SPECIFICATION

Optically readable record and reading apparatus

The invention relates to a record carrier which contains information in an optically readable structure which comprises trackwise arranged areas which alternate with intermediate areas, the areas having a different influence on a read beam than the intermediate areas and the lands between the information tracks. The invention also relates to apparatus for reading such a record carrier.

In the case of a round disc-shaped record carrier the information tracks may comprise a multitude of concentric tracks or alternatively, a multitude of quasi-concentric tracks which are linked to each other, together constituting a spiral track. In either case the tracks are locally substantially parallel to one another.

Such a record carrier is *inter alia* known from: "Philips Technical Review" *33*, no. 7, pages 178-190. In this record carrier a (colour) television programme is encoded in the spatial frequency of the areas and in the lengths of the areas. The width of the information tracks, and thus the width of the areas, is for example 0.5 μm, the track period in the radial direction is for example 1.7 μm, and the average length of the areas for example 0.5 μm. In an annular area with an inner radius of 6.5 cm and an outer radius of 14 cm it is then possible to store a television programme of approximately 30 minutes.

For certain programmes, for example feature films, a longer playing time is desired. A longer playing time could be achieved by arranging the information tracks more closely to each other.

When the record carrier is read care must be taken that the centre of the read spot which is formed on the information structure coincides with the middle of the track portion to be read, because otherwise the modulation depth of the signal being read is small and cross-talk may occur between adjacent tracks. Therefore, a radial error signal is derived during reading, which signal provides an indication about the position of the read spot relative to the middle of the track portion to be read. In a servo system the radial position of the read spot is corrected with the aid of this error signal. For the generation of the radial error signal use is made of the grating-shaped structure of the adjacent information tracks in the radial direction. The optical read system with which the information structure is read is adapted to the information structure to be read. This means that the wavelength of the read beam and the numerical aperture of the read objective are selected in such a way that the areas with the highest spatial frequency, the areas of the inner track in the case of a round disc-shaped record carrier, can still be read with satisfactory discrimination. For a specific read system a compromise should be made in respect of the radial spatial frequency. The radial spatial frequency is selected so that a certain playing time is obtained, whilst the cross-talk between the tracks remains within a certain limit and the radial error signal is still sufficiently large. The radial track period of 1.7 μm stated in the foregoing is valid for a wavelength of $\lambda = 0.63$ μm and a numerical aperture N.A. = 0.45. If the radial spatial frequency were increased, that is, the radial track spacing decreased, for example by a factor 2 for doubling the playing time, this spatial frequency would be situated near the cut-off frequency of the optical system, and radial positional errors of the read spot could then barely be detected.

Furthermore, if the read spot is larger than the width of the information tracks. If the radial period of the information track were reduced, i.e. the track-to-track spacing reduced, a substantial portion of the read radiation would be incident on the tracks adjacent the track to be read. This would give rise to substantial cross-talk between the information tracks, even if the read spot were centered correctly relative to the track to be read.

It is an object of the present invention to increase the information density of a record carrier, whilst avoiding the afore-mentioned disadvantages. Thus, the record carrier and the apparatus for reading the record carrier are complementary to one another.

The invention provides a record carrier on which information is stored in an optically readable structure comprising a plurality of parallel adjacent tracks in a plane, each track comprising internally featureless first areas alternating with intermediate internally featureless second areas in single file along the track, the information being encoded in the sequence of the first and second areas in the track direction, laterally adjacent tracks being separated by lands, the first areas having a different influence on a read beam than the second areas, and each track differing at each point along its length from the corresponding point in either immediately laterally adjacent track, in that they comprise first areas having one or the other of two phase depths, first areas of one phase depth in any track being immediately laterally adjacent to first areas of the other phase depth in an adjacent track, the phase depths being chosen so that radiation of one wavelength may be employed to read any track with low cross-talk from laterally adjacent tracks.

The information is then contained in two structures of different phase depth. The phase depth is defined as the phase difference of a zero-order subbeam and of the higher-order subbeams into which the read beam is split by the information structure. The phase depths of phase gratings and amplitude gratings are given in an article by Braat and Bouwhuis in "Applied Optics", 1st July, 1978, Vol. 17, No. 13, pages 2013 to 2021. Each phase depth then corresponds to a specific arrangement of the detection system with which the relevant structure can be read in an optimum manner. A deep phase structure is read in an optimum manner by detecting the total intensity over the entire pupil of the read objective, whilst a less deep phase structure is read in an optimum manner by determining the difference of the intensities in two tangentially different pupil halves i.e. halves separated by a line across the track. By the use of two different phase depths and of different detector arrangements, the radial period of the information track can be reduced by for example a factor 2, whilst the information tracks can still be

read with satisfactory discrimination.

