# United States Patent [19]

**McClure**

[11] **3,778,145**

[45] **Dec. 11, 1973**


[54] **MAGNETIC IMAGING**


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[73] Assignee: **Bell & Howell Company**, Chicago, Ill.



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[21] Appl. No.: **318,787**

**Related U.S. Application Data**

[62] Division of Ser. No. 29,583, April 17, 1970, Pat. No. 3,717,459.

[52] **U.S. Cl.** .......................... **355/3,** 355/8, 355/16, 355/17, 346/74 M, 346/74 MT, 96/1 E

[51] **Int. Cl.** .......................................... **G03g 15/00**

[58] **Field of Search** ...................... 355/3, 17, 8, 16; 346/74 M, 74 MT, 74 TP; 96/1 R, 1 E


[56] **References Cited**

UNITED STATES PATENTS


2,798,959 7/1957 Moncrieff-Yeates ................. 96/1 E

2,836,766 5/1958 Halsted ................................. 96/1.5

3,485,621 12/1969 Kazan ...................................... 96/1



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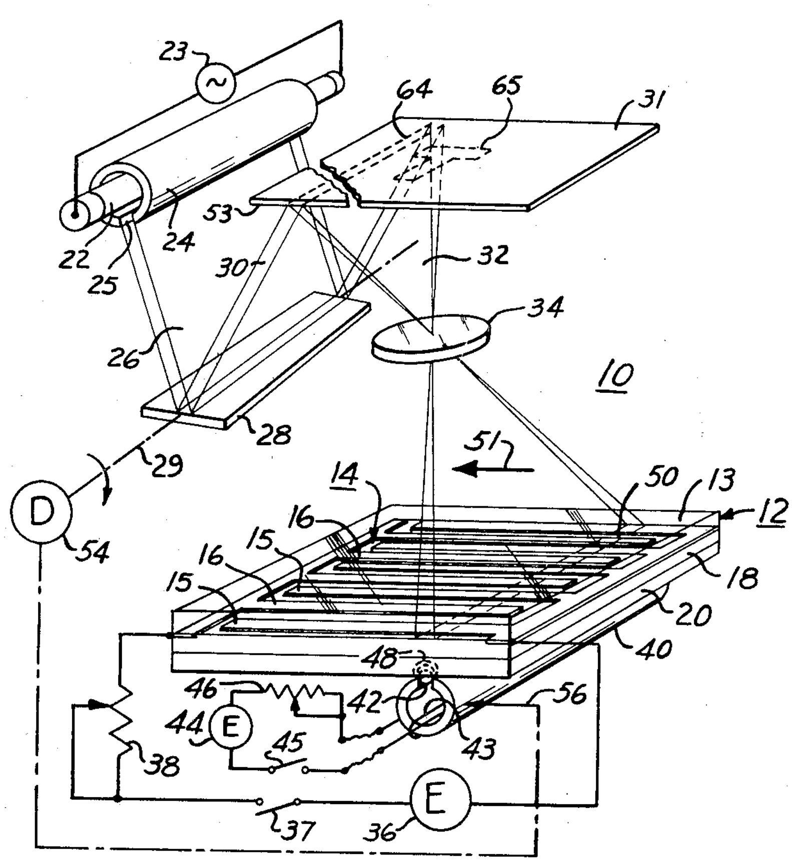
[57] **ABSTRACT**


A composite recording medium comprises a photoconductive layer, a plurality of interdigitated first and second electrodes in electrical contact with the photoconductive layer, and an electrically conductive magnetic recording layer in electrical contact with the photoconductive layer. Methods and apparatus for magnetically recording an image with the assistance of this composite recording medium are also disclosed.


