

July 21, 1970

D. TREVES

3,521,294

MAGNETO THERMAL RECORDING PROCESS AND APPARATUS

Filed March 13, 1967

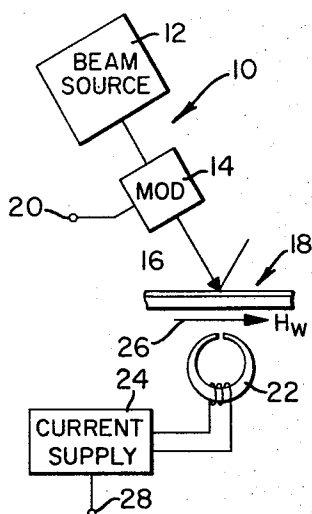


FIG. 1

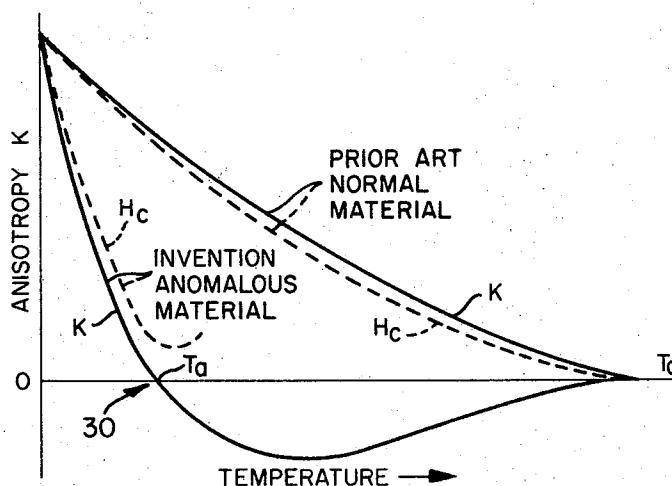


FIG. 2

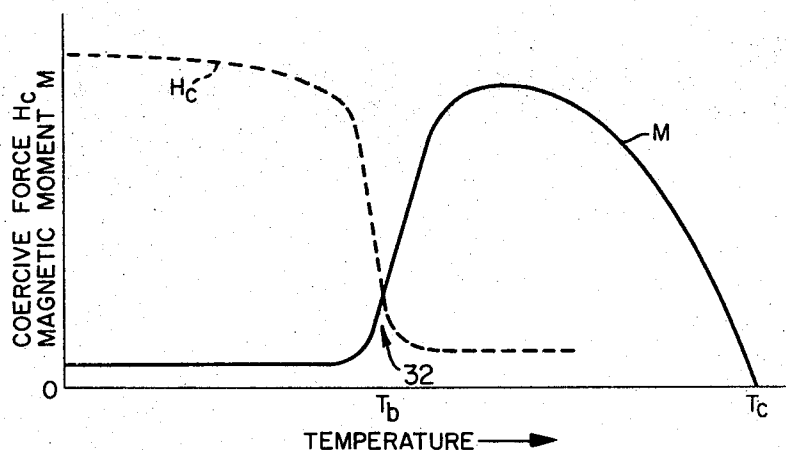


FIG. 3

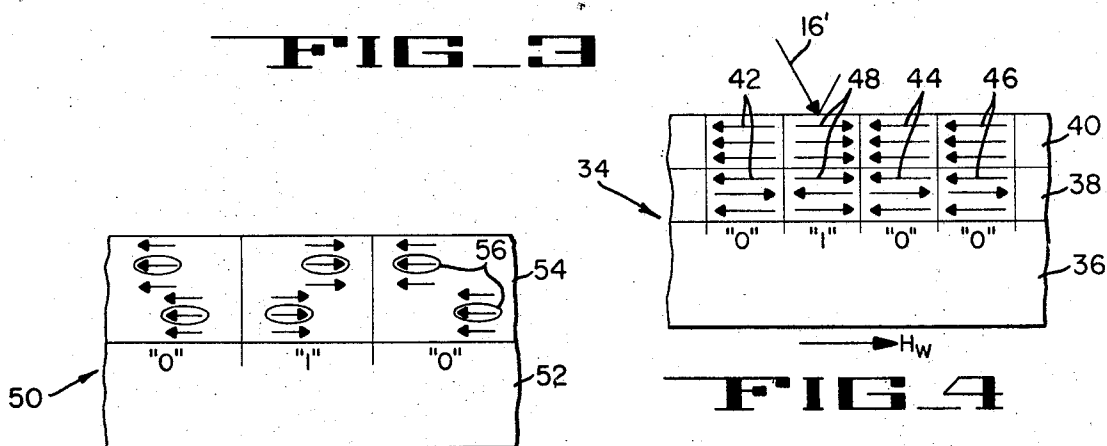


FIG. 5

INVENTOR  
DAVID TREVES

BY *Robert S. Clay*

ATTORNEY

1

3,521,294

**MAGNETO THERMAL RECORDING PROCESS  
AND APPARATUS****David Treves, Palo Alto, Calif., assignor to Ampex  
Corporation, Redwood City, Calif., a corporation  
of California****Filed Mar. 13, 1967, Ser. No. 622,795****Int. Cl. G01d 15/12; G11b 5/00****U.S. Cl. 346—74****7 Claims****ABSTRACT OF THE DISCLOSURE**

Process and apparatus for thermal recording of magnetic information on a selected magnetic recording medium, wherein writing is achieved by locally heating the medium to a temperature region substantially below the Curie temperature of the medium to produce a sudden change in a property of the medium material, such as for example the coercive force, with respect to the applied temperature, whereby the magnetization in the medium may be selectively reversed to represent information.

**BACKGROUND OF THE INVENTION**

Various recording techniques and systems are known in the recording field which involve, in general, the reversible change of the magnetic properties of storage media by the local rise in temperature produced by appropriate means in the system. Typical among such systems is the type utilizing an electron beam to locally heat, to the Curie temperature, a film of for example, manganese bismuth which is initially, uniformly magnetized perpendicular to its surface. As known in the art, the Curie temperature is the transition temperature at which ferromagnetic materials become paramagnetic. The coercivity of the heated spot of film decreases in the region of the Curie temperature, and the magnetization therein is reversed by the demagnetizing field in accordance with the information. Other thermal recording systems