If allowance need only be made for the phase differences between zero-order and the higher-order subbeams, a phase depth of π radians (hereinafter abbreviated to "rad") could be selected for the deep tracks and a phase depth of $\frac{\pi}{2}$ rad for the shallow tracks. However, for a phase depth of $\frac{\pi}{2}$ rad, the radiation energy in the higher-order subbeams is very low, so that the detector signals are also very small. Therefore, in practice a phase depth slightly greater than $\frac{\pi}{2}$ rad is selected for the shallow tracks.

In a preferred embodiment of a record carrier in accordance with the invention the first phase depth is approximately π rad and the second phase depth approximately $\frac{2\pi}{3}$ rad.

It is also possible to attribute a phase depth, namely a phase depth of π rad, to an information structure which comprises radiation-absorbing areas and radiation-transmitting or radiation-reflecting intermediate areas, which information structure is referred to as an amplitude structure. One of the two tracks in the record carrier in accordance with the invention may comprise such an amplitude structure.

Preferably, the tracks with a large phase depth and those with a small phase depth comprise pits or hills. The advantage of a record carrier with pits or hills is that it can be manufactured rapidly in large quantities using known pressing techniques.

In the case of a information structure comprising pits or hills the phase depth defined hereinbefore as the phase difference between the zero-order subbeam and the higher-order subbeams is related to a geometric phase depth. The geometric phase depth φ for a reflecting information structure is given by $\varphi = 2 \times 2\pi\frac{d}{\lambda}$ rad, where d is the geometric depth of the pits and λ the wavelength of the read beam. For a radiation-transmitting information structure $\varphi = 2\pi\frac{d}{\lambda}$ rad.

In comparison with a radiation-transmitting information structure a reflecting information structure has the advantage that during reading the elements of the optical read apparatus are all located on one side of the record carrier and are partly traversed two times by the read beam.

In a record carrier with a reflecting information structure the areas with a phase depth of π rad are constituted by pits with a geometric depth of approximately 1/4 λ and the areas with a phase depth of $\frac{2\pi}{3}$ rad by pits with a depth of approximately $\frac{1}{8}\lambda$, λ being the wavelength of the read beam.

During reading of a record carrier in accordance with the invention the signal from the one detector arrangement and the signal from the second detector arrangement should alternately be transferred to an electronic circuit in which the signals are further processed. The signal which has been read is ultimately displayed, for example by means of a television set, or rendered audible. The modulation transfer functions (M.T.F.) for the read systems with the different detector arrangements differ slightly. If the information is stored in digitized form the alternation of the transfer functions will not be noticeable in the signal which is ultimately supplied by the read apparatus. If the information is recorded in a different manner, for example in the form of a frequency-modulated signal, the alternation between the modulation transfer functions may become noticeable. One transfer function will for example give rise to different gray shades or a different colour saturation in the television picture than the other transfer function. In the case of an audio signal the alternation between the transfer functions may become audible as an undesired frequency.

If a television programme is stored in the record carrier, containing for example one television image per revolution, the variation in gray shades or colour saturation will give rise to flicker with a frequency of 12.5 Hz in the television picture at a speed of rotation of 25 revolutions/second. Flicker of this frequency is perceptible to the human eye and is consequently annoying.

In order to render this effect invisible, in a record carrier in accordance with the invention, consecutive track portions within a track differ from each other in that they comprise areas with a first phase depth and areas with a second phase depth respectively.

In the case of a television programme these track portions each time contain the information of one television line. If the television picture consists of 625 lines, switching between the one read system and the other is effected at a frequency of the order of 7.5 KHz. Flicker of such a high frequency is no longer visible.

To ensure correctly timed switching from the one detector arrangement to the other during reading of a record carrier, a pilot signal may be stored in addition to an information signal, which pilot signal marks the transitions between the areas with the first phase depth and the areas with the second phase depth and *vice versa*. This step may be used when, for example, only an audio signal is recorded in the record carrier.

If a television signal is recorded, the field synchronising pulses or the line synchronising pulses may be employed for switching over, and no separate pilot signal need be recorded.

Apparatus for reading the record carrier may comprise a radiation source which produces a read beam of one wavelength chosen to read tracks of either of the two different phase depths and to discriminate between them, an objective system for focussing the read beam to a read spot on the information layer of the record carrier, and a radiation-sensitive detection system for the conversion of the read beam which has been modulated by the information into an electrical signal, which detection system comprises two radiation-sensitive detectors which are disposed in the far field of the information structure one on each side of a line which is effectively transverse to the track direction, the outputs of the detectors being connected to two inputs of a first electronic circuit in which the detector signals are combined additively in first time intervals during

which said read spot is incident upon first areas of one of said two phase depths and subtractively in second time intervals during which said read spot is incident upon first areas of the other of said two phase depths, the output of this circuit being connected to the input of a second electronic circuit in which a switching signal is derived from the signal read from the record carrier, which switching signal is applied to a control input of the first electronic circuit and determines the said time intervals.