**8 Claims, 6 Drawing Figures**



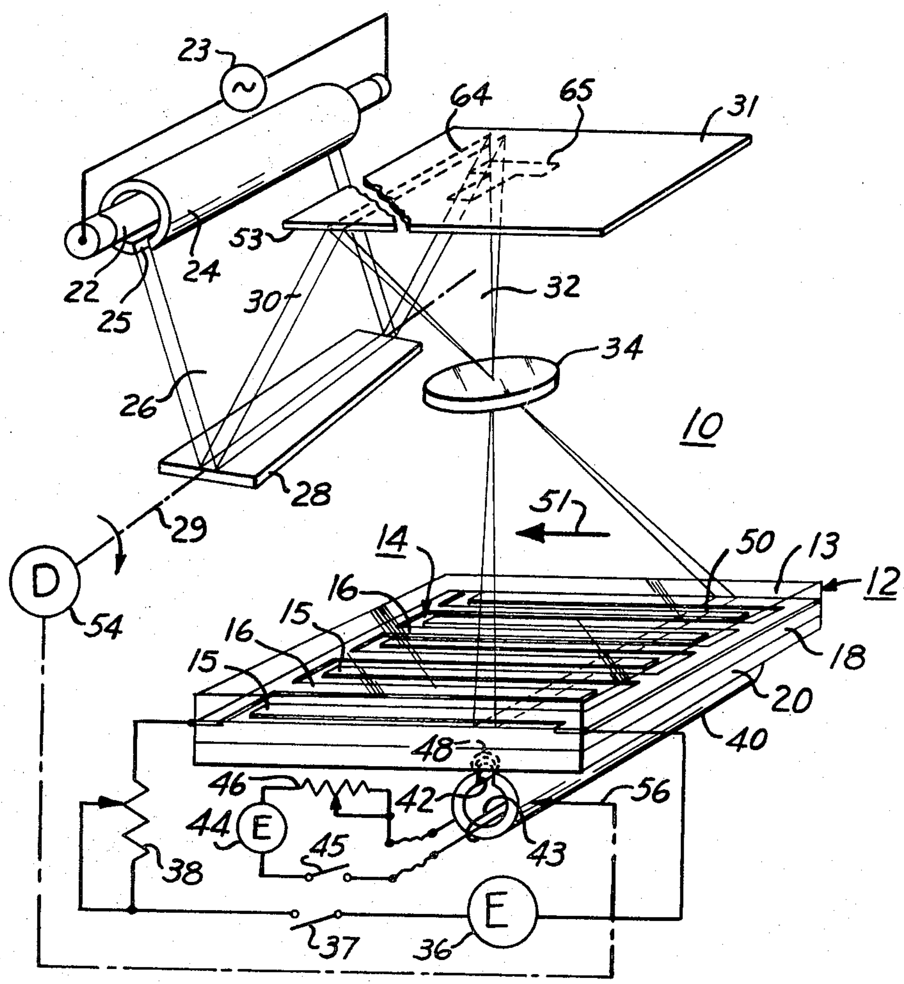



FIG. 1

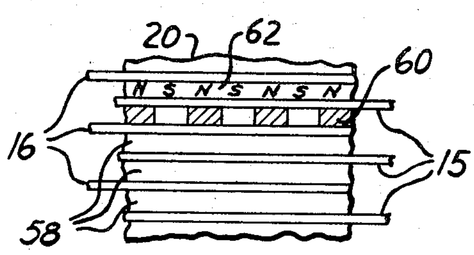



FIG. 2

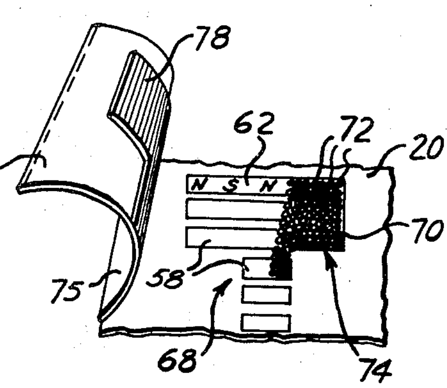



FIG. 3

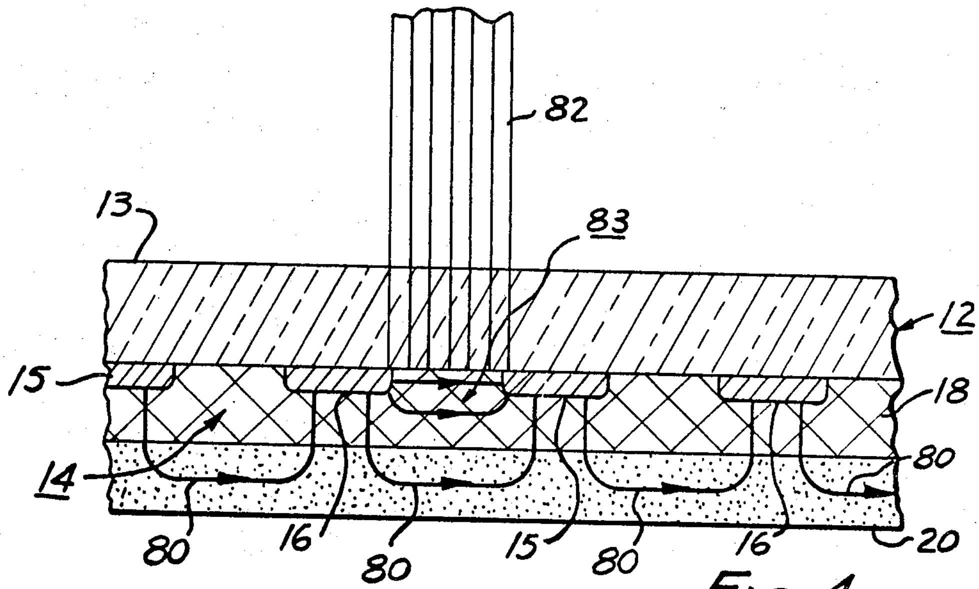



FIG. 4

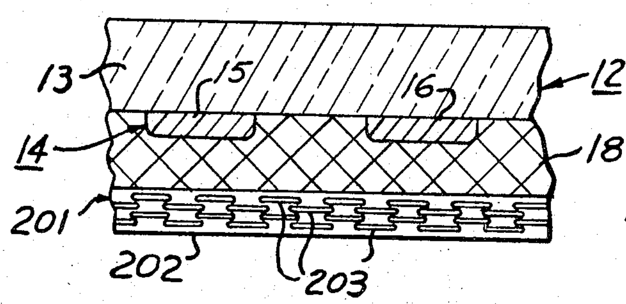



FIG. 5

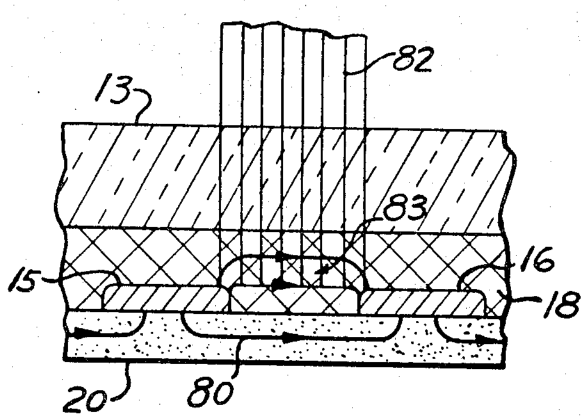



FIG. 6

# MAGNETIC IMAGING

This is a division of application Ser. No. 29,583, filed Apr. 17, 1970, now U.S. Pat. No. 3,717,459.

