

July 18, 1967

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3,331,714

PROCESSING OF MAGNETIC MATERIALS

Filed May 14, 1964

FIG. 1

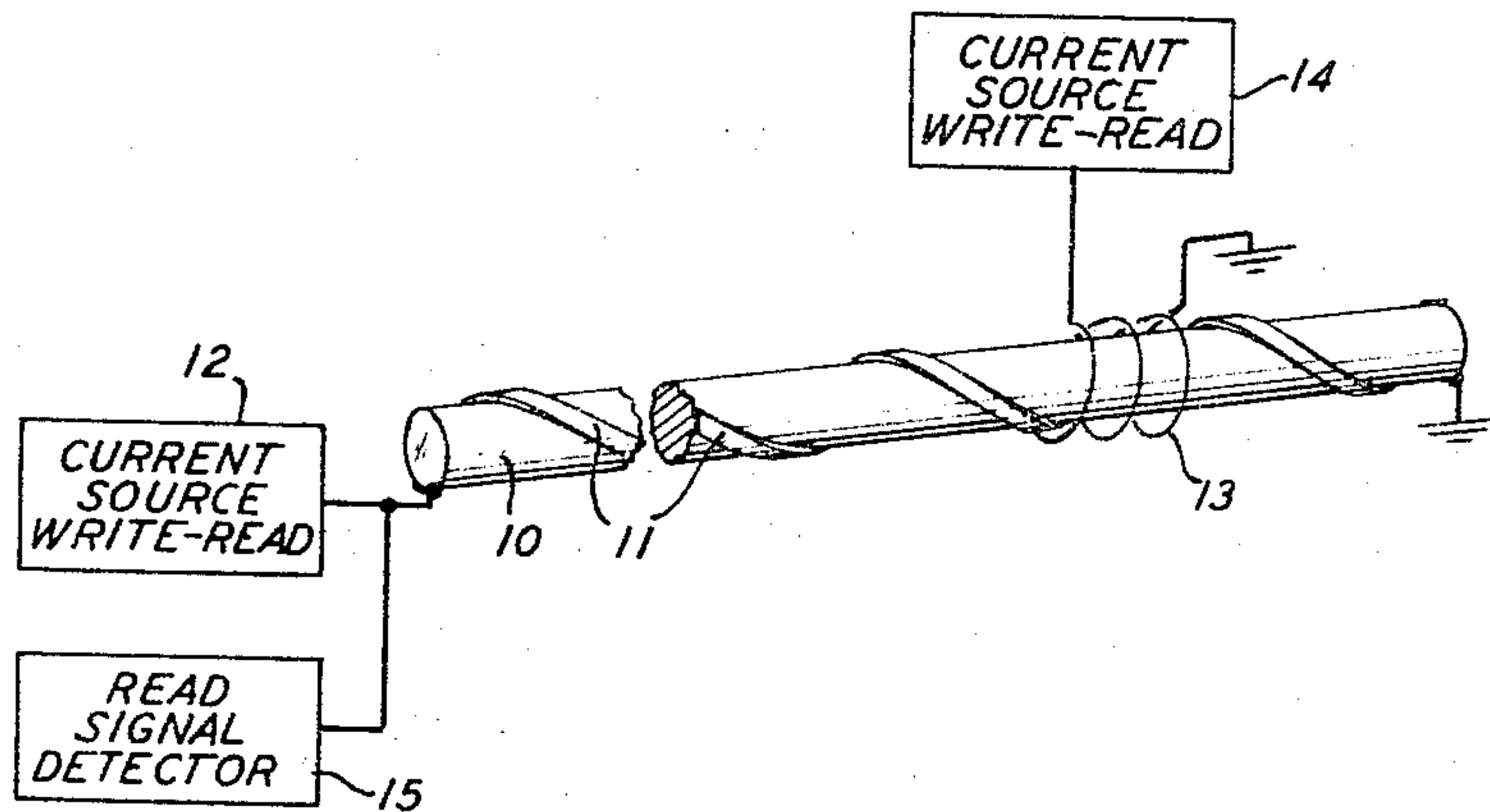
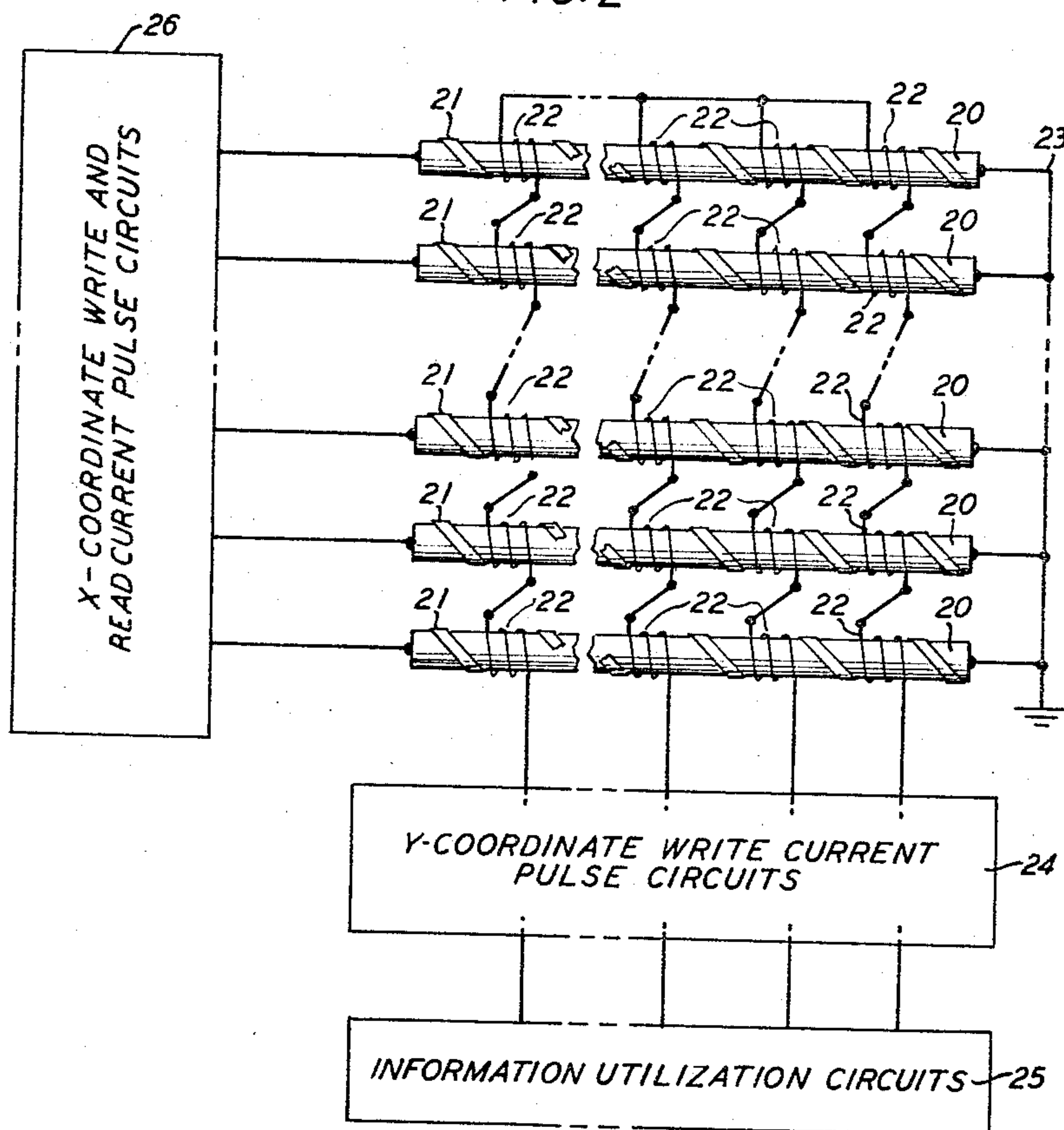