The line on both sides of which the detectors are arranged being "effectively transverse to the track direction" is to be understood to mean that the projection of this line, via the objective system, in the plane of the information structure is transverse to the track direction.

Apparatus which is equipped with a servo system for keeping the read spot positioned at the middle of an information track, may comprise a radiation-sensitive detection system for the generation of a positional error signal, a control circuit for the conversion of said signal into a control signal for an actuator with which the radial position of the read spot can be varied, and, between the detection system and the control circuit, a switchable inverter stage, of which a control input is connected to the output of the second electronic circuit at which the switching signal appears.

Thus, during read-out of a first track whose areas have a specific phase depth the read spot is prevented from being directed to a second track whose areas have a different phase depth.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a plan view of a part of a first embodiment of a record carrier in accordance with the invention,

Figure 2 is a tangential cross-section of this record carrier,

Figure 3 is a radial cross-section of this record carrier,

Figure 4 is a plan view of a part of a second embodiment of a record carrier in accordance with the invention,

Figure 5 is a tangential cross-section of this record carrier,

Figure 6 is a radial cross-section of this record carrier,

Figure 7 shows an embodiment of a read apparatus in accordance with the invention,

Figure 8 shows the arrangement of the detectors, and a first example of the electronic circuit for processing the detector signals,

Figure 9 shows a second example of this electronic circuit,

Figure 10 shows the arrangement of the detectors with respect to the different diffraction orders,

Figure 11 shows the variation of the amplitude of the signal which has been read as a function of the phase depth, and

Figure 12 represents the shape of a radial error signal in one example of a servo system for the radial positioning of the read spot.

In these Figures similar elements always bear the same reference numerals.

Figures 1, 2 and 3 show a first embodiment of a record carrier in accordance with the invention. Figure 1 shows the record carrier in plan view, Figure 2 in tangential cross-section, taken on the line II-II' in Figure 1, and Figure 3 in radial cross-section taken on the line III-III' in Figure 1. The information is contained in a multitude of areas 4, for example pits in the substrate 6. These areas are arranged in accordance with tracks 2. Between the tracks 4 the intermediate areas 5 are located. The tracks 2 are separated from each other by narrow lands 3. The spatial frequency and, as the case may be, the lengths of the areas are determined by the information.

The areas of adjacent information tracks have different phase depths. As is shown in Figure 3, the pits of a first track, a third track etc. are deeper than the pits 4' of the second track, the fourth track etc. The geometric depths of the pits 4 and 4' are designated d_1 and d_2. As a result of the different depths the first track, the third track etc. can be discriminated optically from the second track, the fourth track etc. These tracks may then by situated closely to each other.

In a realized embodiment of a record carrier in accordance with the invention the radial period of the information tracks was 0.85 μm, the width of these tracks 0.5 μm, and the width of the lands 3:0.35 μm.

The information-carrying surface of the record carrier may be reflecting, for example in that a metallic layer 7, such as aluminium, is vacuum-deposited on said surface.

It is to be noted that in Figures 1, 2 and 3 the scale of the areas has been exaggerated for the sake of clarity.

Figure 4 shows part of a second embodiment of a record carrier in accordance with the invention in plan view. This Figure shows a larger part of the record carrier than Figure 1, so that the individual areas are no longer visible. The information tracks are now divided into portions *a* and *b*, the portions *a* comprising pits of greater phase depth (areas with deeper pits) and the portions *b* areas of smaller phase depth.

In Figure 5, which shows an enlarged tangential cross-section of a track, taken on the line V-V' in Figure 4, the pits of the depth d_2 are again designated 4' and the pits of the depth d_1 are designated 4. Figure 6 is a radial cross-section of the second embodiment of the record carrier, taken on the line VI-VI' in Figure 4.

Patent Specification No. 1,447,066 describes a method of optically writing information in a record carrier wherein a photoresist layer is exposed intermittently in accordance with the information to be written. By subsequent development and, as the case may be, etching, the exposed pattern thus obtained can be converted into a depth profile. By selecting a higher radiation intensity during writing of a first track, a third track etc. than during writing of a second track, a fourth track etc. a record carrier can be obtained of which the odd-numbered tracks comprise pits with a greater phase depth and the even-numbered track pits with a smaller phase depth.

Figure 7 shows an embodiment of an apparatus for reading a record carrier in accordance with the invention. The round disc-shaped record carrier is shown in radial cross-section. Consequently, the information tracks are perpendicular to the plane of drawing. It has been assumed that the information structure is disposed on the upper side of the record carrier and is reflecting, so that reading is effected through the substrate 6. The information structure may be covered with a protective layer 8. With the aid of a spindle 16, which is driven by a motor 15, the record carrier can be rotated.

