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PATENT SPECIFICATION (11) 1 560 245

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(21) Application No. 9671/77 (22) Filed 8 March 1977
(31) Convention Application No. 668495
(32) Filed 19 March 1976 in
(33) United States of America (US)
(44) Complete Specification published 30 Jan. 1980
(51) INT CL³ G11B 7/24//7/00
(52) Index at acceptance
G5R B21 B263 B265 B361 B36Y B482 B571 B601 B701 B711 B714 B734 B789
B2E 1721 407T 415S 423U 425U M

(19)



(54) INFORMATION RECORD

(71) We, RCA CORPORATION, a corporation organized under the laws of the State of Delaware, United States of America, of 30 Rockefeller Plaza, City and State of New York, 10020, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to an information record, and methods for use in formation of such an information record.

In the prior art, optical recording methods have been proposed in which light from a laser is focused upon the surface of a recording medium with sufficient intensity to cause ablation of surface material. By suitably controlling the intensity of the focused light in accordance with information to be recorded while relative motion is established between the recording medium and the focused light spot, an information representative pattern of pits may be formed in the surface of the recording medium.

In application of such an ablation process, for example, to the high-density recording of video information at "real-time" recording rates, the achievement of an adequate recording sensitivity requires efficient coupling of energy from the recording light beam into the material to be ablated. In accordance with the principles of the present invention, such efficiency of energy coupling may be enhanced by construction of the recording medium in the form of a substrate having a surface which is highly reflective (at least at the frequency of the light forming the recording beam), with a layer of material highly absorptive at the recording beam light frequency, overlying the reflective surface. With both incident light and reflected light (reflected from the substrate surface) passing through the absorptive layer, the ability to rapidly elevate the temperature of the absorptive layer material to that required for ablation to take place is enhanced.

Pursuant to a further aspect of the present invention, the efficiency of energy coupling into the absorptive layer may be further enhanced by choosing a thickness for the absorptive layer which establishes an anti-reflection condition for the free surface of the coating of the substrate at the recording beam light frequency. With energy loss via reflection minimized due to the anti-reflection condition establishment, and with energy loss via transmission into the substrate minimized by the reflective surface presence, a highly efficient heating of the absorptive layer to an ablation temperature is realizable.

In accordance with an illustrative embodiment of the present invention, a surface of a glass substrate of disc form is processed so as to form a polished flat surface, which is then coated with a thin layer of metal (e.g., aluminum) to establish a highly reflective surface for the substrate. This reflective surface is then coated with a layer of material (e.g., an organic dye, such as fluorescein) which is highly absorptive at the light frequency of a monochromatic light source available for recording use (e.g., an argon laser, providing an output at a wavelength of 4579 angstrom units). The thickness of the dye layer is chosen to establish an anti-reflection condition for the free surface of the absorptive coating of the substrate at the recording wavelength.

The coated disc structure, formed in the above-described manner, constitutes a record blank which may be utilized in conjunction with a suitably controlled light beam source of the appropriate frequency to efficiently effect coupling of energy from the light beam into the absorptive layer.

In an illustrative recording system described further hereinafter, a record blank

of the above-described disc form is subject to rotation at a constant rotational speed while a beam of light from a light source (e.g., a laser, providing light at a frequency at which the anti-reflection condition is obtained) is focused on the coated surface of the disc. The intensity of the light beam is controlled in accordance with information to be recorded. Illustratively, the control is effected in accordance with carrier waves modulated in frequency by picture-representative video signals, with the light beam intensity varying as a result between a high level sufficient to effect ablation of the absorptive material and a low level insufficient to effect such ablation, the frequency of the level alternations varying as the video signal amplitude changes.

An information track comprising a succession of spaced pits is formed in the coated surface of the disc, the pits appearing in those surface regions exposed to the high level beam, due to vaporization of the absorptive layer material in response to the high level beam exposure. Variations in the length and separation of the pits are representative of the recorded information. Where a continuous sequence of pictures is to be recorded, a spiral information track may be formed by providing relative motion, in a radial direction and at a constant rate during the recording between the recording beam and the rotating disc. Alternatively, in the absence of such relative motion during the recording, a circular information track may be formed; appropriate for "slide" recording purposes.