FIG. 2



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PROCESSING OF MAGNETIC MATERIALS

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Filed May 14, 1964, Ser. No. 367,321

5 Claims. (Cl. 148—120)

This invention is directed to a method for the manufacture of magnetic alloys. Of particular interest is the fabrication of soft magnetic materials in the form of thin tapes which are then useful for the manufacture of various magnetic devices. One such device, a memory structure known as a twistor, is described in claimed in United States Patent No. 3,083,353 issued March 26, 1963.

A modification of this device of particular current interest which may utilize this invention in the "piggyback" twistor described and claimed in United States Patent No. 3,067,408 issued December 4, 1962.

The aforementioned devices are designed for use in memory arrays for storing binary information in temporary or permanent form. The information is stored in a segment of a helical flux path provided along a magnetic conductor. A transverse write-read conductor is inductively coupled to the helical flux path. This invention is directed to the fabrication of a magnetic material useful in the device of FIG. 4 of United States Patent No. 3,083,353 in which the helical flux path is a discrete wire or ribbon wrapped around an electric conductor. It is also applicable to the devices described in United States Patent No. 3,067,408 issued December 4, 1962. Other uses will become apparent.

The magnetic materials which have been preferred for devices of the aforementioned character are nickel-iron alloys having 40 to 90 percent nickel. Particularly useful is molybdenum Permalloy which contains 4 percent molybdenum and 79 percent nickel. Certain other minor additions such as manganese and silicon are often added to improve the metallurgical processing of the alloy.

The conventional manner of preparing magnetic tapes of these alloys is to cast the alloy into an ingot. The ingot is then hot-worked to a billet having a cross-section of the order of 0.1 in.² or less and thereafter subjected to a series of cold working operations with intermediate anneals until the desired tape or wire size is obtained. The casting, generally of the order of several square inches in section, cannot be cold-worked to the desired size due to the brittleness of the alloy. Once the billet is reduced to a size of 0.1 in.² the alloy can then be completely cold-worked in any desired manner. These cold working operations are also known to enhance the magnetic characteristics of the material. This processing technique is described in United States Patent No. 2,783,170. In accordance with the present invention a uniform crystal texture and composition are established within the material by initially zone melting the alloy.

The float zone melted rod is then cold worked with or without intermediate anneals to obtain the desired wire or tape.

The advantage of producing magnetic tape in this manner is in the extreme uniformity of the magnetic properties of the processed materials. Using the prior art technique tape produced from one ingot may be well within the desired specification while for reasons previously unknown the successive batch is commercially worthless. Large deviations from one tape length to another within the same batch have been found. The reasons for these inconsistencies are now understood and are attributable to compositional inhomogeneities and non-uniform crystal texture. Both of these variables are eliminated according

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to the present technique with the result that the ultimate magnetic properties of the tape are thoroughly predictable and reproducible.

The hysteresis characteristics of the nickel-iron alloys to which this invention is directed are related to the orientation of nickel-nickel and iron-iron atom pairs. The direction of orientation of these like-atom pairs results in a hard magnetic direction so it becomes desirable to align as many pairs as possible in a single crystal direction or plane thus producing a large magnetic anisotropy and an easy magnetic axis in the normal direction.

A nickel-iron crystal such as Ni₃Fe possesses a face-centered cubic structure which in the ordered crystal state prefers to have alternate nickel-iron atoms. The desired magnetic anisotropy results from pairing iron atoms and nickel atoms. This is usually achieved by mechanically forcing a realignment of the atoms along slip planes so that pairs result. Since the crystal prefers to slip along a {111} crystal plane in a <110> direction the pairs will form in a direction normal to the slip direction. In the case of a single crystal elongated in the [111] direction the pairs will tend to align in the <110> directions lying on the (111) plane thereby making the [111] direction an axis of easy magnetization.