A radiation source 10, for example a helium-neon laser or a semiconductor diode laser, produces a read beam 11. This beam is reflected by a mirror 12 to an objective system 13, which is schematically represented by a single lens. In the path of the read beam an auxiliary lens 14 is included, which ensures that the pupil of the objective system is filled in an optimum manner. Then a read spot V of minimum dimensions is formed on the information structure.

The read beam is reflected by the information structure and, as the record carrier rotates, it is modulated in accordance with the sequence of the areas on the track to be read. By moving the read spot and the record carrier relative to each other in the radial direction, the entire information area can be scanned.

The modulated read beam again passes through the objective system and is reflected by the mirror 12. The radiation path includes means for separating the modulated and unmodulated read beam. These means may for example comprise a polarization-sensitive splitter prism and a quarter lambda plate (lambda is the wavelength of the read beam). For the sake of simplicity it has been assumed that in Figure 7 the said means are constituted by a semitransparent mirror 17. This mirror reflects the modulated read beam to a radiation-sensitive detection system 20.

The detection system is disposed in the so-called "far field of the information structure", *i.e.* in a plane in which the centres of the subbeams formed by the information structure, in particular those of the zero-order subbeam and of the first order subbeams, are separated. The detection system may be disposed in the plane 21 in which an image of the exit pupil of the objective system 13 is formed by the auxiliary lens 18. In Figure 7 the image C' of the point C of the exit pupil is represented by dashed lines.

The detection system 20 comprises two detectors 22 and 23. These detectors are shown in plan view in Figure 8. In this Figure the direction in which an information track is scanned is indicated by the arrow 34. When the areas of a track being read have a large phase depth, for example of π rad, the output signals of the detector should be added, whilst if the areas of the track being read have a small phase depth, for example $2\pi/3$ rad, the signals from the detector should be subtracted from each other.

For this purpose, as is shown in Figure 8, the detectors 22 and 23 may be connected both to an adder circuit 24 and to a subtractor circuit 25. The outputs of the circuits 24 and 25 are connected to the two input terminals e_1 and e_2 of a switch 26, which has one master terminal *e*. Depending on the control signal S_c applied to its control input, this switch transfers either the sum signal from detectors 22 and 23 or the difference signal from these detectors to a demodulation circuit 27. In this circuit the read-out signal is demodulated and rendered suitable for reproduction with for example a television set 28.

For controlling the switch 26 a control signal is generated. In the record carrier a pilot signal may be recorded in addition to the actual information signal, which pilot signal marks the positions on the record carrier where a transition from the areas with a first phase depth to the areas with a second phase depth is located. If a television signal is recorded, one television picture being recorded per track, the picture synchronizing pulses or the field synchronizing pulses contained in the actual television signal may be used for generating the control signal S_c. Said pulses are always easily identifiable.

If the information of the lines of a television picture is contained in the track portions *a* and *b* in accordance with Figure 4, the line synchronizing pulses 31, as is shown in Figure 8, can be separated from the signal from the demodulation circuit 27 in the line synchronizing pulse separator 29. In the circuit 30, which is for example a bistable multivibrator, the pulses 31 are converted into a control signal S_c for the switch 26, so that this switch is changed over everytime after reading one television line.

If each track of the information structure contains only one type of areas the element 29 is a picture synchronizing pulse separator, and the switch 26 is changed over everytime after reading one track, or two television fields.

Figure 9 shows a second example of an electronic circuit with which the output signals of the detectors 22 and 23 can alternately be combined additively and subtractively. These detectors are now connected to a first and a second input of a differential amplifier 35. The detector 22 is connected directly to this amplifier, whilst in the connection between the detector 23 and the differential amplifier an inverter 36 and a switch 37 are included, so that the signal from the detector 23 can be applied to the differential amplifier in inverted or non-inverted form.

Now the physical background of the invention will be discussed in more detail. The information structure, which comprises adjacent tracks which tracks comprise areas and intermediate areas, behaves as a two dimensional diffraction grating. This grating splits the read beam into a zero-order subbeam, a number of first-order subbeams and a number of higher-order subbeams. A part of the radiation re-enters the objective system after reflection at the information structure. In the plane of the exit pupil of the objective system, or in a plane in which an image of said exit pupil is formed, the centres of the subbeams are separated. Figure 10 shows the situation in the plane 21 of Figure 7.