The result of the above-described recording process is the formation of an information record of a form which facilitates recovery of the recorded information by optical playback processes. The information track of such an information record comprises (1) undisturbed surface regions that exhibit very low reflectance at an appropriate light frequency (due to the anti-reflection thickness choice described previously), alternating with (2) pit regions, formed by the ablation process, that exhibit appreciably higher reflectance at the same light frequency (due to complete, or at least partial, removal of the absorptive layer covering of the reflective surface of the substrate, ensuring departure from the anti-reflection condition). A high ratio between the reflectance of the pit regions and the reflectance of the intervening (undisturbed surface) regions is readily provided.

In playback operations, a light beam is focused upon the information track of a rotating information record of the above-described type. The playback beam has a constant intensity at a level insufficient to effect ablation of the disc coatings, and is of a frequency substantially corresponding to that at which the undisturbed surface regions exhibit an anti-reflection condition. A photo-detector, positioned to receive light reflected from the successive regions of the information track as they pass through the path of the focused light, develops a signal representative of the recorded information. A high readout contrast ratio (due to the large differences in reflectance of the pit regions and the intervening track regions, at the light frequency of the playback beam) is readily obtained, permitting recovery of the recorded video signals with an excellent signal-to-noise ratio.

In the accompanying drawings:

Figure 1 provides a cross-sectional view of a portion of a recording medium, exhibiting a construction in accordance with principles of the present invention;

Figure 2 illustrates a cross-sectional view of a portion of the information track of an information record formed from a recording medium of the type shown in Figure 1 pursuant to principles of the present invention;

Figure 3 provides a representation, partially in block diagram form, of optical recording apparatus suitable for use in formation of an information record of the type shown in Figure 2, as well as playback apparatus suitable for use in recovery of recorded information from an information record of the type shown in Figure 2; and

Figure 4 provides a graph of the relationship between surface layer thickness and reflectance for an illustrative form of the recording medium of Figures 1 and 2.

In Figure 1, a cross-sectional view of a portion of a record blank 10, formed for use in an optical recording system, shows the construction of a recording medium persuant to an illustrative embodiment of the present invention. The record blank 10 includes a substrate 11, which is illustratively formed in the shape of a disc, a major surface (s) of which is processed to be polished and flat. Desirably, the substrate 11 is formed of a material, such as glass, for example, which may be conveniently processed to achieve such surface.

Overlying the surface "s" of the substrate 11 is a thin layer 13 of a material exhibiting a high reflectivity (over at least a given portion of the light spectrum). Illustratively, the reflecting layer 13 is formed of a metal, such as aluminum, for example, deposited on the surface "s" by an evaporation process.

Overlying the reflecting layer 13 is a layer 15 of material which is highly light

absorptive (at least over the aforementioned given portion of the light spectrum). Illustratively, the absorptive layer 15 is formed of an organic dye, such as fluorescein, for example, deposited on the reflecting layer 13 by an evaporation process.

An advantage of the use, in the illustrated construction of the recording medium, of an absorptive layer overlying a reflective surface will be recognized by consideration of the effect achieved when a light beam L (of a frequency in the aforementioned given portion of the spectrum) is directed along an axis (x) normal to the surface "s", and focused at or near the surface of the absorptive layer 15. Most of that portion of the incident light which reaches the interior boundary of the absorptive layer 15 is not "lost" through transmission into the substrate 11, as would occur in the absence of the reflecting layer 15, but rather is reflected back into the absorptive layer 15. The consequence is exposure of the absorptive layer 13 to both incident and reflected light. Where it is desired to effect surface ablation in response to recording light exposure, this avoidance of transmission losses into the interior of the recording medium increases the coupling of energy from the recording light beam into the surface material, enhancing recording sensitivity. While a similar avoidance of transmission losses into the interior of the recording medium would be achieved by forming the surface layer of a reflecting material (not covered by an absorptive layer), the transmission loss avoidance would be offset by high reflection losses.

