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MAGNETIC DATA STORAGE DEVICES

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3 Claims. (Cl. 29—183.5)

ABSTRACT OF THE DISCLOSURE

A strain-insensitive magnetic storage device which has uniform magnetic properties and may be economically produced by mass production techniques is formed by interposing an intermediate layer of copper with a randomly-oriented fine-grained surface between a Phosphor-bronze or a copper-beryllium substrate and a saturable ferromagnetic coating.

This application is a continuation of United States patent application Ser. No. 158,885, now abandoned, filed Dec. 12, 1961, in the name of Ignatius Tsu, inventor.

The present invention relates generally to magnetic circuit devices and more particularly to a new and improved process for fabricating new and improved magnetic data-storage devices which are capable of being utilized by electronic computers and data processors for information storage and logical purposes.

In a publication by Jan A. Rajchman entitled "Computer Memories: A Survey of the State of the Art," in the January 1961, issue of the Proceedings of the IRE, substantially all of the various types of devices which have heretofore been proposed for utilization by electronic computers and data processors for information storage and logical purposes are briefly described. In copending United States patent applications Ser. No. 696,987, of John R. Anderson et al., which was filed Nov. 18, 1957, now Patent No. 3,042,997; Ser. No. 791,695, of Ignatius Tsu, now abandoned, which was filed Feb. 6, 1959; Ser. No. 31,573, of Harold E. Haber et al., which was filed May 25, 1960, now Patent No. 3,031,648; and Ser. No. 143,018, of Richard M. Clinehens et al., which was filed Sept. 29, 1961, now Patent No. 3,197,749, and in United States Letters Patent No. 2,945,217, which issued on July 12, 1960, on the application of Robert D. Fisher et al., all of which are assigned to the present assignee, there are disclosed various other novel types of magnetic data-storage and logical devices in which binary information is stored in a preferred magnetic flux path established therein.

More particularly, various types of magnetic data-storage devices having an elongated physical configuration are disclosed therein which possess an easy or "preferred" direction of magnetization which is oriented at a predetermined angle with respect to the longitudinal axis of the device. It is also demonstrated therein that coincident current techniques may be successfully utilized to effect the storage of information in the preferred flux path established in the device, regardless of the angular orientation of the preferred flux path with respect to its longitudinal axis. Further illustrated therein are several unique methods by which there is established in the device a preferred angular flux path having substantially any predetermined orientation; viz, by producing a quiescent torsional stress anisotropy in a ferromagnetic coating which is electrodeposited on an elongated, electrically conductive substrate, which stress causes a preferred path of magnetization to be established within the coating along the path of greatest compression; by applying a torsional stress to the ends of an elongated, electrically conductive substrate prior to and during electrodeposition of the ferromagnetic coating thereon, and thereafter ceasing to apply the torsional stress and allowing the substrate to approach its initial unstressed condition, whereby a preferred path of magnetization is again established in the coating along the path of greatest compression; by depositing the ferromagnetic coating onto the substrate in the presence of a magnetic field in such a manner that the preferred path of magnetization established therein is oriented in the same direction as the applied field; by threading or micro-grooving the substrate prior to the formation of the ferromagnetic deposit thereon in such a manner that a mechanical hard direction of magnetization is imposed which causes an easy direction of magnetization to be established in the deposit which is in the same direction as the micro-grooves; and by utilizing a plating bath containing specific ionic constituent concentrations.

Because substantially all of the above-described devices were found to be highly strain-sensitive after fabrication, it was found necessary to utilize a substrate of Phosphor-bronze or copper-beryllium alloy in the manner described in the before-mentioned United States Patent No. 3,031,648. Even though the utilization of Phosphor-bronze and copper-beryllium alloys as the supporting substrate material substantially solved the problem of strain sensitivity, there was still found to exist the problem of producing acceptable devices having uniform magnetic properties throughout their length; consequently, the above-described magnetic devices have not heretofore been capable of being economically fabricated by mass production techniques and thereby maintaining their costs at a minimum.

One object of the present invention is to devise a new and improved process for fabricating magnetic data storage devices which are capable of being utilized by electronic computers and data processors for information storage and logical purposes.

Another object is to devise new and improved magnetic data-storage devices that have consistently uniform magnetic properties throughout their recording area from one device to another.

Still another object of the present invention is to devise new and improved magnetic data-storage devices which are readily adaptable to mass production techniques using the process of the present invention.

A more specific object of the present invention is to devise new and improved magnetic data-storage devices which may be economically fabricated by mass production techniques and which have consistently uniform magnetic properties from one device to another and are readily adaptable to be utilized by electronic computers and data processors for information storage and logical purposes.

Briefly, in accordance with the present invention, such new and improved magnetic data-storage devices are fabricated by a process which comprises the steps of, first, overlaying a non-magnetic and electrically conductive substrate of an alloy of either Phosphor-bronze or copper-beryllium with a metallic copper coating having a fine-grained, randomly oriented type of surface and, thereafter, depositing a ferromagnetic coating onto the surface of the copper coating.