The circle 40 with the centre 41 represents the cross-section of the zero-order subbeam in this plane. The circles 41 and 42 with the centres 46 and 47 represent the cross-sections of the (+1,0) and (−1,0) order subbeams which are diffracted in the tangential direction. The X-axis and the Y-axis in

Figure 10 correspond respectively to the tangential direction, or the track direction, and to the radial direction, or the direction transverse to the track direction on the record carrier. The distance f from the centres 46 and 47 to the Y-axis is determined by: λ/p, where p represents the local spatial period of the areas in the track portion to be read and λ the wavelength of the read beam.

For reading the information use is made of the phase variations of the subbeams of the orders (+1,0) and (−1,0) relative to the zero-order subbeam. In the hatched areas in Figure 10 these first-order subbeams overlap the zero-order subbeam and interference occurs. The phases of the first-order subbeams vary as a result of the movements of the read spot in the tangential direction relative to the information track. This results in intensity variations in the exit pupil, or in its image, which variations can be detected by the detectors 22 and 23.

When the centre of the read spot coincides with the centre of an area a certain phase difference ψ is produced between the first-order subbeams and the zero-order subbeams. This phase difference is called the phase depth of the information structure. At the transition of the read spot from a first area to a second area the phase of the (+1,0) order subbeam increases by 2π. Therefore, it may be said that during a movement of the read spot in the tangential direction the phase of said subbeam relative to the zero-order subbeam changes with ωt. Herein ω is a time frequency which is determined by the spatial frequency of the areas and by the speed with which the read spot moves over the track.

The phases $\emptyset(+1,0)$ and $\emptyset(-1,0)$ of the first-order subbeams relative to the zero order subbeam may be represented by:

$$\emptyset(+1,0) = \psi + \omega t$$
$$\emptyset(-1,0) = \psi - \omega t$$

The intensity variations as a result of interference of the first-order subbeams with the zero-order subbeam are converted into electrical signals by the detectors 22 and 23. The time dependent output signals S_{23} and S_{22} of the detectors 23 and 22 may be represented by:

$$S_{23} = B(\psi)\cos(\psi + \omega t)$$
$$S_{22} = B(\psi)\cos(\psi - \omega t)$$

In these formulas $B(\psi)$ is a factor which is proportional to the geometric depth of the pits. It may be assumed that $B(\psi)$ is zero for $\psi = \frac{\pi}{2}$.

As is indicated in Figure 8, the signals S_{22} and S_{23} are added to each other yeilding:

$$S_{24} = S_{22} + S_{23} = 2B(\psi).\cos\psi.\cos\omega t.$$

The signals S_{22} and S_{23} are also subtracted from each other, yielding:

$$S_{25} = S_{22} - S_{23} = -2B(\psi).\sin\psi.\sin\omega t.$$

It follows that for a phase depth $\psi = \pi$ rad the amplitude of the signal S_{24}, *i.e.* $B(\psi).\cos\psi$ is a maximum and that of the signal S_{25} *i.e.* $B(\psi)\sin\psi$, is a minimum. For a phase depth $\psi = 3\pi/4$ rad $B(\psi)\sin\psi$ is a maximum.

Figure 11 represents the variation of the amplitude A_1 (*i.e.* $B(\psi)\cos\psi$) of the signal S_{24}, and that of the amplitude A_2 (*i.e.* $B(\psi)\sin\psi$) of the signal S_{25} as a function of the phase depth. For $\psi = \pi/2$ rad both A_1 and A_2 are zero. A_1 reaches a maximum for $\psi = \pi$ rad. The maximum for A_2 is situated at $\psi = \frac{3\pi}{4}$ rad. However, at this phase depth A_2 has a substantial value. Therefore, in practice the value $\psi = \frac{2\pi}{3}$ rad is selected for the small phase depth. The amplitude A_2 at the phase depth $\psi = \frac{2\pi}{3}$ is not significantly smaller than the amplitude A_2 at a phase depth $\frac{3\pi}{4}$. However, the amplitude A_1 changes comparatively strongly between the phase depths $\psi = \frac{3\pi}{4}$ and $\psi = \frac{2\pi}{3}$.

Thus, when during reading the signals from the detectors are added to each other, the pits with a phase depth of π rad are read in an optimum manner. Pits with a phase depth of $2\pi/3$ rad, *i.e.* the pits of the adjacent tracks, are then virtually disregarded, so that little cross-talk occurs. Conversely, it is obvious that when during reading the signals from the detectors are subtracted from each other, the pits with a phase depth of $2\pi/3$ rad are read in an optimum manner, whilst the pits with a phase depth of π rad are then disregarded.

The values for the phase depths $\psi = \pi$ rad and $= \frac{2\pi}{3}$ rad given in the foregoing are not strict values. Deviations of the order of ±5% from the large phase depth and of the order of ±15% for the smaller phase depth are permissible. It will be evident from Figure 11 that the phase depth for the deeper tracks is more critical than for the shallow tracks. The slope for A_2 at $\psi = \pi$ rad is steeper than the slope for A_1 at $\psi = \frac{2\pi}{3}$ rad.