For optimum efficiency of coupling of energy from the recording light beam L into the absorptive layer 15, reflection losses are reduced to a low level by choosing the thickness (d_1) of the absorptive layer 15, with relation to the thickness (d_2) of the reflecting layer 13 and the optical constants of the elements of the system 15—13—11, to establish a so-called anti-reflection condition for the system at the free surface of absorptive coating 15 at the recording beam frequency. The achievement of an anti-reflection effect by use of thin films of appropriate thicknesses and optical properties is well-known, per se, and applications of the effect with films of transmissive materials are widespread in optical equipment. Formulae which may be used in arriving at parameter combinations for the absorptive media (15, 13) of the Figure 1 system that result in the desired anti-reflection condition are presented herein subsequently, in connection with a discussion of Figure 4.

When the intensity of the focused light beam L is of sufficient magnitude, material of the absorptive layer 15 is elevated to an ablation temperature, and vaporization of the material occurs, forming a pit in the surface of the record blank 10. With suitable modulation of the intensity of the beam L in accordance with a recording signal, as successive regions of the record blank 10 pass through the beam path, an information track may be formed comprising spaced pits in regions of the absorptive layer subject to the high intensity beam exposure, separated by undisturbed regions of the absorptive layer (that were not subject to such high intensity beam exposure).

Figure 2 illustrates a portion of an information record formed when the record blank 10 of Figure 1 is subjected to such controlled beam exposure. As shown in cross-section in Figure 2, the information track comprises a succession of spaced pits p_1, p_2, p_3, p_4, separated by regions (u_1, u_2, u_3, u_4) in which the surface of the absorptive layer 15 is undisturbed. For illustrative purposes, the depth of each pit is shown as being equal to the thickness of the absorptive layer 15, whereby the reflective layer 13 is wholly uncovered in the pit regions. As will be discussed subsequently, while such a depth of ablation may desirably result in maximization of the readout contrast ratio, it is not essential for good playback results. Thus, in an acceptable alternative to the illustrated form of information record, a residual portion of the absorptive material (with a thickness, of course, less than d_1) may overlie the reflecting layer 13 in the pit bottoms.

Figure 3 illustrates combined recording/playback apparatus. For an initial explanation of operation of the illustrated apparatus in the recording mode, it should be assumed that the disc 10′, supported on a turntable 20 which is subject to rotation at a constant rotational rate (e.g., 1800 rpm) by the turntable rotational drive mechanism 21, is a record blank of the form shown in Figure 1.

The monochromatic light output of a laser 31 (illustratively, of an argon type providing an output wavelength of 4579 angstrom units) is passed via a polarizer 32 and an intensity modulator 33 to a polarized beam splitter. The polarizer 32 effects a polarization of the laser output in a direction that permits passage of the intensity modulated light through the beam splitter 35. The intensity modulator 33 is driven by a modulator driver 55, responsive to a carrier wave source in the form of a frequency modulated oscillator 53. The frequency of the carrier wave output of oscillator 53 is subject to variation in accordance with the amplitude of a modulating signal provided by a source 51 of video signals to be recorded. The light intensity of

the output of modulator 33 is shifted between high and low levels in consonance with the modulated carrier waves.

A lens 37 forms the light passed by beam splitter 35 into a beam which passes through a quarter-wave plate 39 to a mirror 41 which reflects the beam onto the entrance aperture of a lens 43. The lens 43 focuses the light beam reflected by mirror 41 on the absorptive surface layer (15) of the disc 10'. An absorptive layer region in the path of the focused light beam when the light beam intensity level is high suffers ablation, while an absorptive layer region in the path of the focused light beam when the light beam intensity level is low remains undisturbed. The result is formation of an information track of the general type shown in Figure 2. When the frequency of the carrier waves controlling the intensity modulator 33 is high, the spacing between successive pits in the information track is short (see e.g., spacing between pits p_1 and p_2); when the carrier wave frequency is low, the pit spacing is long (see, e.g., spacing pits p_3 and p_4).