The prior art procedures for fabricating tape such as that described in United States Patent No. 3,086,280 ignore the original crystal texture of the cast alloy. However, they often produce a successful product since, in the process of working the wire by drawing in a single axial direction, the wire tends to develop a <111> texture in the direction of flow and the magnetic anisotropy resulting from the mechanically induced pairings produces a significant <111> easy axis. However, the amount of <111> texture originally present and the texture developed in the wire during cold drawing is not wholly controllable and variations are occasionally found from one batch to another. The magnetic squareness of these sections is understandably different.

According to this invention the importance of this crystal texture is now realized and the wire is initially given a completely uniform <111> texture prior to working it to the desired form. It has been found that this texture is preserved throughout the process of drawing the wire and all wire made according to a given set of cold working and anneal conditions will exhibit consistently uniform magnetic characteristics.

In the process of roll flattening the <111> textured wire to form tape the alloy is made to flow in a direction normal to the wire axis. In so doing the tape is found to have a <211> orientation in the flow direction while maintaining the <111> direction along the wire axis. The like-atom pairs induced along slip planes in the laterally deformed material are found to lie close to the <111> tape axis and thus some of the magnetic anisotropy present in the wire prior to roll flattening is destroyed.

Consequently if roll flattening is to be used it is found desirable to anneal the wire prior to the flattening step. The result of this anneal is to introduce some cubic <100> texture into the wire axis prior to roll flattening. When this wire is now made to flow laterally the slip planes due to the <100> texture component are arranged so that like-atom pairs occur in the desired plane, that is, normal to the tape axis. Consequently even though roll flattening is harmful to a tape with <111> texture in terms of squareness, the presence and behavior of a <100> component in the wire compensates for the loss in squareness which would be expected if the wire texture was pure <111>. The anneal is effective in producing a cubic texture because the cubic crystal habit is preferred by the wire on recrystallizing. The details of this intermediate anneal are described and claimed in United

States Patent No. 3,086,280. The anneal conditions prior to roll flattening have been determined as follows. The cold-drawn wire is heat treated at a temperature in the range of from 100° C. to 900° C. for one second to 24 hours, the shorter times corresponding with the higher temperatures. The temperatures and times of the heat treatment are interrelated so as to require a minimum temperature of one second and a maximum time of four seconds for the temperature range of 700° C. to 900° C. and a heat treatment of 24 hours at 100° C.

This heat treatment produces the desired amount of cubic texture in the wire and the wire is then ready to roll-flatten to the appropriate dimension.

Whereas roll flattening is the procedure commonly employed for making magnetic tape, it is now found that if the wire is die-drawn into the desired ultimate shape, the foregoing heat treatment becomes unnecessary. This is because the wire is deformed axially in die-drawing and there is no significant lateral flow of the wire as in the case of roll flattening. Hence a pure $\langle 111 \rangle$ texture is desirable.

In processing a zone refined single crystal of the alloy it is not necessary to make additions of silicon or manganese to facilitate mechanical working. Thus the elimination of these and other contaminants from the magnetic composition contributes to the ultimate uniformity and predictability of the magnetic characteristics of the material. Furthermore the discovery that an alloy produced by zone melting can be completely cold-worked thus eliminating the hot working operation and attendant oxidation of the alloy is a significant technical advance.

Exemplary device applications for which the material of this invention is adapted are treated in the following description. In the drawing:

FIG. 1 is a perspective view of a magnetic memory element utilizing the material made by the process of this invention; and

FIG. 2 is a schematic representation of a magnetic matrix illustrating the practical utilization of the element of FIG. 1 for information storage and retrieval.

While the magnetic tapes or wires produced in accordance with this invention may find a variety of uses this description is made in terms of one exemplary device application, the twistor. The term "twistor" was applied to devices of this type since the device as originally proposed possessed a helical flux path made by mechanically twisting the conductor. However, this flux pattern can also be obtained by wrapping an electrical conductor with a helix of magnetic wire or tape and it is this form of the device which now appears to be preferred due to the obvious difficulties in applying and maintaining a uniform mechanical stress on wires of very small dimensions.