utilize the rapid change in coercive force with temperature near the compensation point in garnet materials to accomplish thermal writing, where the compensation point is that temperature below the Curie point where the average magnetic moment of the material goes to zero. Since the magnetooptic effects are mainly due to the iron ions in the garnets, readout in these systems can be effected even though the macroscopic magnetization is zero at the compensation point. Further prior art recording systems utilize the combination of thermally induced stresses and magnetostriction effects to provide recording on associated recording mediums. Still other proposed recording schemes utilize the possibility of changing the coercive force of gadolinium iron garnets (GdIG) near the compensation point by affecting the magnetic moment of the Gd ions. This system proposes that the change could be brought about by partially exciting the Gd ions to the first excited state, which has a spin of only 5/2 instead of 7/2 (and thus a lower moment) by irradiation with ultraviolet radiation. The effect is proportional to the absorption cross-section, the radiation power and the lifetime of the excited state.

At present, the typical thermal recording schemes utilize materials and associated temperatures which allow recording only in the region of the Curie temperature  $T_c$

2

of the recording medium. Typical of the Curie temperature thermal write devices are those described in U.S. Pat Nos. 3,176,278 to L. J. Mayer and 2,915,594 to L. L. Burns et al. In such systems the magnetocrystalline anisotropy energy  $K$  drops with the temperature  $T_c$  as a high power of the magnetization  $M$ . Therefore, the anisotropy field  $H_K$ , which is proportional to  $K/M$ , will drop sharply in the vicinity of  $T_c$ . In cases where  $H_c$  is dominated by  $K$ ,  $H_c$  will also drop rapidly near  $T_c$ . In cases where  $H_c$  is dominated by shape anisotropy, it will decrease as  $M$ , and will also decrease sharply near  $T_c$ .