## CROSS-REFERENCE TO RELATED APPLICATION

Subject matter of the present application is disclosed in the following copending application, the disclosure of which is herewith incorporated by reference herein: U.S. Pat. application Ser. No. 29,584, MAGNETIC IMAGING, filed Apr. 17, 1970, by Sherman W. Duck and Frederick J. Jeffers now U.S. Pat. No. 3,717,460, and assigned to the present assignee.

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The subject invention relates to magnetic recording and, more particularly, to the magnetic recording of images with the assistance of thermal gradients.

2. Description of the Prior Art

Magnetic imaging has been the subject of serious investigation in recent years, since it has several advantages over more conventional imaging techniques.

For instance, magnetic imaging offers the prospect of an avoidance of time-consuming and delicate chemical processing steps now required in customary photography. Magnetic imaging also offers the prospect of an avoidance of expensive and potentially dangerous high-voltage equipment now required in electrostatic xerography and related techniques.

Unfortunately, magnetic imaging techniques which have become publically known to date cannot compete in terms of light sensitivity and exposure speed with photographic methods or even with electrostatic xerography.

## SUMMARY OF THE INVENTION

The subject invention overcomes or materially alleviates the above mentioned disadvantages and, from one aspect thereof, resides in a method of magnetically recording an image, comprising in combination the steps of providing a plurality of interdigitated first and second electrodes, providing a photoconductive layer electrically connected to the interdigitated first and second electrodes, and providing an electrically conductive magnetic recording layer electrically connected to the interdigitated first and second electrodes. This method further includes the steps of applying electrical energy to the interdigitated first and second electrodes to provide electrical current through the electrically conductive magnetic recording layer so as to heat the magnetic recording layer, exposing the photoconductive layer to the image so as to produce with the aid of the electrical energy a thermal pattern corresponding to the image, and changing the state of magnetization of the heated recording layer with the aid of the thermal pattern so as to produce a magnetic record of the image.

From another aspect thereof, the subject invention resides in apparatus for magnetically recording an image, comprising in combination a plurality of interdigitated first and second electrodes, a photoconductive layer electrically connected to the interdigitated first and second electrodes, and an electrically conductive magnetic recording layer electrically connected to the interdigitated first and second electrodes. This apparatus further includes means for applying electrical energy to the interdigitated first and second electrodes to establish electrical currents in the electrically conducting magnetic recording layer for heating the magnetic recording layer, means for exposing the photoconductive layer to the image to produce with the aid of the electrical energy a thermal pattern corresponding to the image, and means operatively associated with the magnetic recording layer for changing the state of magnetization of the heated recording layer with the aid of the thermal pattern whereby a magnetic record of the image is established.

The subject invention further resides in a composite recording medium, comprising in combination a plurality of interdigitated first and second electrodes, a photoconductive layer electrically connected to the interdigitated first and second electrodes, and an electrically conductive magnetic recording layer electrically connected to the interdigitated first and second electrodes.

As is explained in the above mentioned copending patent application, a composite magnetic recording medium comprising a combination of a photoconductive layer, interdigitated electrodes, and a magnetic recording medium possesses several advantages over combinations in which the photoconductive layer is sandwiched between two sheet electrodes.

These advantages may be summarized as follows: Improved electrical current rheology, improved halftone rendition, facilitated premagnetization, decreased sensitivity to pin holes and lumps in the photoconductor, increase in light sensitivity by a factor two or more, and possibility of considerable reduction of instantaneous electrical current flow.

The subject invention further provides substantial advantages which result in a convenient and advantageous heating of the magnetic recording layer and a substantial decrease of the thermal load on the photoconductive layer.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention will become more readily apparent from the following detailed description of preferred embodiments thereof, illustrated by way of example in the accompanying drawings, in which:

FIG. **1** is a perspective view of an imaging apparatus in accordance with a preferred embodiment of the subject invention;

FIG. **2** illustrates a first phase in the operation of the apparatus of FIG. **1**;

FIG. **3** illustrates further phases in the operation of the apparatus of FIG. **1**;

FIG. **4** is a cross-section, on an enlarged scale, of a fraction of the composite recording medium shown in FIG. **1**;

FIG. **5** is a cross-section, on an enlarged scale, of a fraction of a composite recording medium in accordance with a further preferred embodiment of the invention; and

FIG. **6** is a cross-section, or an enlarged scale, of a composite recording medium in accordance with yet another preferred embodiment of the subject invention.

Like reference numerals in the drawings designate like or functionally equivalent parts.

## DESCRIPTION OF PREFERRED EMBODIMENTS

The apparatus **10** of FIG. **1** includes a composite photoelectromagnetic recording medium **12** which embodies key features of the subject invention. The composite recording medium **12** includes a transparent substrate **13** which may be a sheet of glass or of an organic equivalent thereof, such as a high-temperature polyimide or polybenzamidazole.

An interdigitated electrode structure **14** including interdigitated first and second electrodes **15** and **16** is in the preferred embodiments of FIGS. **1** and **4** located on the transparent substrate **13**. The deposition of electrode structures on a transparent substrate is a well-established art and does not as such form part of the subject invention. Suffice to say therefore, that the electrode structure **14** may be deposited on the substrate **13** by evaporation, painting or sputtering, and that preferred electrode materials include gold, indium, chromium, and aluminum.