So far, only the first-order subbeams have been discussed. It is evident that the information structure will diffract the radiation also to higher orders. However, the radiation energy of higher diffraction orders is low and the diffraction angles are such that only a small part of the higher-order beams falls within the pupil of the objective system 13. The influence of the higher-order subbeams may therefore be neglected.

During reading the read spot should remain accurately centred on the track to be read. For this purpose the read apparatus comprises a fine control for the radial position of the read spot. As is shown in Figure 7, the mirror 12 may be arranged so as to be rotatable. The axis of rotation 38 of the mirror is perpendicular to the plane of drawing, so that by rotating the mirror 12 the read spot is radially shifted. The rotation of the mirror is obtained by means of the drive element 39. This element may take different forms; it is for example an electromagnetic element as shown in Figure 7, or a piezoelectric element. The drive element is controlled by a control circuit 50 to whose input a radial error signal S_r is applied, *i.e.* a signal which provides an indication of any deviation from the position of the read spot relative to the middle of the track.

For generating the signal S_r various methods have

been proposed. As is described in Patent Specification No. 1,434,834, two servo spots may be projected on the information structure in addition to the read spot. These spots are positioned relative to each other, so that when the centre of the read spot exactly coincides with the middle of the track to be read, the centres of the servo spots are situated at the two edges of said track. For each servo spot a separate detector is provided. The difference of the signals from these detectors is determined by the magnitude and the direction of the radial positional error of the read spot.

In Figure 12 the continuous line represents the variation of the signal S_r as a function of the radial position r of the read spot, in the case that deep tracks only, are provided (tracks with areas having a large phase depth only). When the read spot is located exactly on a deep track, *i.e.* at the positions r_o, $2r_o$, etc., the signal S_r is zero. The servo system for tracking is designed in such a way that for a negative value of S_r the tilting mirror 12 in Figure 17 is rotated anti-clockwise, so that the centre of the read spot is positioned exactly on the middle of the deep track. In the case of a positive value of S_r the mirror 12 is rotated clockwise. The points D in Figure 12 are the stable points for the servo system.

In a record carrier in accordance with the invention shallow tracks 2' are provided between the deep tracks 2. The point E on the curve for S_r corresponding to the centre of the track 2' is an unstable point. If the read spot were located slightly to the right of the centre of the track 2', *i.e.* if S_r were positive, the mirror 12 would be rotated clockwise and the read spot would move further to the right. In a similar way, in the case of deviation to the left of the position of the read spot, this spot would be moved further to the left. Without further steps the read spot could not remain positioned on a shallow track 2', but would always be directed to a deep track.

For reading a shallow track or track portion, the signal S_r, in accordance with the invention, is inverted before being applied to the control circuit 50. The inverted signal $\bar{S}_r$ is represented by the dashed curve in Figure 12. The point E on the curve for $\bar{S}_r$ corresponding to the middle of the track 2' is a stable point and the points D on this curve are unstable points.

In the apparatus in accordance with Figure 7 a combination of an inverter 51 and a switch 52 has been provided. As a result of this the signal S_r may be applied to the controller 50 in inverted or non-inverted form. The switch 52 is controlled by the signal S_c in synchronism with the switch 26 of Figure 8. During reading of a deep track the signal S_r is not inverted and during reading of a shallow track it is inverted. During reading of a track 2 the heavy part of the curve for S_r is used and during reading of a track 2' the heavy part of the dashed curve for S_r.

A radial error signal can also be generated during reading by radially moving the read spot and the track to be read periodically relative to each other with a small amplitude, for example 0.1 times the track width, and with a comparatively low frequency of for example 30 kHz. The signal supplied by the information detectors then comprises an additional component whose frequency and phase are determined by the radial position of the read spot. The relative movement of the read beam periodically in the radical direction. Alternatively, as is described in Patent Specification No. 1,489,756 the information tracks may take the form of undulating tracks. A positional error signal thus generated is also inverted when a shallow track is read.

Finally, a radial error signal can also be generated with the aid of two detectors which are disposed in the plane 21 on both sides of a line which is effectively parallel to the track direction, as described in for example German Patent Application 2,342,906, which has been laid open for public inspection.

By subtracting the output signals of the detectors from each other a radial error signal S_r is obtained. Thus a radial asymmetry of the radiation distribution in the pupil is determined. As a deep track, *i.e.* a track with a phase depth π for the pits, gives a symmetrical variation over the pupil, this method is only suitable for determining a positional error of the read spot relative to a shallow track. The signal S_r thus generated varies in accordance with the continuous curve in Figure 12, but with the positions of the deep tracks 2 and the shallow tracks 2' being interchanged.