The tape-wrapped twistor is shown in FIG. 1. The rod 10 is an electrical conductor such as a copper wire having a helically wound tape 11 wrapped at a 45° angle with the wire axis. The tape 11 consists of a magnetic alloy such as Permalloy fabricated in accordance with this invention. One end of the conductor 10 is connected to ground and the other end is connected to a write-read current source 12. Since devices of this character usually rely on coincident write and/or read on orthogonal coordinates defining the address, a coil 13 is inductively coupled to the conductor 10 to establish a field normal to that of the conductor. The coil 13 is connected to ground and to a suitable write-read current source 14. In practice the coil 13 is generally a single conductor inductively coupled to the conductor 10 as seen in FIG. 2. The current sources 12 and 14 may be of any known type and are shown in block form for convenience.

In the operation of the device the information stored is read by determining the remanent magnetization of a portion of the wire at the address of interest. The binary information is written by coincident current pulses fed to the address along the coordinate conductors 10 and 13. The state of magnetization at the address is repre-

sented by either of the directions indicated by the arrows, and is indicated by the presence or absence of a pulse generated by a switching field applied in a predetermined direction.

Assuming the presence in the tape 11 of a flux in one direction as represented by the arrows, a current must be applied of a magnitude sufficient to generate a magnetomotive force which will switch the direction of flux in the opposite direction of the helical path. The magnitude of this force may be determined as h . When a current pulse producing a magnetomotive force of the magnitude $h/2$ is now applied from the source of a polarity to oppose the helical flux simultaneously with a current pulse producing a magnetomotive force of the magnitude $h/2$ from the source, the total magnetomotive force will be sufficient to switch the flux state of the tape 11. The polarity of the current pulse required from the source will depend upon the sense of the winding of the solenoid 13. The flux state to which the tape 11 has been thus switched may be regarded as a particular information bit, say a binary "1," which it is desired to store and this operation would constitute the write phase of the memory function. It should be noted that, in accordance with the principles of coincident current memory elements generally, either of the current pulses applied from the sources 12 and 14 alone will be insufficient to accomplish the magnetic switching.

Information stored in the tape 11 is read out by reversing the polarity of the currents applied from the current sources. The simultaneous reverse current pulses will again cause a switch in the direction of magnetization in the helical path if an information bit has been previously stored in the manner described above. Obviously, if in the write phase of operation the tape 11 had not been magnetically switched for whatever reason, no switching will occur during the read-out phase. When the magnetic state of the tape 11 is switched, a change in the potential between its ends will result. This change may be detected by suitable detection means 15 as an output pulse superimposed upon the switching current pulse applied to the conductor 10. When the magnetic state of the tape 11 is not reversed with respect to polarity, as would be the case, say if a binary "0" had been stored, no pulse will be read.

Read-out may also be accomplished by simply overdriving the solenoid 13 by a current producing a sufficient reverse magnetomotive force applied from the current source 14 alone. In this case the conductor 10 would act only as a read-out lead, the output signal also being detected by the means 15. This means of read-out is particularly adaptable in the employment of the memory element of this invention in the formation of memory arrays as will be described with respect to FIG. 2.

In FIG. 2 a coordinate memory array is illustrated. Such an array comprises a lattice of transverse parallel conductors 20 wrapped with magnetic tape 21 and parallel conventional insulated copper conductors constituting the solenoids 22. One end of each of the conductors 20 and 22 is connected to a ground bus 23. The other end of each of the solenoids 22 is connected to suitable y coordinate write current pulse circuits 24. Such circuits are well known in the magnetic memory and information handling art and in this case would produce appropriately timed current pulses of a magnitude to generate an $h/2$ magnetomotive force with respect to the magnetic tape 21. In addition, each of the solenoids 20 is also connected to information utilization circuits 25 capable of accepting binary coded output pulses. Such circuits will also present themselves to one skilled in the art and do not require detailed description.