A photoconductive layer **18** is deposited on the substrate **13** and electrode structure **14**. Suitable photoconductive materials include cadmium sulfide, cadmium selenide, alloys of cadmium sulfide or cadmium selenide, and sensitized zinc sulfide. High-gain photoconductor materials are presently preferred, since they provide for the large currents needed for heating of the magnetic material but require only moderate input light levels. The thickness of the layer **18** is not generally critical, but a layer thickness of about 3 to 10 microns is presently preferred for resolutions of more than about 10 line pairs per millimeter.

The composite recording medium **12** further includes an electrically conductive magnetic recording layer **20** which is pressed against, coated on, or deposited on the photoconductive layer **18** and in electrical contact therewith. As is well known, there are several materials which are both electrically conductive and amenable to thermomagnetic change at temperatures below 200°C. By way of example and not by way of limitation, ferromagnetic chromium dioxide is a material that is not only electrically conductive, but also has a sufficiently low Curie point to be practically suitable for information-controlled thermoremanent magnetization or thermo-induced demagnetization, as may for instance be seen from U.S. Pat. No. 8,250,636, by P.A. Wilferth, issued May 10, 1966, U.S. Pat. No. 8,364,496, by Greiner et al, and British Pat. Specification No. 1,139,232, filed Apr. 27, 1966, by E.I. du Pont de Nemours and Company. Other suitable materials for the magnetic recording layer **20** include manganese arsenide alloys and compounds which are not only electrically conductive but typically have a Curie temperature significantly below 100° C.

If desired, the magnetic material for the medium **20** may be provided in the form of an integral layer, by such techniques as vapor deposition. A preferred known method for providing manganese arsenide layers resides in a superimposition of manganese and arsenide strata and an alloying thereof in situ.

The magnetic recording medium **20** preferably has an acute temperature-dependent transition between the ferromagnetic and paramagnetic states. Where the requisite acuity is not inherent in the material, it may, according to the allowed U.S. Pat. application Ser. No. 649,540, Magnetic Information Recording, filed June 28, 1967, by James U. Lemke, and assigned to the subject assignee, be realized by providing the low-Curie point magnetic particles with a shape anisotropy that dominates their crystal anisotropy. By way of preferred example, the magnetic recording medium **20** may comprise acicular ferromagnetic chromium dioxide particles dispersed in a temperature-resistant binder, such as an acrylic copolymer, polyamide or polyurethane binder, all of which may be obtained in thermosetting form.

If the magnetic recording layer **20** comprises acicular ferromagnetic particles, having long axes and short axes, then these particles are in accordance with a preferred embodiment of the subject invention so oriented that the long axes extend is geometrical planes that intersect the electrodes **15** and **16**. In this manner the electrical conductivity of the recording layer is maximized from electrode to electrode. A preferred arrangement of this type is shown in a somewhat idealized manner in FIG. **5**.

The composite recording medium **12'** of FIG. **5** comprises the above mentioned transparent substrate **18**, the electrode structure **14** including interdigitated first and second electrodes **15** and **16**, the photoconductive layer **18**, as well as a magnetic recording layer **201**.

In accordance with the preferred embodiment illustrated in FIG. **5**, the magnetic recording medium layer **201** comprises, in a binder layer **202**, acicular particles **208** of a ferromagnetic material, such as chromium dioxide. As shown in FIG. **5**, the acicular recording material particles are oriented with their long axes extending in geometrical planes (here planes parallel to the paper on which FIG. **5** is drawn) which intersect the electrodes **15** and **16** at right angles. In electrical circuit terms this means that the direction of lowest electrical resistivity or highest electrical conductivity extends at right angles to the electrodes **15** and **16**, which greatly facilitates the flow of heating currents **80** in the manner illustrated in FIG. **4**.

Moreover, the paths of maximum thermal conductivity extend in the embodiment of FIG. **5** also at right angles to the electrodes **15** and **16**. In this respect it is to be noted that the electrodes **15** and **16** typically are good heat conductors and that the heating of the photoconductive layer **18** primarily takes place between the electrodes, so that the regions of the medium **201** immediately below individual electrodes tend to remain cooler than portions of the medium located, so to say, midway between adjacent electrodes. Accordingly, if the path of maximum thermal conductivity extend at right angles to the electrodes **15** and **16**, then heat generated in response to a light stimulus acting on the photoconductive layer **18** can readily spread to the cooler regions below the electrodes **15** and **16**. This effect may be employed to at least narrow the widths of cool medium portions in which no information-induced magnetization changes take place.

By way of contrast, the preferred embodiment of FIG. **5** also lends itself to an improved rendition of gray-scale values at increased resolution. Since the intensity of the currents **80**, shown in FIG. **4** and occurring also in the embodiment of FIG. **5**, is one factor that determines the temperature of the recording medium **201**, it is readily possible to maintain, by an intensity adjustment of the currents **80**, the cool portions of the recording medium **201** immediately below electrodes **15** and electrodes **16** at temperatures that remain, despite the flow of heat along the acicular particles **208**, at temperatures which are lower than those required for an information-controlled magnetization change.

In consequence, practically unavoidable heat transfers occur chiefly from information-representative heated portions of the recording medium **201** into areas of a cooler gray-scale pattern that corresponds to the electrode structure **14.** Accordingly, practically unavoidable heat transfers are conveniently channeled without a corresponding undue broadening of recorded image elements in the general direction of the currents **80.**

An undue broadening of recorded image elements in directions parallel or substantially parallel to the electrodes **15** and **16** is in addition avoided in the preferred embodiment of FIG. **5** by the fact that electrical and thermal conductivities are at a minimum in a direction perpendicular to the long axes of the acicular particles **208.** It will thus be recognized that the preferred embodiment of FIG. **5** affords maximum image resolution coupled with a superior image recording speed and efficiency. A desired orientation of the particles **208** presents no problem, since several particle orientation techniques, including the use of a doctor blade or of an orienting magnetic field, are well known in the related art of magnetic recording tape manufacture.