The servo system is now adapted to follow a shallow track. When a deep track is followed, the signal S_r should be inverted again. This means that during reading of a deep track in fact a line midway between two shallow tracks is followed.

The detectors for reading the information (22 and 23 in Figure 10) and those for generating the radial error signal may be combined, in the form of four detectors which are disposed in the four different quadrants of the X-Y system. For reading the information the signals from the detectors in the first and the fourth quadrant are added to each other as well as the signals from the detectors in the second and third quadrant. The sum signals thus obtained are either added to each other or subtracted from each other as described hereinbefore. For generating the radial error signal the signals from the detectors in the first and the second quadrant are first added to each other, as well as the signals from the detectors in the third and fourth quadrant. The sum signals thus obtained are subtracted from each other, so that the signal S_r is obtained.

The invention has been described on the basis of a reflecting record carrier. It is alternatively possible to use the invention for a record carrier with a phase structure which is read in transmission. If the phase structure comprises pits or hills, these should be deeper or higher than the pits or hills of a reflecting record carrier.

Furthermore, the invention may also be utilized in a record carrier in the form of a tape. In that case the expression "radial direction" used hereinbefore should read: "the direction perpendicular to the track direction".

CLAIMS

1. A record carrier on which information is stored in an optically readable structure comprising a plurality of parallel adjacent tracks in a plane, each track comprising internally featureless first areas alternat-

been proposed. As is described in Patent Specification No. 1,434,834, two servo spots may be projected on the information structure in addition to the read spot. These spots are positioned relative to each other, so that when the centre of the read spot exactly coincides with the middle of the track to be read, the centres of the servo spots are situated at the two edges of said track. For each servo spot a separate detector is provided. The difference of the signals from these detectors is determined by the magnitude and the direction of the radial positional error of the read spot.

In Figure 12 the continuous line represents the variation of the signal S_r as a function of the radial position r of the read spot, in the case that deep tracks only, are provided (tracks with areas having a large phase depth only). When the read spot is located exactly on a deep track, *i.e.* at the positions r_o, $2r_o$, etc., the signal S_r is zero. The servo system for tracking is designed in such a way that for a negative value of S_r the tilting mirror 12 in Figure 17 is rotated anti-clockwise, so that the centre of the read spot is positioned exactly on the middle of the deep track. In the case of a positive value of S_r the mirror 12 is rotated clockwise. The points D in Figure 12 are the stable points for the servo system.

In a record carrier in accordance with the invention shallow tracks 2' are provided between the deep tracks 2. The point E on the curve for S_r corresponding to the centre of the track 2' is an unstable point. If the read spot were located slightly to the right of the centre of the track 2', *i.e.* if S_r were positive, the mirror 12 would be rotated clockwise and the read spot would move further to the right. In a similar way, in the case of deviation to the left of the position of the read spot, this spot would be moved further to the left. Without further steps the read spot could not remain positioned on a shallow track 2', but would always be directed to a deep track.

For reading a shallow track or track portion, the signal S_r, in accordance with the invention, is inverted before being applied to the control circuit 50. The inverted signal $\bar{S}_r$ is represented by the dashed curve in Figure 12. The point E on the curve for $\bar{S}_r$ corresponding to the middle of the track 2' is a stable point and the points D on this curve are unstable points.

In the apparatus in accordance with Figure 7 a combination of an inverter 51 and a switch 52 has been provided. As a result of this the signal S_r may be applied to the controller 50 in inverted or non-inverted form. The switch 52 is controlled by the signal S_c in synchronism with the switch 26 of Figure 8. During reading of a deep track the signal S_r is not inverted and during reading of a shallow track it is inverted. During reading of a track 2 the heavy part of the curve for S_r is used and during reading of a track 2' the heavy part of the dashed curve for S_r.

A radial error signal can also be generated during reading by radially moving the read spot and the track to be read periodically relative to each other with a small amplitude, for example 0.1 times the track width, and with a comparatively low frequency of for example 30 kHz. The signal supplied by the information detectors then comprises an additional component whose frequency and phase are determined by the radial position of the read spot. The relative movement of the read beam periodically in the radical direction. Alternatively, as is described in Patent Specification No. 1,489,756 the information tracks may take the form of undulating tracks. A positional error signal thus generated is also inverted when a shallow track is read.

Finally, a radial error signal can also be generated with the aid of two detectors which are disposed in the plane 21 on both sides of a line which is effectively parallel to the track direction, as described in for example German Patent Application 2,342,906, which has been laid open for public inspection.

By subtracting the output signals of the detectors from each other a radial error signal S_r is obtained. Thus a radial asymmetry of the radiation distribution in the pupil is determined. As a deep track, *i.e.* a track with a phase depth π for the pits, gives a symmetrical variation over the pupil, this method is only suitable for determining a positional error of the read spot relative to a shallow track. The signal S_r thus generated varies in accordance with the continuous curve in Figure 12, but with the positions of the deep tracks 2 and the shallow tracks 2' being interchanged.