A lens translational drive mechanism 61 provides a constant rate radial motion of an assembly 40 (incorporating lens 43 and mirror 41), when a spiral track formation is desired, or a stepped radial motion when it is desired to form a circular track, or a series thereof.

When the light frequency of the recording beam provided by laser 31 falls in the given spectrum portion for which the disc's layer 13 is highly reflective and for which the disc's layer 15 is highly absorptive, and at or close to the frequency at which the system 15—13—11 exhibits the anti-reflection effect, a high recording sensitivity is obtained.

For an explanation of operation of the apparatus of Figure 3 in a playback mode, it may be assumed that the rotating disc 10' is of a recorded form as shown by the information record construction of Figure 2. In the playback mode, variation of the intensity of the laser output is discontinued by a suitable disabling of the modulation control system 51—53—55. The mode of operation of the translational drive mechanism 61 is chosen to be appropriate for scanning of the form of information track desired to be played back. The constant intensity of the laser output is set at a playback level safely below the level causing ablation of the material of the absorptive layer 15. The laser beam follows the previously described path (via elements 32, 33, 35, 37, 39, 41) to lens 43 which focuses the beam on the desired information track of disc 10'. Light reflected from the information track is returned via elements 43, 41, 39 and 37 to the beam splitter 35. As the returned light has made two passes through the quarter-wave plate 39, its polarization has been altered to a direction which results in reflection of the returned light by beam splitter 35 to a photodetector 71.

The intensity of light falling upon the photo-detector 71 alternates between a minimum level and a maximum level as the successive regions (p_1, u_1, p_2, u_2, etc.) of the information track pass through the path of the focused beam. The minimum intensity level for light reaching the photodetector 71 is obtained when an undisturbed region (u_1, u_2, etc.) of the absorptive layer 15 is in the focused beam path, while the maximum intensity level for light reaching the photodetector 71 is obtained when a pit (p_1, p_2, etc.) is in the focused beam path.

The output of photodetector 71 comprises carrier waves with zero crossings recurring at frequencies varying in consonance with the pit edge spacing variations passing through the focused beam path. The photodetector output is applied to a bandpass filter 73, which selectively passes signal components falling within the deviation range employed for oscillator 53 and appropriate sidebands thereof. The output of bandpass filter 73 is applied via a limiter 75 (removing spurious amplitude modulation of the frequency modulated carrier waves) to the input of an FM demodulator 77, which recovers the recorded video signal information.

When the light frequency of the playback beam provided by laser 31 falls in the given spectrum portion for which the disc's layer 15 is highly absorptive and for which the disc's layer 13 is highly reflective, and at or close to the frequency at which the undisturbed regions of the system 15—13—11 exhibits the anti-reflection effect, a high readout contrast ratio is realized, permitting the video signal recovery with an excellent signal-to-noise ratio. Illustratively, with use of a deviation range of 7—10 MHz., color television signals of an NTSC format have been recovered with a video signal-to-noise ratio of 55—60 db (peak-to-peak video to rms noise) for a video bandwidth of 5 MHz.

The reflectance of a system of two absorbing layers, such as the system of Figure 1 (incorporating a dye layer on top of a metallic layer on a glass substrate), can be calculated using formulae well known in the theory of thin film optics. The reflectance of such a system is given by the square of the modulus of the amplitude

reflection coefficient of the system. The amplitude reflection coefficient of such a system is given by the following expression:

$$r=\frac{r_1+r_2\,e^{-2i\delta_1}+r_3\,e^{-2i(\delta_1+\delta_2)}+r_1r_2r_3\,e^{-2i\delta_2}}{1+r_1r_2\,e^{-2i\delta_1}+r_1r_3\,e^{-2i(\delta_1+\delta_2)}+r_2r_3\,e^{-2i\delta_2}}$$

where r_1, r_2, r_3 are the Fresnel reflection coefficients at the air to dye, dye to metal, and metal to substrate interfaces respectively, and are complex numbers, and where $i=\sqrt{-1}$.