**SUMMARY OF THE INVENTION**

The present invention provides a process for thermal recording of magnetic information wherein writing is achieved by locally heating the medium generally to a temperature region substantially below that of the Curie temperature region. The invention contemplates the use of selected materials for forming the recording medium, wherein the materials have the property of a rapidly dropping anisotropy  $K$  in the selected, relatively low temperature region, and wherein the coercive force  $H_c$  is generally also a function of the application of the selected temperature. Thus, the recording medium of the invention exhibits a low coercive force in response to the application of a relatively small increase in temperature in a temperature region below the Curie temperature of the material, wherein lowering the coercive force allows the direction of magnetization of the medium to be reversed in accordance with the input signals which represent the recorded information.

Accordingly, the invention provides an improved thermal recording system utilizing in general, a temperature lower than the Curie temperature  $T_c$ . By way of further defining the temperature region of the invention and as further exemplified hereinafter in the figures, when using the conventional material cobalt as a recording medium the prior art Curie temperature system would require temperatures of the order of 1000° C., whereas the improved write system of the invention requires the substantially lower temperature of the order of only 150°–200° C. This allows the use of relatively less complicated apparatus, and results in generally a more reliable and practical write system. In addition, the invention provides a thermal write system wherein the magnet moment of the associated recording medium is relatively high due to the use of temperatures which are lower than the Curie temperature, whereby magnetooptical readout may be performed with much greater efficiency.

**BRIEF DESCRIPTION OF THE DRAWING**

FIG. 1 is a simplified block diagram of apparatus exemplifying one system in which the invention concepts are applicable, shown by way of example only to facilitate an understanding of the invention.

FIG. 2 is a graph showing the relationship between temperature  $T$ , the coercive force  $H_c$  and the anisotropy  $K$  of the recording materials employed by typical prior art write systems and the write system of the invention.

FIG. 3 is a graph showing the relationship between temperature  $T$ , the coercive force  $H_c$  and the magnetization moment  $M$  of an alternative embodiment of the invention concept, and

FIGS. 4 and 5 are views of mediums and materials which form further alternative embodiments of the invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a simplified block diagram of a write system 10 capable of applying the invention concepts, and which includes a heat beam source 12 and beam modulation means 14 disposed to generate and focus a beam 16 upon the surface of a magnetic recording medium 18 in a manner generally known in the art and shown for example in the aforementioned patents. The source 12 may be an electron beam source, a heat beam source or any other type of source capable of delivering a beam which may be focused to locally heat the medium 18. The modulating means 14 may be any of various light, electron or heat beam modulators chosen to match the type of beam source used, and may be operated to modulate the beam 16 in accordance with the information to be recorded, which is in turn introduced to an input terminal 20 connected to the modulating means 14.

The magnetic recording medium 18 is formed with a selected geometry and of materials selected from those materials which exhibit the desired properties, as is further described below with respect to the various embodiments of the invention.

Magnetic field generating write means 22 is disposed adjacent the recording medium 18, and is connected to a supply of current 24 whereby a magnetic write field, herein indicated by numeral 26, may be applied to the recording medium 18 in either direction along the easy axis of magnetization. The current supply 24 may be modulated by means of input signals introduced thereto via an input terminal 28. Thus signals representing the information to be recorded may be introduced as a modulating signal to either the beam modulating means 14 or the current supply 24, or to both the means 14 and supply 24 simultaneously.

In the embodiments of the invention, further described hereinafter, writing is accomplished by heating a small area of the medium 18 around the point of incidence of the beam 16, in the general manner of the prior art devices. However, due to the particular properties of the medium 18, and the associated mode of operation, the invention process for the greater part utilizes temperatures substantially below the Curie temperature as shown in FIGS. 2 and 3, and as defined hereinbefore.

