

[54] **PLATED FERROMAGNETIC WIRE FOR WIRE MEMORY**
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[58] **Field of Search** **340/174 PW, 174 QA; 29/193, 199, 196.6, 191.6; 204/27, 28, 40**

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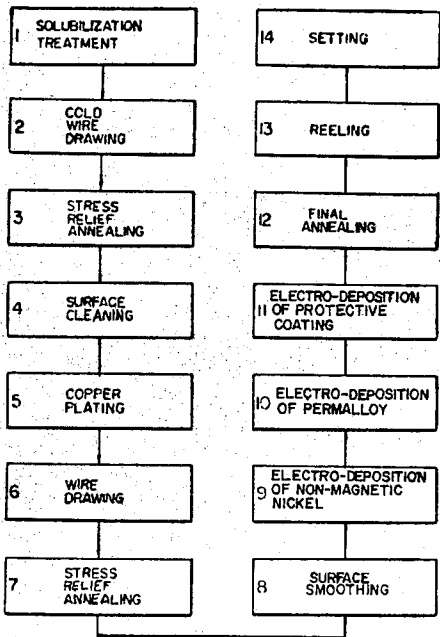
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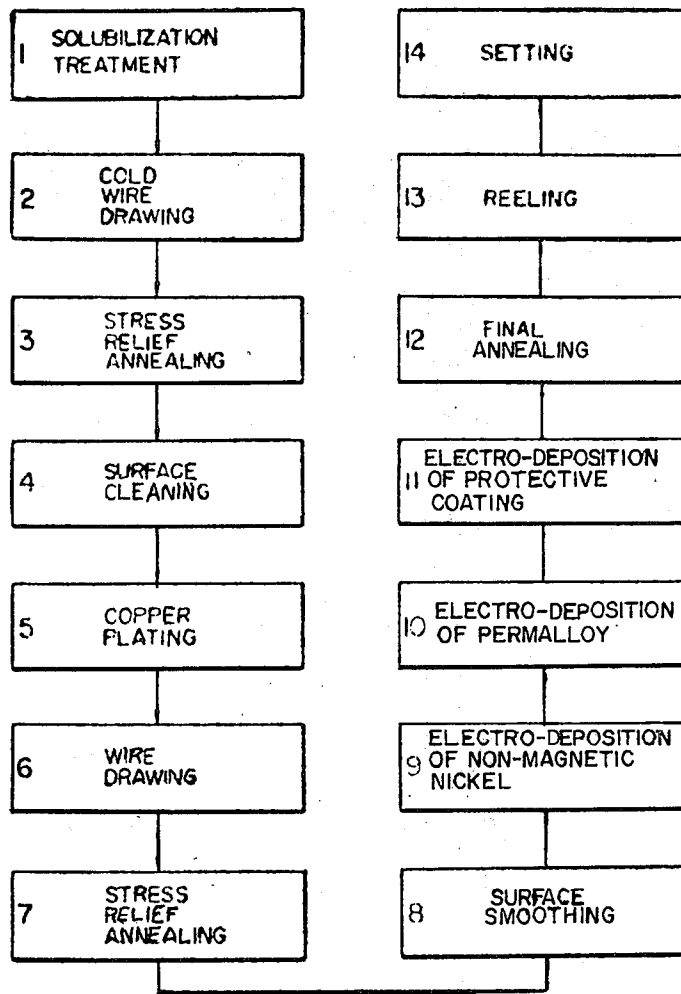
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[57] **ABSTRACT**

Plated ferromagnetic wire for wire memory, in which silver-copper alloy having precipitation-hardening property is used as the core wire. A method for manufacturing the plated ferromagnetic wire, wherein the core wire is heat-treated and coated with at least one layer of ferromagnetic material.

8 Claims, 1 Drawing Figure





PLATED FERROMAGNETIC WIRE FOR WIRE MEMORY

This is a continuation of application Ser. No. 834,080 filed June 17, 1969 and now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to plated wire for wire memory to be used for high speed memory device, etc. in electronic computers, and, more particularly, it is concerned with an improvement in the core material for the plated magnetic wire.