The Fresnel reflection coefficients are given in terms of the complex indices of refraction, as follows:

$$r_1=\frac{\tilde{\eta}_0-\tilde{\eta}_1}{\tilde{\eta}_0+\tilde{\eta}_1}\qquad r_2=\frac{\tilde{\eta}_1-\tilde{\eta}_2}{\tilde{\eta}_2+\tilde{\eta}_3}\qquad r_3=\frac{\tilde{\eta}_2-\tilde{\eta}_3}{\tilde{\eta}_2+\tilde{\eta}_3}$$

where $\tilde{\eta}_0$, $\tilde{\eta}_1$, $\tilde{\eta}_2$, $\tilde{\eta}_3$ are the complex indices of refraction respectively of the media: air, dye, metal, and glass substrate. The complex index of refraction is a complex number, $\tilde{\eta}=\eta-ik$, which incorporates the real part η and the imaginary part k and characterizes the intrinsic optical properties of a medium. For non-absorbing media the imaginary part of the index is zero.

The quantities δ_1 and δ_2 are given by

$$\delta_1=\frac{2\pi}{\lambda}\,\tilde{\eta}_1 d_1$$

$$\delta_2=\frac{2\pi}{\lambda}\,\tilde{\eta}_2 d_2$$

where d_1 and d_2 are the thicknesses of the dye and metal layers respectively and λ is the wavelength of the light in air. Note that δ_1 and δ_2 are complex quantities because of the dependence on the complex indices.

The reflectance of the system of Figure 1 can thus be readily evaluated with a computer as a function of the film thicknesses and optical constants. One such calculation for fluorescein on aluminum on glass is plotted in Fig. 4. In this case the assumed parameters were: aluminum thickness=100 Å; wavelength of light=4579Å; index of dye=(1.842−*i*.362); and index of aluminum=(.47−*i*4.84).

The graph of Figure 4 shows that the minimum reflectance for the illustrative system parameter choices for the system of Figure 1 occurs at a dye layer thickness of approximately 500 angstrom units. Thus, when this thickness value is associated with the illustrative system parameter choices, the record blank of Figure 1 (and the non-depressed regions of the information record of Fig. 2) exhibits an anti-reflection condition for the argon laser output.

While the principles of the present invention have been demonstrated with particular regard to the illustrative structures of Figures 1 and 2, it will be recognized that various departures from such illustrative structures may be undertaken in practice of the invention. For example, the substrate itself may be formed of material having high reflectivity, eliminating the need for employing a separate reflecting layer in forming a reflective surface underlying the absorptive layer. For another example, since wideband reflection is not required of the reflecting layer, the metal coating may be supplanted by a multilayer (or even a single layer) dielectric reflector. It should also be appreciated that other forms of optical recording (such as pulsed holographic recording) may use the advantageous record blank structure described herein.

WHAT WE CLAIM IS:—

1. A record blank for use with a recording light source providing light of a given frequency, said record blank comprising a layer of material exhibiting high reflectivity

reflection coefficient of the system. The amplitude reflection coefficient of such a system is given by the following expression:

$$r=\frac{r_1+r_2\,e^{-2i\delta_1}+r_3\,e^{-2i(\delta_1+\delta_2)}+r_1r_2r_3\,e^{-2i\delta_2}}{1+r_1r_2\,e^{-2i\delta_1}+r_1r_3\,e^{-2i(\delta_1+\delta_2)}+r_2r_3\,e^{-2i\delta_2}}$$

where r_1, r_2, r_3 are the Fresnel reflection coefficients at the air to dye, dye to metal, and metal to substrate interfaces respectively, and are complex numbers, and where $i=\sqrt{-1}$.