Accordingly, referring to FIG. 2 there is shown a graph which compares the anisotropy  $K$  and coercive force  $H_c$  with the temperature  $T$  of prior art material and of an anomalous material used in accordance with one embodiment of the invention. In such a material the magnetocrystalline anisotropy  $K$  goes through zero, as indicated by numeral 30, as the anisotropy curve reverses sign with increasing temperature. In the temperature region where  $K$  goes through zero, the coercive force  $H_c$  will become very low. To perform the write process, it is desirable to have as low a coercive force as possible to permit the magnetization to be readily manipulated to record information in the medium. As shown in the FIG. 2 graph, the temperature at the point 30, where the anisotropy of the anomalous material goes through zero, is substantially below the Curie temperature  $T_c$ , which is the point or temperature at which the anisotropy  $K$  and thus the coercive force  $H_c$  of conventional thermal write materials used by prior art devices goes through zero. Thus the anomalous material of the invention provides the properties of a low coercive force at a temperature  $T_a$  which is below  $T_c$ , and a relatively rapid change in anisotropy  $K$  and thus in the coercive force  $H_c$  with a small change in temperature. By way of example only, typical anomalous materials of this type are nickel, hexagonal cobalt, iron boride ( $\text{Fe}_2\text{B}$ ) and neodymium cobalt alloy ( $\text{NdCo}_5$ ). As may be seen, these typical anomalous materials speci-

fied by way of example only, are all ferromagnetic materials which as described provide the properties specified by the invention, i.e., provide a sudden decrease in coercive force  $H_c$  due to a change in anisotropy, with a small increase in temperature in a temperature region  $T_a$  substantially below the Curie temperature  $T_c$ .

Thus it may be seen that in a thermal record system shown in FIG. 1, used in accordance with the invention, as long as the medium is not heated the coercive force is high and no writing takes place. But upon heating the medium to the temperature  $T_a$  the coercive force drops close to zero and writing can be effected. To effect the writing process various modes of operation with the apparatus of FIG. 1 are possible, and are hereinafter described by way of example only.

Regarding a first mode of operation, the field  $H_w$  applied via the write means 22 is chosen smaller than the coercive force  $H_c$  of the medium temperature or some other selected bias temperature, and greater than the coercive force  $H_c$  of the medium when heated to or close to the temperature  $T_a$ . The medium is erased to provide a field by magnetizing it in one selected direction which for example may define a "zero" binary digit. Thereafter a field  $H_w$  is applied in an opposite direction which accordingly would represent the "1" binary digit. When recording, the field  $H_w$  is kept constant and no writing is performed until such time as the beam 16 impinges and heats the medium 18, thereby lowering the coercive force to permit writing. The beam 16 is modulated via the input to terminal 20 and the modulating means 14 in accordance with the information to be recorded.

A second mode of operation utilizes the same conditions as does the first mode except that the beam 16 is kept on constantly, and the field  $H_w$  is modulated via the input to terminal 28 and the supply 24 in accordance with the information to be recorded, thereby allowing writing. A third mode of operation is similar except that both the beam 16 and the field  $H_w$  are modulated in accordance with the input information.

Referring to FIG. 3 there is shown a graph which compares the magnetization moment  $M$  and the coercive force  $H_c$  with the temperature  $T$  of an alternative type of selected material used in accordance with the invention concepts. In some magnetic materials there simultaneously exists ferromagnetic and antiferromagnetic exchange forces. The stronger of the two couplings existing between the materials will determine if the material will act as a ferromagnet or an antiferromagnet. The exchange constants depend on the lattice spacings, and these in turn depend upon the temperature. Thus it is possible with selected materials to vary the exchange constants with temperature in such a way as to invert the material from a ferro to an antiferromagnetic state. The antiferromagnetic state will be virtually insensitive to an externally applied field, but the ferromagnetic state has a relatively low coercive force and the magnetization therein can be manipulated by an external field. In accordance with the invention this type of material is used in conjunction with an exchange coupled ferromagnet, where the temperature which is used to cause the inversion process is substantially lower than the Curie temperature of prior art systems.