As the memory element, in which cylindrical ferromagnetic film is used, plated wires and clad wires are well known. Of these, the clad wire is manufactured by first covering a core wire of high electric conductivity with a thin tube consisting of magnetic material such as permalloy, etc., then simultaneously drawing both of the core wire and the thin tube to reduce the diameter thereof, and finally depositing a ferromagnetic substance on the core wire. On the other hand, the plated wire for the wire memory is manufactured by first reducing the diameter of the core wire to a required thickness, and then electro-plating on the core surface a magnetic material such as permalloy, etc.

From the preceding explanation, both types of wires appear to be very similar to each other in their construction. However, they are actually of different characteristics, and also are entirely distinct in the field of their application. These differences may be summarized as follows.

- a. In the case of the clad wire as the so-called bulk magnetic material which is shaped into a required configuration beforehand is used, it is not possible to reduce the crystal size of the ferromagnetic material less than 10 microns. Contrary to this, in the case of the plated wire, the crystal size can be reduced to less than 100A.
- b. In the case of the plated wire, thickness of the magnetic material can be made extremely thin, i.e., the thickness of less than 1 micron can be easily obtained. In contradistinction, the clad wire may have its minimum thickness of 3 to 4 microns at best.
- c. On account of the fact that the clad wire is fabricated by covering its core wire with a magnetic material shaped previously and stretching it in the axial direction thereof, the wire has an easy magnetization axis in its axial direction rather than the circumferential direction thereof. Contrary to this, since the plated wire is manufactured by electroplating the magnetic material on the core wire while applying a magnetic field thereto in the circumferential direction of the wire axis, the plated wire is provided with a ferromagnetic thin film having its easy magnetization axis in the circumferential direction of the wire axis.

In view of the above differences in the wire characteristics, the wire memory made of the clad wire is suited for constructing the memory element of a telephone switching system, wherein a semi-permanent memory element is required. In contrast to the clad wire, the reverse magnetization in the plated wire memory is not caused by the movement of the domain wall as in the case of the clad wire, but it is caused by the coherent rotation of magnetization. In this consequence, the plated wire is capable of causing extremely rapid reverse magnetization in comparison with the conventional reversing speed, and also of constructing the

memory device for high speed electronic computer, as the non-destructive reading is possible.

In principle, the plated wire memory is constituted by combining several numbers of memory planes, each being composed of the plated wires arranged in parallel at an equal space interval between them on one plane, and word lines also arranged in parallel at an equal space interval between them in an orthogonal direction with respect to the abovementioned plated ferromagnetic wires.

As the method for manufacturing the memory plane, the following are well known. The one is called a strip line coil type, in which the plated ferromagnetic wires are inserted into a tunnel sheet provided with a plurality of tunnels in parallel and at equal space interval to permit insertion of the plated wire, and, on both surfaces of the tunnel sheet, word coils are provided in the form of the strip line and intersecting with the plated wires. The other is called a woven type, wherein piano wires which correspond to the plated ferromagnetic wires and insulated conductor wires which correspond to the word lines are woven like weaving of cloth with the piano wires as the weft and the insulated conductor wires as the warp. In this case, the piano wires are subjected to tension and weaving is carried out as they are maintained straight without being bent in any way. Next, this woven wire cloth is fixed with resin, after which the piano wires are pulled out and the plated ferromagnetic wires are inserted into these places, whereby a memory plane is obtained.

The abovementioned plated ferromagnetic wire is fabricated by plating a magnetic alloy, etc. on a core wire which has high mechanical strength and high electric conductivity and whose surface is smoothed by an appropriate treatment. This plated layer is extremely thin of about 0.1 - 1 micron thick, and, in order for the plated layer to be electrically deposited uniformly and tightly on the core wire, the material of the core wire should have such property that electroplating thereon is easily carried out. Further requirements on this core material are that it should be able to maintain stability of ferromagnetic thin film after it is electro-plated thereon; it should have as high mechanical strength as possible in consideration of workability in constructing the memory planes; and it should have as high an electric conductivity as possible in view of the fact that electric current flows constantly therethrough during operation.