More specifically, the core or supporting substrate, onto which the magnetic deposit is to be formed, is desirably a stiff, resilient, and wire-like filament of either Phosphor-bronze or copper-beryllium alloy and has a circular cross-section of an average diameter in the order of 2 to 50 mils. Prior to deposition of the magnetic coating thereon, the substrate is first rigorously cleansed by any of the conventional alkaline-acid-water methods well known to the plating industry. For example, immersion in a commercially available alkaline solution known as "Shipley's Alkaline Cleaner" has been found to give excellent results. However, it is preferred that the substrate be subjected to a conventional cathodic alkaline type of cleaning action in which the substrate is immersed as a cathode in an alkaline solution comprising approximately 45 grams/liter of a commercially available cleaner known as "Oakite's Cleaner No. 91" and approximately 12 grams/liter of a commercially available cleaner known as "Oakite's Cleaner No. 91A." The substrate is maintained in the cleaning solution for a period of from 7 to 10 seconds and operated as a cathode at a current density of from 20 to 50 amperes per square foot. Upon emergence from the cleaning bath, the substrate is thoroughly rinsed with distilled water and then immersed in an 18% to 50% hydrochloric acid solution for a period of approximately 7 to 10 seconds in order to remove any oxide layer existing on its surface, and also to activate the surface. Thereafter, the substrate is again thoroughly rinsed with distilled water.

Immediately following the just-described cleaning operation, the substrate is subjected as a cathode to electrolytic action in an aqueous plating solution maintained at room temperature and containing approximately 150 grams/liter of copper sulfate ($CuSO_4 \cdot 5H_2O$) and approximately 60 grams/liter of concentrated sulfuric acid (H_2SO_4). The substrate is maintained immersed in the plating solution for approximately 50 seconds and operated as a cathode at a current density of approximately 227 amperes per square foot, during which time a fine-grained nucleated copper coating is electrodeposited on the surface thereof. The grain size of the copper coating has been found to be in the order of from .1 to 1.0 micron and to be randomly oriented and therefore isotropic.

It is to be noted that the particular method just described for depositing a fine-grained, randomly-oriented copper coating onto the surface of the supporting substrate, prior to deposition of the ferromagnetic deposit thereon, is not critical, and any of the various other well-known methods of "copper flashing" may be used with equal success. The only restriction is that the copper coating be fine-grained, randomly-oriented, and of a thickness sufficient to effectively remove all epitaxial effects of the depositing surface of the supporting substrate. Undesirable epitaxial effects arise in a ferromagnetic coating that is deposited on wire substrates that are manufactured by conventional manufacturing methods, since the microscopic surface characteristics of these substrates have an elongated orientation. When the ferromagnetic coating is deposited over the randomly-oriented copper coating of the present invention, which is deposited directly on the wire substrate, these undesirable epitaxial effects do not arise in the ferromagnetic coating.

An exemplary aqueous electrolytic plating solution capable of being utilized for effecting the deposition of a ferromagnetic coating onto the copper-coated substrate is made up of the following constituent concentrations measured in grams/liter of aqueous solution:

	G./l.
Ferric chloride ($FeCl_3 \cdot 6H_2O$)	8
Nickel chloride ($NiCl_2 \cdot 6H_2O$)	20
Ammonium chloride (NH_4Cl)	50
Ammonium citrate [$(NH_4)_2HC_6H_5O_7$]	40
Ammonium heptamolybdate [$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$]	.5

After the above plating solution has been prepared and its pH adjusted to approximately 8.6 by the addition of approximately 40 milliliters/liter of ammonium hydroxide (NH_4OH), its temperature is preferably adjusted to approximately 88 to 90 degrees centigrade, even though the plating operation may be successfully carried out at room temperature; thereafter, the plating solution is introduced into a plastic-lined plating tank or an equivalent inert container.

As disclosed in the aforementioned copending United States patent applications, in the fabrication of the "twistor" type of magnetic data-storage devices it is desirable to secure a relatively thin deposit on the supporting substrate in the order of one ten-thousandth of an inch, so as to maintain eddy current losses therein at a minimum during operation of the device, and yet be thick enough to insure adequate output and not fracture when torsional stresses are subsequently applied thereto. Consequently, it is desirable that the previously-described copper-coated substrate be exposed as a cathode in the plating solution for approximately 60 seconds at a current density of approximately 500 amperes per square foot of cathode surface area exposed in the plating solution. It is also preferred that the process be a continuous one in which the cathodic substrate is drawn through the plating solution with minimum tension exerted thereon and at a constant speed, with electrical contact at all times maintained therewtih in order that the desired constant plating current may be supplied thereto. Additionally, it is preferred that the substrate be centrally encompassed at all times while in the plating solution by a helically-shaped anode having a coil diameter of approximately one inch and composed of a molybdenum wire approximately 50 mils in diameter.