The servo system is now adapted to follow a shallow track. When a deep track is followed, the signal S_r should be inverted again. This means that during reading of a deep track in fact a line midway between two shallow tracks is followed.

The detectors for reading the information (22 and 23 in Figure 10) and those for generating the radial error signal may be combined, in the form of four detectors which are disposed in the four different quadrants of the X-Y system. For reading the information the signals from the detectors in the first and the fourth quadrant are added to each other as well as the signals from the detectors in the second and third quadrant. The sum signals thus obtained are either added to each other or subtracted from each other as described hereinbefore. For generating the radial error signal the signals from the detectors in the first and the second quadrant are first added to each other, as well as the signals from the detectors in the third and fourth quadrant. The sum signals thus obtained are subtracted from each other, so that the signal S_r is obtained.

The invention has been described on the basis of a reflecting record carrier. It is alternatively possible to use the invention for a record carrier with a phase structure which is read in transmission. If the phase structure comprises pits or hills, these should be deeper or higher than the pits or hills of a reflecting record carrier.

Furthermore, the invention may also be utilized in a record carrier in the form of a tape. In that case the expression "radial direction" used hereinbefore should read: "the direction perpendicular to the track direction".

CLAIMS

1. A record carrier on which information is stored in an optically readable structure comprising a plurality of parallel adjacent tracks in a plane, each track comprising internally featureless first areas alternat-

ing with intermediate internally featureless second areas in single file along the track, the information being encoded in the sequence of the first and second areas in the track direction, laterally adjacent tracks being separated by lands, the first areas having a different influence on a read beam than the second areas, and each track differing at each point along its length, from the corresponding point in either immediately laterally adjacent track, in that they comprise first areas having one or the other of two phase depths, first areas of one phase depth in any track being immediately laterally adjacent to first areas of the other phase depth in an adjacent track, the phase depths being chosen so that radiation of one wavelength may be employed to read any track with low cross-talk from laterally adjacent tracks.

2. A record carrier as claimed in Claim 1, wherein a first phase depth is approximately π radians and the second phase depth approximately $\frac{2\pi}{3}$ radians.

3. A record carrier as claimed in Claim 2, having a reflecting information structure, wherein the first areas with the phase depth of π radians are constituted by pits with a geometric depth of approximately 1/4 λ and the first areas with a phase depth of $\frac{2\pi}{3}$ radians by areas with a depth of approximately 1/8 λ, λ being the wavelength of the read beam.

4. A record carrier as claimed in Claim 1 or Claim 3, wherein consecutive track portions within a track differ from each other in that they comprise first areas with the first phase depth and first areas with the second phase depth respectively.

5. A record carrier as claimed in any one of Claims 1, 2, 3 or 4, comprising a recorded pilot signal which marks the transitions between the first areas with the first phase depth and the first areas with the second phase depth and *vice versa*.

6. Apparatus for reading a record carrier as claimed in Claim 1 which apparatus comprises a radiation source which produces a read beam of one wavelength chosen to read tracks of either of the two different phase depths and to discriminate between them, an objective system for focussing the read beam to a read spot on the information layer of the record carrier, and a radiation-sensitive detection system for the conversion of the read beam which has been modulated by the information into an electrical signal, which detection system comprises two radiation-sensitive detectors which are disposed in the far field of the information structure one on each side of a line which is effectively transverse to the track direction, the outputs of the detectors being connected to two inputs of a first electronic circuit in which the detector signals are combined additively in first time intervals during which said read spot is incident upon first areas of one of said two phase depths and subtractively in second time intervals during which said read spot is incident upon first areas of the other of said two phase depths, the output of this circuit being connected to the input of a second electronic circuit in which a switching signal is derived from the signal read from the record carrier, which switching signal is applied to a control input of the first electronic circuit and determines the said time intervals.

7. Apparatus as claimed in Claim 6, which is equipped with a servo system for keeping the read spot positioned at the middle of an information track, which servo system comprises a radiation-sensitive detection system for the generation of a positional error signal, a control circuit for the conversion of said signal into a control signal for an actuator with which the radial position of the read spot can be varied, and, between the detection system and the control circuit, a switchable inverter stage, of which a control input is connected to the output of the second electronic circuit at which the switching signal appears.

8. A record carrier substantially as described with reference to Figures 1, 2 and 3 of the accompanying drawings.

9. A record carrier substantially as described with reference to Figures 4, 5 and 6 of the accompanying drawings.

10. Apparatus for reading a record carrier substantially as described with reference to Figures 7 and 8 or Figures 7 and 9 of the accompanying drawings.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1982.
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.