In the further course of this description, reference will primarily be made to a composite recording medium of the type shown in FIG. **4,** but it should be understood that the composite medium **12'** of FIG. **5** may in all method and apparatus embodiments be substituted for the composite medium **12** of FIG. **4.**

If the recording medium **20** is present in the form of an integral layer, a sufficient electrical conductivity is typically assured by the integral nature of the layer. If the medium **20** is present in the form of particles, a sufficient electrical conductivity is also attainable without particular problems, since techniques for rendering metallic paints electrically conductive are well known in the conductive paint art and also in areas of the printed circuit field. By way of example, we have found that the electrical conductivity of the magnetic recording layer is easily controlled by varying the amount or "loading" of ferromagnetic particles per volume unit in the magnetic recording layer. In accordance with a preferred embodiment, but not by way of limitation, the layer **20** or **201** contains up to 40 percent by volume of ferromagnetic particles. Also in accordance with a preferred embodiment of the subject invention, the average electrical resistivity of the magnetic recording layer in the direction of maximum electrical conduction is substantially intermediate between the resistivity of the photoconductor layer in the dark condition and the resistivity of the photoconductor layer in the light-exposed condition.

Two preferred magnetic recording techniques include information-selective thermal demagnetization and information-selective thermoremanent magnetization. In selective demagnetization the recording medium **20** is typically premagnetized and is thereupon demagnetized by above-Curie point heating until the remaining magnetized areas present a record of the input image. In thermoremanent magnetization a thermal pattern which represents the input image is imposed upon the typically unmagnetized recording medium **20** so that selected portions of that medium are heated above Curie point. These portions are thereupon cooled in the presence of a magnetic field whereby an amplified thermoremanent magnetization of the type described by C.D. Mee, The Physics of Magnetic Recording (North-Holland Publishing Company, 1964), pp. 80–84, and in the above mentioned Greiner et al US patent and British du Pont Patent Specification takes place. If desired, strong positive magnetic records may be produced in the manner disclosed in U.S. Pat. applications Ser. Nos. 821,282 and 821,432, filed by Luc P. Benoit on May 2, 1969, and assigned to the subject assignee. As will become apparent in the further course of this disclosure, either of these magnetic recording techniques, or a combination of these techniques to be more fully described below, may be employed in the practice of the subject invention.

The apparatus **10** further includes a source of light **22,** such as an incandescent lamp or a fluorescent tube, which is energized from an electric power source **23** and which is combined with a reflector and shade **24** that defines a narrow longitudinal slit **25** for the emission of a sheet of light **26.** The light sheet is reflected by a mirror **28** which is tiltable about a longitudinal axis **29** and which reflects the impinging light in the form of a light sheet **30** onto a master record **31** that may, for instance, be supported on a sheet of glass (not shown).

The light **32** reflected by the master record **31** is imaged by a lens **34** onto the interdigitated electrode structure **14** and photoconductive layer **18.**

The first and second electrodes **15** and **16** of the interdigitated electrode structure **14** are connected to opposite terminals of a source of electric energy **36.** A switch **37** and a variable resistor **38** are connected in this circuit to control timing and intensity of the current flow to the electrode structure **14.**

As illustrated in FIG. **4,** application of electrical energy to the interdigitated electrodes **15** and **16** results in the flow of electrical currents **80** in the electrically conductive magnetic recording medium **20.** These currents enter and leave the magnetic recording medium **20** by way of current paths that extend through the photoconductive layer **18** between the electrodes **15** and **16** and the magnetic recording layer **20** as shown in FIG. **4.** These current paths owe their existence not only to the conductivity of the magnetic recording layer **20,** but also to the finite dark resistance of the photoconductive layer **18.**

In one preferred embodiment of the subject invention, the dark resistivity of the photoconductor portions covered by or below the electrodes **15** and **16** is substantially lower than the dark resistivity of photoconductor portions located between these electrodes, so that the currents **80** are sufficiently intense to heat the recording medium **20** to a temperature in the vicinity of the Curie point. The requisite relatively low dark resistance may for instance be provided by a photoconductive layer construction or design in which the distance between any electrode **15** or **16** and the magnetic recording layer is substantially smaller than the distance between adjacent electrodes **15** and **16.** Many doping techniques which lower the resistance of photoconductors are well known in semiconductor technology and may if desired be applied at regions below the electrodes **15** and **16** to lower the dark resistivity. Alternatively, light may be shone through the magnetic recording layer **20** so as to lower the resistivity of photoconductor portions below the electrodes **15** and **16** for the desired heating of the magnetic recording medium by the currents **80.**

It should be understood at this juncture that I do not intend to limit myself to methods and apparatus in which the heating of the magnetic recording medium by the currents **80** precedes an information-controlled light exposure of the photoconductive layer **18** in time and is thus a preheating in the strict sense of the word. To be sure, such a preheating is, indeed, intended to be covered herein in accordance with a preferred embodiment of the subject invention. But even where a temporal succession of heating and light exposure is expressed herein by way of example or for the purpose of explanation or : streamlined definition, it is to be understood that heating by the currents **80** may commence simultaneously or concurrently with the light exposure to the input image.

In fact, concurrent commencement of the heating of the recording layer **20** to the vicinity of the Curie point and of the exposure of the photoconductive layer **18** is preferred in accordance with a further embodiment of the subject invention in situations where heat energies provided by a temporal preheating step woud be dissipated too quickly as to be of benefit during the image exposure step.