It is to be appreciated that the specific plating process herein shown and described for depositing a saturable ferromagnetic coating onto the before-described copper-coated beryllium-copper or Phosphor-bronze substrate is exemplary only, and any of the various plating processes disclosed in the before-referred-to United States Letters Patent and abandoned United States platent application may be used with equal success, in addition to various other well-known processes for forming the desired coating on the supporting substrate.

On emergence from the plating bath, the ferromagnetic element is rinsed and dried and is then ready to be operated as a coincident current "twistor" type of data-storage device in the following manner:

The substrate, along with the ferromagnetic coating, is simultaneously stretched and twisted, and its ends are thereafter held in a fixed position. As a result of the stretching and twisting actions, an easy direction of magnetization is established in the coating and is oriented from a direction substantially parallel to the longitudinal axis of the substrate to one of substantially helical configuration about the body of the substrate and throughout the length in the same manner as the threads of a screw. Due to the fact that the ferromagnetic coating has been found to possess a substantially high positive and negative magnetic remance and a substantially rectangular hysteresis loop, selected length portions of the coating, in the direction of twist, are allowed to attain one or the other of the two stable states; namely, a residual positive or negative magnetic remanence. Therefore, a magnetic field of $\pm$ H oersteds, applied along the direction of twist, switches selected length portions from one remanent state to another, whereas a field of $\pm$ H/2 oersteds produces only negligible changes in the residual magnetic remanence. A plurality of similar coils are separately wound about the coated wire-like substrate and are positioned in a spaced side-by-side relationship with respect to one another to define a corresponding plurality of helical-path length portions of saturable ferromagnetic material. Storage of binary information in a select length portion of the coating is accomplished by sending a current impulse of "half-select" magnitude down the conductive substrate and simultaneously sending a second current impulse of "half-select" magnitude into the select coil, in such directions that the vector summation of the magnetic fields produced by the two coincident currents is equal in magnitude to $\pm$ H oersteds and is oriented in the same direction as the direction of twist, and hence in the same direction as the easy direction of magnetization of the coating.

During reading of a selected length portion of the coating, the corresponding coil is energized with a full-select current impulse to individually develop a magnetic field of ± H oersteds in the opposite direction from the magnetic field developed during storage of the function. In response to the read impulse, an electrical signal is or is not available across the ends of the substrate, depending upon whether the binary information 1 or 0 had previously been established in that particular length portion of the coating, as represented by its remanent state of magnetization.

Listed below in chart form are the electrical operational characteristics of a "twistor" type of magnetic data-storage device which was fabricated in accordance with the teachings of the present invention.

Amount of twist applied to ends of substrate °/inch	18
No. turns/coil	20
Half-select substrate write current ma	64
Half-select coil write current ma	32
Full-select coil read current ma	200
Half-select noise across ends of substrate mv	10–15
Signal output across ends of substrate mv	100–150
Signal-to-noise ratio	10
Switching time μ sec	<.3
Diameter of substrate mils	3
Hysteresis squareness approx	99
Magnetic coercivity oersteds	<2

The magnetic devices fabricated in accordance with the present invention, in addition to possessing the desirable magnetic properties listed above, have also been found to possess extremely uniform magnetic properties along their entire length, which properties are reproducible from one device to another. Consequently, the plating process used to produce the magnetic data-storage devices of the present invention is ideally suited to be operated as a continuous plating process in which the wire-like substrate is initially stored on a suitable reel in lengths of several hundred feet or more and is continuously fed therefrom through the various previously-described cleaning and plating solutions, thereby mass-producing the magnetic devices and thus maintaining their cost at a minimum.

While a particular embodiment of the present invention has been shown and described in detail, it will immediately be obvious to those skilled in the art that changes and modifications may be made without departing from the teachings of the present invention. For example, while the uniqueness of the present invention has been demonstrated with respect to new and improved "twistor" types of data-storage and logical devices, it is of course quite obvious that the present invention is equally applicable and adaptable to be utilized in the new and improved "bit wire" types of devices such as those initially described and claimed in the aforementioned abandoned United States patent application, Ser. No. 791,695, and said United States Letters Patent No. 2,945,217, in addition to those and similar devices described in the aforementioned publication. Therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. In a magnetic data storage device comprising a stiff, resilient, and wire-like substrate of an alloy of Phosphor-bronze or copper-beryllium, the substrate having an average diameter on the order of 5 to 50 mils and having a substantially uniform structural cross-section throughout a major portion of its length, and a saturable ferromagnetic coating having a substantially rectangular hysteresis characteristic, said ferromagnetic coating extending throughout a major portion of the length of the substrate, the improvement comprising an intermediate coating of copper extending throughout a major portion of the length of the substrate and having a randomly-oriented fine-grained surface, said copper coating being deposited on the substrate to substantially eliminate the surface effect of the substrate upon the saturable ferromagnetic coating, the ferromagnetic coating being deposited on the copper coating.

2. A device as in claim **1** wherein the substrate is Phosphor-bronze.

3. A device as in claim **1** wherein the substrate is copper-beryllium.

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