For such material that is capable of satisfying the abovementioned condition, attention is eventually drawn to hard copper or copper alloys, and there have heretofore been used phosphorus bronze or beryllium bronze, or the like as the core wire. These materials have been selected on the basis of their having excellent mechanical strength and higher electric conductivity than other metals or alloys in general, although these copper alloys are disadvantageously defective from the standpoint of easiness in plating. Particularly, in the case of beryllium bronze, the condition of the plated layer is inferior due to the fact that beryllium which has precipitated on the surface of the core wire is easily oxidizable, and that this oxide of beryllium produced on the surface of the core wire is liable to remarkably deteriorate the conditions of the plated material. Furthermore, the abovementioned two alloys are still not so sufficient in their electric conductivity. That is, the electric conductivity of phosphorus bronze is approximately 20 to 40% to that of pure copper, and ber-

yllium bronze approximately 40 to 60%.

SUMMARY OF THE INVENTION

It is therefore a primary object of the present invention to provide a specially improved plated ferromagnetic wire for wire memory which exhibits excellent capability when used as memory elements, etc. of high speed electronic computer as mentioned in the foregoing.

It is another object of the present invention to provide a plated magnetic wire which is superior to the heretofore known plated wires in its mechanical and electrical characteristics, particularly in its electrical conductivity.

It is still other object of this invention to provide a method for producing the plated magnetic wire.

The foregoing objects and other objects of this invention will become more apparent from the following detailed description of the invention when read in conjunction with the accompanying drawing, in which the single FIGURE represents a flow process chart for manufacturing the plated ferromagnetic wire according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As already stated in the foregoing, in order to obtain a wire memory having excellent performance, it is necessary that a core material for the plated magnetic wire capable of giving satisfactory condition to the plated material thereon be selected.

The present invention has been made on the basis of finding that ferromagnetic wires having excellent plated layer could be obtained by selecting a silver-copper alloy, wherein very fine crystals of silver precipitate on the copper phase (base). That is, the characteristic point of the present invention resides in discovering that the magnetic wire for the wire memory consists of the silver-copper alloy containing 0.2 to 99.5 atomic % of silver as the core.

The solid solubility of silver with respect to copper is 8 at.% at the eutectic temperature of both materials, i.e., 779°C, and the solid solubility of copper with respect to silver, when the quantity of silver becomes increased, is 4.9 at.% at the same eutectic temperature. The solid solubility of both elements at a normal or room temperature is 0.1 at.% or so. The silver-copper alloy of medium composition with respect to that as above-noted assumes its precipitation hardening property at a normal temperature. According to the researches conducted by the present inventor, it has been found out that a silver-copper alloy containing 0.2 to 99.5 at.% of silver and the balance of copper indicates excellent precipitation hardening property after it is subjected to solubilization treatment and then to a severe cold reduction.

This binary alloy of silver and copper consists of the copper phase containing some amount of silver in solid-solution and the silver phase containing some amount of copper in solid-solution, and possesses extremely high electric conductivity nearly equal to the electric conductivity of pure copper irrespective of the added amount of silver. From the standpoint of mechanical strength, too, it excels phosphorus bronze, and is substantially equal to beryllium bronze. For example, a core wire, which is manufactured by subjecting the silver-copper alloy containing 6 at.% of silver to the solubilization treatment at a temperature of 800°C, then to a wire-drawing treatment at room temperature to give

surface reduction of 99.98% or so to render the material into a wire of 0.1mm dia., and further subjecting this wire to a stress relief annealing, is found to have extremely good rectilinearity, a tensile strength of about 60 kg/mm² and above which is twice as much as that of phosphorus bronze wire obtained by the same process as mentioned above, and electric conductivity of about 90% to that of pure copper which is far superior to beryllium bronze.