The variable resistor **38** shown in FIG. **1** is adjusted so that the electric currents **80** heat the magnetic recording layer **20** toward the temperature at which the desired magnetic transition is to take place for image recording. In the illustrated embodiment, the currents **80** heat the magnetic recording layer **20** to a temperature in the vicinity of the Curie point and somewhat below the acutely declining region of the remanence-versus-temperature curve.

In such heating step, the dark photoconductive layer **18**, the electrodes **15** and **16** and the substrate **13** act as a heat sink which prevents the thermal energy provided by the electrical currents **80** from heating the medium **20** to temperatures too close to and through the Curie point. Since the electrode **15** and **16** are better thermal conductors than the photoconductive layer **18**, the temperature of the recording layer **20** is typically lower below the electrodes **15** and **16** than in recording layer portions midway between these electrodes. As will be apparent as this description proceeds, this fact may be exploited to provide halftone premagnetization patterns.

If a light stimulus **82** impinges on the photoconductive layer **18** between a pair of electrodes **15** and **16**, electrical photocurrents **83** occur in response to the increased conductivity of the photoconductive layer at the particular location. These photocurrents produce thermal energy between the electrodes **15** and **16**, which impairs the flow of heat from the magnetic recording layer **20** to the electrodes **15** and **16** and to the substrate **13** at the particular location. The resulting localized and temporary loss of a heat sink causes an above-Curie point rise in temperature of the particular portion of the magnetic recording medium **20.** In this manner, a thermal pattern corresponding to the image to be recorded can be provided and impressed on the magnetic recording layer **20.**

If the magnetic record is to be established by thermoremanent magnetization, then the apparatus **10** requires means for magnetizing portions of the magnetic recording layer **20** that, after an image-wise thermal exposure, cool down through the Curie point of the magnetic recording medium. If the magnetic record is to be established by selective demagnetization, then the apparatus **10** requires means for premagnetizing the magnetic recording layer **20** prior to its image-wise thermal exposure. The same elongated magnetizing head **40** may be employed for both methods with the difference that the magnetic field provided by the head **40** is applied to the magnetic recording layer **20** prior to image exposure if the record is to be established by selective demagnetization, and is applied after thermal exposure during the subsequent cooling step if the record is to be established by thermoremanent magnetization.

By way of example, it is assumed that the illustrated apparatus **10** operates with a combination of the two methods by imposing a premagnetization through the agency of thermoremanent magnetization and by establishing the magnetic record by an image-wise selective demagnetization.

The magnetizing head **40** has an air gap **42,** as well as an energizing winding **43** which is connected to a source of electric energy **44** through a switch **45** and a variable resistor **46** which serve to control the timing and intensity of the magnetic field **48** provided at the air gap **42.**

To provide for a premagnetization, the photoconductive layer **18** and interdigitated electrode structure **14** are subjected to a uniform exposure. A flood lamp (not shown) which uniformly irradiates the electrode structure **14** and photoconductive layer **18** may be provided for this purpose. A light exposure which operates within a narrow exposure band **50** that extends across the alternating electrodes **15** and **16** and that progresses in the direction of an arrow **51** parallel to the electrodes **15** and **16** is, however, preferred for two reasons. First, if the exposure is at any instant limited to a narrow exposure band, then the intensity of electric current flow is very substantially reduced relative to intensities that would occur if the entire composite medium were exposed at that instant. Secondly, it is easier to impose a premagnetization that has the requisite uniformity over the recording layer if such premagnetization takes place successively along a progressing band, rather than over the entire recording layer at once. Also, the total electric current flow is distributed over the electrodes if the exposure band extends across the electrodes rather than parallel thereto.

Accordingly, a light-reflecting element **58,** only part of which has been shown, is initially substituted for the master record **31.** The reflecting element **53,** may, for instance, include a white sheet of paper or a mirror. The exposure band **50** is then swept across the composite recording medium **20** in the direction of the arrow **51** by a tilting of the mirror **28** about its axis **29.** This tilting motion is effected by a drive **54** which is coupled to the mirror **28** and also to the magnetizing head **40** so as to move this head in the direction of an arrow **56** and in proportion to the tilting motion of the mirror **28,** in such mutual synchronism that the magnetic field **48,** which extends across the magnetic recording layer **20,** follows the exposure band **50** in the direction of the arrow **51.**

In this manner successive portions of the magnetic recording layer **20** are heated above the Curie point of the magnetic recording medium, and do thereupon cool through the Curie point as the exposure band **50** travels along the arrow **51.** The position of the traveling magnetizing head **40** relative to the moving exposure band **50** is selected such that the magnetic field **48,** which extends in parallel to the exposure band **50,** trails this exposure band at such a distance that the magnetic field **48** is successively present at all the magnetic layer portions that cool back through their Curie point.

In preparation of this thermoremanent magnetization, the switch **45** is closed and the variable resistor **46** is adjusted so that the magnetic field **48** has an intensity which is insufficient to magnetize the layer **20** while the same remains at a temperature below its Curie point, but which is sufficient to magnetize portions of the layer **20** that cool through their Curie point. As is known in magnetics, thermoremanent magnetization has the highest efficiency and linearity of all forms of magnetization.

