use may be modified somewhat within the scope of the present invention where there are particular advantages to be derived therefrom within the scope of the present invention, where the modifications accomplish the same or comparable results.

What I claim is:

1. The apparatus for continuously building a plurality of laminations upon the inside of a rotating cylinder comprising a rotating hollow cylinder, means imparting a magnetic field to the cylinder, and a plurality of series connected electrically heated vapor supplying means within the cylinder, and partition means positioned inside of and diametrically across the inside of the cylinder between the vapor supplying means and restricting the vapor distribution within the cylinder.

2. An apparatus for vaporizing a material comprising a transformer consisting of a pair of primary and secondary windings, the secondary windings consisting of an upwardly open container having a decreased section high temperature portion from which an electrically conductive material is vaporized.

3. An apparatus for solidifying magnetic laminations comprising a substrate, a substantially concave cathode emitting electrons from a concave electron emission surface, a lamination source material tip heated to vaporization by electron bombardment from the concave electron emission surface of the cathode and which vaporized lamination source material solidifies as laminations on the substrate, and an electric power source applied to the cathode and to the lamination source material and sequentially vaporizing the lamination source material.

4. An apparatus for consecutively solidifying a plurality of different laminations comprising a hollow cylinder substrate, an induction heating coil within the cylinder, conveyor belt means for consecutively introducing into the induction coil a plurality of materials discharged into the electromagnetic field of the induction heating coil and deposition as adhering laminations upon the inner surface of the cylinder.

5. The apparatus for solidifying a plurality of laminations on a substrate base comprising a rod that consists of a plurality of superimposed material compositions adhered together for the length of the rod and the rod having a melting end and a supported end, a rod support engaging the supported end of the rod in adjustable relation therewith, a cathode with a concave surface for directing fast electrons to the melting end tip of the rod when a sufficient potential difference is applied across the cathode and the rod of sufficient magnitude to vaporize the rod material and the cathode being apertured centrally, a base metal substrate spaced from the side of the cathode remote from the rod and to a surface of which substrate vaporized lamination material from the rod tip contacts and solidifies as films after having passed through the aperture in the cathode, and a power source applying a potential difference across the cathode and rod.

6. The apparatus for successively solidifying a plurality of laminations on a centrally apertured circular substrate base that comprises a pair of aligned electrodes between which an arc may be struck, a power source connected for supplying power to the pair of electrodes for maintaining an arc therebetween, a pair of electrode supports separately attached between the electrodes and the power source, and a centrally apertured circular substrate base through which aperture one of the electrodes extends and maintains a magnetic field within which the substate is positioned and to one surface of which substrate laminations come in vapor state from electrolytic action between the electrodes following the striking of an arc therebetween whereafter the vaporized electrode material solidifies as laminations upon the substrate within the magnetic field maintained by the electrode that passes through the substrate base.

7. The apparatus for solidifying a plurality of circular laminations on a substrate base strip comprising a base strip movable linearly thereof intermittently for predetermined periods of time and stopped for intervening periods of time, a plurality of open-topped crucibles of circular shape with their open tops adjacent the base strip and with their contents vaporizing and adhering as rings on the adjacent base strip surface during the periods the base strip is stopped over the crucibles, and a plurality of inductive heating coils on the crucibles for vaporizing the contents thereof.

8. The apparatus for continuously building laminations on the inside of a rotating cylinder comprising a rotating hollow magnetizable substrate cylinder, means imparting a magnetic field to the cylinder, vapor supplying means within the cylinder from which vapor supplying means vapors are deposited within the cylindrical magnetic field in adhering to the inner surface of the cylinder substantially solid successive laminations characterized by uniformly aligned magnetic domains, and divider means within the cylinder and limiting the area of deposition of vapor from the vapor supplying means and adhering to the inner surface of the cylinder.

9. A method for producing a body of thin laminations from a laminated rod by successively vaporizing the laminations of the rod from a rod end that is continuously fed for vaporization at a predetermined proximity to a cathode that is apertured centrally, and by solidifying in the same succession the vapors that pass through the cathode aperture in approaching the body and adhering thereto as thin laminations adhered together.

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