The silver-copper alloy wire thus obtained is highly excellent in its plating capability, the reason for which is considered as follows.

a. The silver phase which constitutes a precipitation phase contains some amount of copper in solid-solution, the quantity of which may be regarded as being almost equal to pure silver, hence the preliminary treatment before the electro-deposition is extremely simple as is the case with pure copper.

b. The lattice constant of the crystals of both silver and copper is very similar, which facilitates growth of the plated layer on the surface of the core wire, as well as increases adhesion of the plated layer on the surface thereof.

c. As the magnetic field is applied in the axial direction of the core wire, the electro-plating is carried out, while causing current to flow in the core wire. However, since the electric resistance of the core wire is low, it is possible to maintain uniform condition for the electro-plating within a plating vessel. Moreover, as quantity of heat generated from the core wire is small, temperature regulation for the electro-plating becomes easy.

On the other hand, however, when excessive quantity of silver is added to the copper phase, the rate of the silver phase to be exposed on the surface of the core wire increases for its excessive amount with the consequence that growth of the plated layer on the surface of the core wire tends to become increasingly non-uniform and, at the same time, adhesiveness of the plated layer to the core wire becomes deteriorated. In view of this fact, it can be said that the adding quantity of silver is preferably less than 50 at.% or so. Considering further the economy in production, the quantity of silver to be added is preferably selected at less than 10 at.%.

Production of the plated ferromagnetic wires for the wire memory utilizing the core wire consisting of silver-copper alloy according to the present invention can be carried out in accordance with the process steps as shown in FIG. 1.

In this flow-chart, the solubilization treatment of the material alloy rod is carried out as the first step at a temperature of about 800°C, followed by a second step of cold wire drawing, where the thickness of the rod is reduced to a required size. In most cases, the diameter of the core wire is selected to be from 0.2 to 0.1 mm, and, in some cases where necessity arises, its diameter is selected to be more or less than the abovementioned range. For example, if it is intended to facilitate high compactness of the memory device, to prevent deterioration in the memory characteristics due to magnetic strain, to reduce the amount of driving current, and so forth, it will become necessary to reduce the wire thickness to less than 0.1 mm. In this connection, studies and experiments are being made as to forming the core wire in ribbon-shape by a rolling mill.

The stress relief annealing as the third step of production is conducted in a reducing atmosphere at a se-

lected temperature within a range between 350° and 600°C.

At the fourth step of the surface cleaning of the core wire, various treatments such as electrolytic defatting, supersonic cleaning, etc. are performed.

The copper plating on the core wire is sufficient to be extremely thin, which may be less than a few microns. Although this process step may be dispensed with in some cases, and permalloy or like material can be directly plated on the core wire, it is still considered efficacious to include this step with a view to increasing uniformity in the plated layer.

The wire drawing process after the copper plating may also be dispensed with in some cases.

The stress relief annealing subsequent to the wire drawing is conducted in the same manner as in the third step annealing.

The surface smoothing includes a step of electro-deposition of, for example, amorphous non-magnetic nickel on the surface of the core wire to remove fine irregularities on its surface to the least possible.

For the electro-plating of permalloy, a current of 0.5 amp. or so is applied to the core wire. A preferable electrolytic solution for the electro-deposition of permalloy is one prepared by, for example, dissolving nickel sulfate and ferrous sulphate into a saturated aqueous solution of boric acid.

This process step also includes one, in which electro-deposition of permalloy and that of a hard magnetic material, such as nickel-cobalt alloy, are alternately performed in repetition.

As a protective coating for the permalloy, non-magnetic nickel may be considered suitable as is the case with the surface smoothing treatment.

The final annealing is carried out at a temperature of about 200°C in a reducing atmosphere of nitrogen gas containing therein hydrogen or alcohol vapor. In this case, electric current is caused to flow through the magnetic wire in a somewhat increased amount depending on necessity with a view to avoiding disturbance of the direction of the easy magnetization axis of the plated permalloy during the heat treatment.