As in the material of FIG. 2, the alternative material also has the property of a rapid drop in coercive force  $H_c$  as shown by the dashed curve and indicated by numeral 32, whereby writing can take place with increased temperature in the temperature region  $T_b$ . The drop in coercive force here is a function of the change of the magnetization moment of the selected material, and more particularly a sharp increase in moment  $M$ . Note that the inversion temperature  $T_b$  wherein recording takes place is substantially below the Curie temperature  $T_c$  of prior art systems.

In essence, the material acts as an antiferromagnetic material as long as it is held at a temperature below  $T_b$ ,

5

with essentially infinite coercive force. Upon heating the material to the region  $T_b$ , the material exhibits the property of an increased magnetization moment  $M$ , whereupon the coercive force drops rapidly to allow thermal recording in accordance with the invention concepts. Types of materials which exhibit the exchange inversion property are by way of example only, manganese antimonide ( $Mn_2Sb$ ) and iron rhodium ( $FeRh$ ).

Referring to FIG. 4, there is shown still another embodiment of a thermal write system in accordance with the invention. In this embodiment a dual layered thermal recording medium 34 of selected materials is utilized to provide a writing function in a selected antiferromagnetic material, which material normally has a very high coercive force  $H_c$  and which accordingly is not usually amenable or responsive to a write process.

By way of example, the material 34 comprises a substrate 36, upon which is disposed first a layer 38 of selected antiferromagnetic material of very high coercive force, and then a layer 40 of selected ferromagnetic material of relatively low coercive force. In addition, the antiferromagnetic layer 38 is the type which has a Neel point temperature which is lower than the Curie temperature of the ferromagnetic material forming the layer 40. The Neel point is that temperature at which ferromagnetic and antiferromagnetic materials become paramagnetic.

Thermal writing utilizing the embodiment of FIG. 4 is effected by means of the exchange anisotropy effect, which is a well-known coupling phenomenon existing between an antiferromagnetic and a ferromagnetic material when disposed against each other. The antiferromagnetic layer 38 has a very large anisotropy field and forces the ferromagnetic layer 40 to be magnetized in one direction through the exchange coupling existing between the layers, as exemplified herein by the arrows 42. Even if the magnetization of the ferromagnetic layer 40 is changed by an external field, as during some types of readout, it will return to its original direction upon removal of the field. If the medium 34 is heated above the Neel temperature of the antiferromagnetic layer 38, the exchange coupling between the layers 38, 40 disappears. During this part of the writing process when the temperature is up, a field having a desired direction in accordance with the information being recorded, is applied to the ferromagnetic layer 40. The medium is then cooled to below the Neel temperature of the layer 38, whereupon the antiferromagnetic spin structure of the layer 38 will be altered by the ferromagnetic layer 40 spin structure via the exchange coupling, such that the magnetic moment of the ferromagnetic layer 40 is forced to remain in the new direction.

Thus, in FIG. 4, if arrows 42, 44 and 46 depict "0" binary digits or bits, wherein the state of magnetization was provided by premagnetization of the medium, and if a "1" bit is to be written, a beam 16' may be used to heat the medium 34 and a field  $H_w$  of reverse direction is applied to layer 40 to reverse the spin direction thereof as indicated by numeral 48. This also reverses the spin of the antiferromagnetic layer 38. Upon cooling the medium 34, the layer 38 spin structure shown by the arrows and numeral 48, remain reversed and force the magnetic moment of the layer 40 to remain likewise, thus recording a "1" bit. Combination materials which are capable of providing the antiferromagnetic layer 38 and ferromagnetic layer 40 respectively are for example nickel oxide-nickel, Ferr sulfide-iron and cobalt oxide-cobalt.