The source **44** which energizes the magnetizing head **40** may be a source of direct current, in which case the thermoremanent premagnetization produces in the layer **20** a pattern of magnetized lines that extend in parallel to the electrodes **15** and **16** and occupy regions that correspond to areas located between the interdigitated first and second electrodes. This magnetic line pattern effect is brought about by the fact that light exposure of the photoconductive layer **18** takes place between the interdigitated electrodes **15** and **16** whereby areas below these electrodes remain colder than adjacent areas between these electrodes. To be sure, areas below the electrodes can be heated by thermal diffusion from adjacent regions, but a diffusion effect can easily be overcome by decreasing the light intensity of the source **22** or by increasing the traveling speed of the exposure region **50**, or by a combination of these measures. Also, the heat sink effect which drains thermal energy from the magnetic recording layer during heating by the currents **80** (see FIG. 4) is stronger below the flat electrodes **15** and **16** than midway between these electrodes, so that the areas of the recording medium **20** below the electrodes tend to remain cooler than the areas between these electrodes.

In contrast to a uniform premagnetization, a line-pattern premagnetization provides a multitude of sharp magnetic gradients which promote large-area fill-in, increased contrast and increased resolution.

If a point-pattern, rather than a line-pattern, is desired, then the reflecting element **53** may be provided with a pattern of alternating light-reflecting and light-absorbing areas, or the source **44** may be a source of current pulses, whereby every line **58** is only magnetized along spaced points, as shown at **60** in FIG. **2.** Point-patterns are sometimes preferred to line-patterns as is well known in the book and newspaper printing arts.

If the source **44** is a source of alternating current, each of the premagnetization lines **58** possesses a pattern of alternating magnetizations as shown in FIG. **2** at **62.** In practice, this corresponds to a point-pattern magnetization, since no magnetizing effect takes place at and adjacent the zero cross-overs of the alternating current. A strong toner attraction may result in this type of pattern from the alternating polarity of the magnetized points.

After the premagnetization step has been completed the reflecting element **53** is replaced by an information master record **31** that may, for instance, be a drawing, a writing, or a printed text. By way of example, it is assumed in FIG. **1** that the master record **31** is a white sheet of paper on which a black character **65** has been printed.

For imaging according to the embodiment shown in FIG. **1,** the switch **45** is opened and the magnetizing head **40** is decoupled from the drive **54** so that no magnetic field **48** follows the exposure band **50.** The mirror **28** is, however, coupled to the drive **54** so that the light sheet **30** is moved across the master record **31** whereby successive portions of the master record are illuminated within a traveling narrow band **64.** As before, the lens **84** images the band **64** onto the composite recording medium **12** whereby the latter is exposed within an exposure band **50** that travels in the direction of the arrow **51.**

As mentioned above, the photocurrents **88** occurring in the photoconductive layer at the areas of light impingement cause an above-Curie point heating of corresponding portions of the recording medium **20.** An application of magnetic fields to the recording layer **20** is avoided at this stage to preclude an undesired remagnetization of demagnetized areas through the agency of thermoremanent magnetization.

No significant light is reflected by the black character **65,** whereby portions of the photoconductive layer that correspond to that character remain dark. Since no photoelectric currents **88** are caused to flow at those corresponding portions the temperature of the magnetic recording layer **20** remains below its Curie point within an outline occupied by an image of the character **65.** The resulting lack of demagnetization of the premagnetization line or point-pattern leads to a magnetic record **68** of the character **65** as shown in FIG. **3.**

Special advantages of the subject invention may again be considered at this juncture. First, since the electric currents **80** heat the magnetic recording layer **20** close to its Curie temperature, the photocurrents **88** only need to be strong enough to cause the occurrence of a temperature increment of a few degrees in the Curie point region. Secondly, since the photoconductive layer is part of a heat sink arrangement, its heating in response to luminous stimuli need only be strong enough to reduce the drainage of heat from the magnetic recording layer. This stands in favorable contrast to arrangements in which the thermal image pattern is generated in the photoconductive layer **18** to be thereupon applied by thermal conduction to the magnetic recording layer **20.**

The magnetic image **68** may be stored in the magnetic recording medium **20** and printed out as often as desired. A magnetic toner **70** may be applied to the magnetic image **68** to render the same visible or printable. Magnetic toners typically comprise magnetically attractable particles **72** in powdered form or liquid suspension. Suitable materials for the toner particles **72** include iron, nickel, cobalt or ferromagnetic alloys. By way of example and not by way of limitation, preferred materials for the toner particles **72** include submicron particles of iron, carbonyl iron, and magnetite ($Fe_3O_4$). Magnetic toners, toning techniques, and toning apparatus are disclosed in U.S. Pat. No. 2,932,278, by J.C. Sims, issued Apr. 12, 1960; U.S. Pat. No. 3,052,564, by F.K. Kulesza, issued Sept. 4, 1962; and U.S. Pat. No. 3,250,636, by R.A. Wilferth, issued May 10, 1966.

The toner image **74** resulting from a toning of the magnetic image **68** may be printed out on a sheet of paper, on a film, or on another material having similar surface qualities. If desired, a sheet of paper **75** may be provided with an adhesive coating **76** to assure a transfer and retention of the toner image **74** in the form of a copy **78** or the original character **65.** To effect such a transfer, the adhesive paper **75** is pressed onto the magnetic recording layer **20** and is thereupon removed whereby the toner image **74** adheres to and is pulled off together with the paper **75**. As is known in the art of magnetic printing, the toner **70** may be present in the form of a magnetic ink that is absorbed by the paper **75**, or the toner particles may be provided with shells of a thermoplastic or other fusible material that may be fused to the paper **75** by a combination of pressure and heat. No adhesive coating **76** is provided if a magnetic ink or a fusible material is employed.

If no further printout or storage is desired, the magnetic image **68** may be erased by such conventional methods as an exposure of the magnetic recording layer **20** to anhysteretic magnetic erasing fields, or to above-Curie point heating. The latter may be effected by a sweeping of the light sheet **32** across the interdigitated electrode structure **14** and photoconductive layer **18**, while the electrodes are connected to the electric energy source **36** and the reflective element **58** is substituted for the information record **51**.