The ferromagnetic wire of the present invention manufactured in accordance with the aforementioned process steps is given an extremely uniform plated layer. When this ferromagnetic wire is cut into pieces of 30 cm long each, for example, and each of them is tested to determine its goodness or badness in quality, the rate of badness in the ferromagnetic wire of this invention is less than 10%. Here, the standard of bad quality is based on a piece of wire having even a single defect in its plated layer. Contrary to this, when the aforementioned beryllium bronze or phosphorus bronze is used as the material for the core wire, satisfactory plating can hardly be carried out. Also, even if the plated layer may be grown on the core wire, it is easily torn off. This is due to the fact that oxides of tin and beryllium which could not be removed completely at every treatment prior to plating of the core wire remain on the surface thereof, which constitute the main cause for deterioration of the plating characteristics in the core wire. Further causes of such inferiority in the plating characteristics are that the crystal structures of beryllium bronze and phosphorus bronze are not suited for plating, and the plating condition within the same plating tank are non-uniform due to poor electric conductivity, and so on.

As stated in the foregoing, the present invention makes it possible to obtain the plated ferromagnetic wires of high quality at a higher rate of yield, which is the important determining factor in the manufacture of the plated wire memory of superior quality.

I claim:

1. A plated ferromagnetic wire usable as a memory element comprising a core wire consisting essentially of a copper-silver binary alloy containing from 0.2 to 10 atomic percent of silver, a layer of copper uniformly formed on the surface of said core wire, a non-magnetic nickel layer uniformly electroplated on said layer of copper, a layer of a permalloy uniformly electroplated on said non-magnetic nickel layer, a layer of nickel-cobalt binary alloy uniformly electroplated on said layer of a permalloy, said layers of a permalloy and a nickel-cobalt alloy having, respectively, an easy axis of magnetization circumferential about said core wire and a protective coating of non-magnetic nickel on said layer of a nickel-cobalt alloy.

2. A memory element comprising a core component consisting essentially of a copper-silver binary alloy containing from 0.2 to 99.5 atomic percent of silver, a copper layer electroplated on the surface of said core component, a non-magnetic nickel layer electroplated on the surface of said copper layer, a layer of ferromagnetic material uniformly electroplated on the surface of said non-magnetic nickel layer, and a protective coating of non-magnetic material on said layer of ferromagnetic material.

3. A memory element according to claim 2 wherein said layer of ferromagnetic material comprises a composite layer comprising a layer of permalloy electroplated on the surface of said non-magnetic nickel layer and a layer of a nickel-cobalt binary alloy electroplated on the surface of said layer of permalloy.

4. A plated ferromagnetic memory element according to claim 2; wherein said copper-silver binary alloy consists of 0.2 to 10 atomic percent of silver.

5. A memory element comprising a core component consisting of a copper-silver binary alloy containing 0.2 to 99.5 atomic percent of silver, a copper layer electroplated on the surface of said core component, a non-magnetic nickel layer electroplated on the surface of said copper layer and at least one layer of a ferromagnetic material uniformly electroplated on the surface of said non-magnetic nickel layer.

6. A plated ferromagnetic wire useable as a memory element comprising a core wire consisting of a copper-silver binary alloy containing 0.2 to 99.5 atomic percent of silver; a copper layer plated on said core wire; a non-magnetic nickel layer plated on said copper layer; a composite ferromagnetic layer plated on said non-magnetic nickel layer, said composite ferromagnetic layer comprising at least one layer of permalloy and at least one layer of a nickel-cobalt binary alloy; and a protective coating layer of non-magnetic material on said composite ferromagnetic layer.

7. A plated ferromagnetic wire according to claim 6, wherein said copper-silver binary alloy consists of 0.2 to 10 atomic percent of silver.

8. A memory element according to claim 6 wherein said layer of ferromagnetic material comprises alternate layers of permalloy and a nickel-cobalt binary alloy alternately electroplated on each other.

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