The Fresnel reflection coefficients are given in terms of the complex indices of refraction, as follows:

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where $\tilde{\eta}_0$, $\tilde{\eta}_1$, $\tilde{\eta}_2$, $\tilde{\eta}_3$ are the complex indices of refraction respectively of the media: air, dye, metal, and glass substrate. The complex index of refraction is a complex number, $\tilde{\eta}=\eta-ik$, which incorporates the real part η and the imaginary part k and characterizes the intrinsic optical properties of a medium. For non-absorbing media the imaginary part of the index is zero.

The quantities δ_1 and δ_2 are given by

$$\delta_1=\frac{2\pi}{\lambda}\,\tilde{\eta}_1 d_1$$

$$\delta_2=\frac{2\pi}{\lambda}\,\tilde{\eta}_2 d_2$$

where d_1 and d_2 are the thicknesses of the dye and metal layers respectively and λ is the wavelength of the light in air. Note that δ_1 and δ_2 are complex quantities because of the dependence on the complex indices.

The reflectance of the system of Figure 1 can thus be readily evaluated with a computer as a function of the film thicknesses and optical constants. One such calculation for fluorescein on aluminum on glass is plotted in Fig. 4. In this case the assumed parameters were: aluminum thickness=100 Å; wavelength of light=4579Å; index of dye=(1.842−*i*.362); and index of aluminum=(.47−*i*4.84).

The graph of Figure 4 shows that the minimum reflectance for the illustrative system parameter choices for the system of Figure 1 occurs at a dye layer thickness of approximately 500 angstrom units. Thus, when this thickness value is associated with the illustrative system parameter choices, the record blank of Figure 1 (and the non-depressed regions of the information record of Fig. 2) exhibits an anti-reflection condition for the argon laser output.

While the principles of the present invention have been demonstrated with particular regard to the illustrative structures of Figures 1 and 2, it will be recognized that various departures from such illustrative structures may be undertaken in practice of the invention. For example, the substrate itself may be formed of material having high reflectivity, eliminating the need for employing a separate reflecting layer in forming a reflective surface underlying the absorptive layer. For another example, since wideband reflection is not required of the reflecting layer, the metal coating may be supplanted by a multilayer (or even a single layer) dielectric reflector. It should also be appreciated that other forms of optical recording (such as pulsed holographic recording) may use the advantageous record blank structure described herein.

WHAT WE CLAIM IS:—

1. A record blank for use with a recording light source providing light of a given frequency, said record blank comprising a layer of material exhibiting high reflectivity

at least at said given frequency, and a coating of material exhibiting high absorptivity at said given frequency, said coating overlying said layer and having a thickness value substantially equal to a thickness at which reflectivity from the free surface of said coating increases if its thickness is made slightly greater or slightly smaller.

2. A record blank according to Claim 1, including a substrate having a surface comprising said high reflectivity layer and with said coating of light absorptive material overlying said light reflecting surface of said substrate.

3. A record blank according to Claim 1, comprising a substrate, said high reflectivity material layer overlying a surface of said substrate.

4. A record blank in accordance with Claim 3, wherein said substrate is in the form of a disc, and wherein said light reflecting surface is formed by a metal coating on a major surface of said disc.

5. A record blank in accordance with Claim 4, wherein said disc is formed of glass.

6. A record blank in accordance with any preceding claim, wherein said light absorptive material comprises an organic dye.

7. A record blank in accordance with any preceding claim, wherein said high reflectivity layer comprises aluminium.

8. A record blank in accordance with Claim 6 or 7 when appended to claim 6, wherein said organic dye comprises fluorescein.

9. An information record formed from a blank in accordance with any preceding claim, for use in playback apparatus employing a playback beam of light of a given frequency;

said absorptive coating comprising an information track formed therein;

said information track having a succession of spaced pits, with variations in the spacing between successive pit edges representative of recorded information; wherein

the thickness of said absorptive coating in those regions of the coating occupied by said pits being less than the thickness required to establish an anti-reflection condition at the free surface of said absorptive coating for those coating regions not occupied by said pits.

10. A record blank, or a record, or methods for their formation substantially as hereinbefore described with reference to any Figure of the accompanying drawings.

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Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1980
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.