The other end of each of the conventional conductors 20 is connected to suitable x coordinate write and read current pulse circuits 26 also well known in the art and similar in operation to the write pulse circuits included in the block 24. The illustrative memory array of FIG. 2

is word-organized, that is, the information bits of each word stored appear at the portions of the solenoids 22 inductively coupled to the transverse conductors 20. In the writing operation in the array the word level is selected by applying a current pulse of the proper magnitude to a selected x coordinate conductor 20. Simultaneously the particular bit information is introduced by pulsing the y coordinate conductors 22 in accordance with the bits of the word to be stored. The read operation is simply performed by applying a read current pulse of opposite polarity to that of the write current pulse and of proper magnitude to only the particular x coordinate conductor 20 defining the row in which the word appears. Output signals will then appear in parallel form at the terminals of the conductors 22 which contained the information bits of the word read out.

The magnetic tape or wire used in the device described is prepared by zone melting the required amounts of high purity nickel and iron and other ingredients such as molybdenum where required. The zone melting technique and suitable apparatus are described in B. F. Oliver, Trans. AIME, vol. 227, p. 960, 1963.

The details of the zone refining procedure may vary according to accepted prior art practice. See Zone Melting by W. G. Pfann, John Wiley & Sons, Inc., 1958. No invention is predicated on zone melting the alloy per se.

The following procedure is given by way of example:

The proper amounts of high purity Ni, Fe and Mo (4 wt. percent Mo, 70 wt. percent Ni, 17 wt. percent Fe) powders are mixed together thoroughly and pressed into bars. These pressed bars have sufficient mechanical strength that they can be zone refined without presintering. Alternatively, rods of Mo, Ni, and Fe of the proper diameters to give the above composition can be bundled together. One forward pass and one reverse pass result in a chemically uniform material. The molten zone travel rate used is 0.0015"/sec. However, faster rates can be employed.

The rod or billet which is to be cold worked is initially given a pure $\langle 111 \rangle$ crystal orientation in the direction the rod is to be cold worked. Accordingly a properly oriented seed crystal is employed to give the $\langle 111 \rangle$ crystal orientation in the axial direction of the rod.

Various other modifications and extensions of this invention will become apparent to those skilled in the art. All such variations and deviations which basically rely on the teachings through which this invention has advanced the art are properly considered within the spirit and scope of this invention.

What is claimed is:

1. A method for processing magnetic alloys composed

substantially of nickel and iron to produce magnetic wire or tape which comprises the steps of zone melting the magnetic alloy to form a single crystal body and cold-drawing the single crystal body in a $\langle 111 \rangle$ crystal direction to produce the ultimate desired product.

2. The method of claim 1 applied to an alloy composition of approximately 4 percent molybdenum, 79 percent nickel, balance essentially iron.

3. A method for processing magnetic alloys composed substantially of iron and nickel to produce magnetic wire or tape which comprises the successive steps of zone melting a body of the magnetic alloy to form a single crystal, cold-drawing the single crystal in essentially a $\langle 111 \rangle$ crystal direction to form a wire, heat treating the cold-drawn wire at a temperature in the range of from 100° C. to about 900° C. for one second to 24 hours, the shorter times corresponding with the higher temperatures, the temperatures and times of the heat treatment being so interrelated as to require a minimum time of one second and a maximum time of four seconds for the temperature range of 700° C. to 900° C. and a period of 24 hours at 100° C., further cold-working said wire so as to reduce its diameter a minimum of five percent, and flattening the cold-drawn wire to form a tape of the desired dimensions.

4. The method of claim 3 applied to a magnetic alloy composed of 4 percent molybdenum, 79 percent nickel, balance essentially iron.

5. The method of claim 3 wherein the heat treatment is conducted at a temperature of approximately 800° C. for a period of approximately one second.

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