The magnetic recording layer **20** may be permanently deposited on the photoconductive layer **18**. Since the magnetic recording layer **20** is typically much cheaper than the combined interdigitated electrode structure **14** and photoconductive layer **18**, it may be advantageous to provide the magnetic recording layer **20** on a substrate that is selectively movable into contact with, and removable from, the photoconductive layer **18**.

In accordance with a further preferred embodiment of the subject invention the interdigitated electrodes **15** and **16** are located adjacent the magnetic recording layer **20** in electrical contact with both the photoconductive layer **18** and the electrically conductive recording layer **20**. In this embodiment the electrical resistivity of the magnetic recording medium **80** is sufficient to prevent a short-circuiting of the photoconductive layer **18**. More specifically, the resistivity of the magnetic recording layer **20** is lower than the dark resistivity of the photoconductive layer **18** to provide for a flow of the above mentioned electric currents **80** through the magnetic recording layer **20**; and the resistivity of the magnetic recording layer **20** is comparable with or higher than the light resistivity of the photoconductive layer **18** to permit the flow of the above mentioned photocurrents **83** in response to a light stimulus **82** and at sufficient intensities to provide for a localized above Curie-point heating of the magnetic recording layer **20**. If desired, the recording layer **20** in FIG. **6** may be replaced by the recording layer **201** of FIG. **5**.

The embodiment of FIG. **6** has the advantage that the electrodes **15** and **16** do not obscure incoming light at the substrate **13**, and that the electric heating currents **80** need not traverse portions of the photoconductive layer **18**. In this connection, it should however be noted that it is intended to be within the scope of the subject invention that the interdigitated electrodes **15** and **16** may be embedded within the photoconductive layer **18** at locations spaced from both the substrate **13** and the magnetic recording medium **20** or **201**.

Also, by way of explanation and not by way of limitation, an electrode arrangement of the type shown in FIG. **4** in which the interdigitated electrodes are located at the substrate **13** is presently preferred, since available manufacturing techniques favor a deposition of interdigitated electrodes on a substrate over a deposition of such electrodes on a photoconductive layer, and since incoming light stimuli have to penetrate a lesser depth of the photoconductive layer when the electrodes are located at the transparent substrate rather than being remote therefrom.

In accordance with another preferred embodiment of the subject invention, the interdigitated electrodes **15** and **16** and the photoconductor layer **18** together form an assembly to which the electrically conducting magnetic recording layer **20** or **201** is selectively applicable and from which such magnetic recording layer is selectively removable. This embodiment, which is applicable to any of the composite recording media of FIGS. **1, 4, 5** and **6**, has chiefly the advantage of increased economy, since the less expensive magnetic recording layer **20** or **201** can be made disposable, while the more expensive electrode and photoconductor assembly has a more permanent character.

Since a uniform electrical and thermal contact between the layer **20** or **201** and the electrode and photoconductor assembly are important, mounting and spring devices of the type shown for instance in U.S. Pat. No. 2,798,960, Photoconductive Thermography, by A.J. Moncrieff-Yeates, issued July 9, 1957, and herewith incorporated by reference herein, may be employed for mounting the magnetic layer **20** or **201** relative to the electrode and photoconductor assembly.

The selectively removable layer **20** or **201** may either be self-supporting or may be provided with a substrate of its own, which may be similar to, but separate from, the illustrated substrate **13**.

I claim:

**1.** Apparatus for magnetically recording an image, comprising in combination:

a plurality of interdigitated first and second electrodes;

a photoconductive layer electrically connected to said interdigitated first and second electrodes;

an electrically conductive magnetic recording layer electrically connected to said interdigitated first and second electrodes;

means for applying electrical energy to said interdigitated first and second electrodes to establish electrical currents in said electrically conducting magnetic recording layer for heating said magnetic recording layer;

means for exposing said photoconductive layer to said image to produce with the aid of said electrical energy a thermal pattern corresponding to said image; and

means operatively associated with said magnetic recording layer for changing the state of magnetization of said heated recording layer with the aid of said thermal pattern whereby a magnetic record of said image is established.

**2.** Apparatus as claimed in claim **1**, wherein:

said electrically conductive magnetic recording layer is electrically connected to said interdigitated first and second electrodes through portions of said photoconductive layer.

**3.** Apparatus as claimed in claim **1**, wherein:

said exposing means include means for progressively exposing said photoconductive layer to said image in a direction progressing parallel to said interdigitated electrodes.

**4.** Apparatus as claimed in claim **1**, wherein:

said apparatus includes a substrate;

said interdigitated first and second electrodes are located on said substrate;

said photoconductive layer is located on said substrate and said interdigitated first and second electrodes; and

said electrically conductive magnetic recording layer is located on said photoconductive layer.

**5.** Apparatus as claimed in claim **1**, wherein:

said interdigitated electrodes protrude into said photoconductive layer in a direction toward said magnetic recording layer.

**6.** Apparatus as claimed in claim **1**, wherein:

each of said interdigitated first and second electrodes is spaced more from each of the adjacent electrodes than from said magnetic recording layer.

**7.** Apparatus as claimed in claim **1**, wherein:

said electrically conductive magnetic recording layer comprises acicular magnetic recording medium particles having short axes, and having long axes extending substantially in geometrical planes intersecting said first and second electrodes.

**8.** Apparatus as claimed in claim **7**, wherein:

said long axes of said particles extend substantially in geometrical planes intersecting said first and second electrodes at right angles.

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