The medium does not have to be fabricated in the form of layers, but may assume other forms. For example as shown in FIG. 5, a medium 50 may be formed of a substrate 52 and a heterogeneous single layer. The antiferromagnetic material may be interspersed throughout a single layer 54 of ferromagnetic material in the form of small particles 56. Thus the thermal recording medium of FIGS. 4 and 5 may assume various configurations utiliz-

6

ing adjacent regions of antiferromagnetic and ferromagnetic materials.

Although the present invention has been described herein with respect to several particular embodiments, various modifications may be made within the spirit of the invention, and accordingly it is intended to limit the scope of the invention only as defined in the following claims.

I claim:

1. In an apparatus for thermal recording of magnetic information in a magnetic recording medium having a substrate and a recording layer of specific properties disposed thereon the improvement comprising, means for locally heating said medium to a selected temperature region substantially below the Curie point temperature of the recording layer, said recording layer of said medium including a ferromagnetic material which exhibits the property of being readily responsive to a selected applied magnetic field within said selected temperature region substantially below the Curie point temperature time, and to assume the magnetization moment of said applied magnetic field only upon achieving said selected temperature region, and means for applying said magnetic field to said heated medium, wherein said applied magnetic field and said means for heating combine to determine the information to be recorded.

2. The improved apparatus of claim 1 wherein the ferromagnetic material of said magnetic recording medium exhibits a rapid decrease in coercive force when its magnetocrystalline anisotropy passes through a minimum value during the application of increasing temperature in the region substantially below the Curie temperature of the ferromagnetic material.

3. The improved apparatus of claim 2 wherein said magnetic recording layer of specific properties further includes an antiferromagnetic material in selected combination with said ferromagnetic material, wherein the combination of materials exhibits an exchange inversion and a decoupling effect and thus the rapid decrease in coercive force within said selected region of increasing temperature substantially below the Curie temperature of the ferromagnetic material.

4. The improved apparatus of claim 3 wherein said recording layer further comprises an antiferromagnetic layer disposed upon said substrate, and a ferromagnetic layer disposed upon said antiferromagnetic layer.

5. The improved apparatus of claim 3 wherein said recording layer further comprises a layer of ferromagnetic material disposed upon said substrate, and a heterogeneous suspension of antiferromagnetic particles interspersed throughout said ferromagnetic layer.

6. A process for thermal recording of magnetic information in a recording medium which is responsive to heat, including a ferromagnetic material which exhibits the property of a rapid decrease in coercive force in keeping with a rapid decrease through a minimum value of the anisotropy within a temperature region substantially below the Curie temperature of the ferromagnetic material, comprising the steps of, uniformly magnetizing the medium in one direction to represent one mode of information, selectively applying a magnetic field in an opposite direction to reverse the material magnetization to represent another mode of information, simultaneously locally scanning the medium with a heat producing beam, maintaining the heat produced by the beam within the temperature region substantially below the Curie temperature of the ferromagnetic material to produce the rapid decrease in coercive force to render the medium responsive to the applied magnetic field, wherein the beam and the applied field define the means for selectively introducing the information to be recorded.

7. The process of claim 6 wherein the medium further includes an antiferromagnetic material, further including the step of, maintaining the temperature locally produced by the beam in the ferromagnetic and antiferromagnetic

materials substantially below the Curie temperature of the ferromagnetic material to provide an exchange inversion and a decoupling effect between the materials and an associated rapid decrease of coercive force within said materials.

#### References Cited

##### UNITED STATES PATENTS

|           |        |                       |          |
|-----------|--------|-----------------------|----------|
| 3,368,209 | 2/1968 | McGlauchlin et al. -- | 346—74 X |
| 3,164,816 | 1/1965 | Chang -----           | 346—74   |

#### OTHER REFERENCES

Mee, C. D.: The Physics of Magnetic Recording, Amsterdam, North-Holland Publishing Company, 1964, pp. 82-84 and 146.

<sup>5</sup> JAMES W. MOFFITT, Primary Examiner  
G. M. HOFFMAN, Assistant Examiner