

1

"OPTICALLY READABLE DIGITAL INFORMATION DISC AND MANUFACTURING,
RECORDING AND READING APPARATUS THEREFOR"

The invention relates to a record carrier comprising a disc-shaped substrate with a radiation-sensitive information layer and provided with information areas arranged in accordance with a spiral or concentric track pattern, which record carrier is intended for the recording and/or reproduction, via a radiation beam, of digitally coded information having a fixed bit frequency in the information areas.

The invention further relates to an apparatus for manufacturing such a record carrier, the track pattern being inscribed by means of a radiation beam before said information layer is applied.

The invention also relates to an apparatus for recording information on such a record carrier, which apparatus comprises a radiation source, an optical system for directing a radiation beam to the information areas of said record carrier, a recording circuit for modulating the radiation beam depending on the digital signal to be recorded, and an optical system comprising a detector for the detection of radiation which is reflected or transmitted by the record carrier.

The invention also relates to an apparatus for reading such a record carrier, in whose information areas digital information has been recorded, which apparatus comprises an optical system for scanning said information areas with a radiation beam, a detector for detecting the radiation reflected or transmitted by said information areas and a read circuit for extracting the recorded digital information signal from the detected radiation.

A record carrier of the type mentioned in the preamble as well as apparatus for recording and/or reading information on and/or from such a record carrier, is known from Patent Application No. 2,016,744A, which has been laid open to public inspection, the information areas alternating with synchronization areas which each

contain the address of the information area that follows such a synchronization area. When such a record carrier is used the clock generation is intricate and sometimes not very reliable. During reading it is possible though intricate to derive a clock signal from the recorded data signal and from the information signals contained in the synchronization areas. When the data signal is written in the information areas the clock generation is even more intricate, because then only the information contained in the synchronization areas is available, in which case a clock generator may be used, which generator, during reading of the synchronization areas, can be synchronized with the information contained in the synchronization areas by means of a phase-locked loop, which apart from the said complexity has the additional drawback that at the beginning of each synchronization area said phase-locked loop must be locked in again and that the synchronism of the record-carrier motion during the process of recording data in the information areas is not reliable, so that not all of each information area is utilized because space must be reserved in order to allow for the effect of possible speed variations of the record carrier and of the information recording process as a result of the drift of the clock generator frequency. In said Patent Application it has therefore been proposed to include additional synchronization areas in the information areas, which mitigates said problems but does not eliminate them and which reduces the information storage capacity of the record carrier. In record carriers in which no synchronization areas are employed between the information areas, such as for example record carriers for recording digitally coded audio signals, the clock generation is even more intricate.

It is an object of the invention to provide a record carrier of the type mentioned in the preamble which does not present the said problems. The invention is embodied in the record carrier, the apparatus for manufacturing said record carrier, the apparatus for recording information on said record carrier, and the apparatus for reproducing information which has been recorded in the information areas of such a record carrier.

5 The invention provides a record carrier comprising a
 radiation-sensitive information layer upon a disc-shaped substrate,
 in which layer optically detectable changes can be produced by a
 radiation beam, said record carrier being provided with information
 areas arranged in accordance with a spiral or concentric track
 pattern, which record carrier is intended for the recording and/or
 reproduction, via the radiation beam, of digitally coded
 information having a fixed bit frequency in the information areas,
 wherein the substrate in the information areas has a periodic track
 10 modulation, which is optically detectable via the information layer
 and whose period corresponds to a frequency for which the power
 spectrum of the digitally coded information at least substantially
 exhibits a zero point, said periodic track modulation generating a
 clock signal corresponding to said fixed bit frequency, for
 15 synchronising the digitally coded information during recording and
 during reproduction to provide said power spectrum.

The invention is based on the recognition that in the case of
 digital recording it is possible to pre-record a frequency which is
 in synchronism with the bit frequency of the data signal to be
 20 recorded on the record carrier, which frequency can be detected,
 both during information reading and writing, without any
 significant interference with said data signal and without loss of
 storage capacity, so that a correctly synchronized and reliable
 clock signal is made available.

25 In a preferred embodiment of a record carrier in accordance
 with the invention the digitally coded information to be recorded
 is coded in accordance with a modulation whose power spectrum
 exhibits a zero point at the bit frequency and the period of the
 periodic track modulation corresponds to the bit frequency.

30 In this embodiment the period of the track modulation
 corresponds to the actual bit frequency without the occurrence of
 interference.

Preferably, the track modulation in accordance with the
 invention is also employed for reading the synchronization areas.

To this end, in a record carrier in accordance with the invention, the information areas are spaced from each other by synchronization areas, both types of area exhibiting the periodic track modulation, and the period of the periodic track modulation corresponds to a frequency at which the digital information power spectrum of the synchronization areas substantially exhibits a zero point.

Suitably, in this embodiment the synchronization area information is recorded in accordance with a digital modulation whose power spectrum exhibits a zero point at the bit frequency and the frequency corresponding to the period of the periodic track modulation is equal to the bit frequency of said modulation.

In respect of the nature of the periodic track modulations of a record carrier in accordance with the invention, the information areas may contain an optically detectable continuous servo track, and the periodic track modulation may then be constituted by a track-width modulation of the servo track.

In an alternative embodiment of such a record carrier the periodic track modulation may be constituted by a periodic radial undulation of the servo track.

In respect of the nature of the periodic track modulation of another embodiment of a record carrier in accordance with the invention, the track modulation may be constituted by an optically detectable track-depth modulation.

In this embodiment said track-depth modulation may extend between the surface of said record carrier and a level situated below said surface.

To be suitable with a method of obtaining a radial tracking signal, the record carrier in accordance with the invention may have the periodic track modulation superimposed on a radial undulation having a wavelength which is long relative to the period of said modulation.

An apparatus for manufacturing a record carrier in accordance with the invention may comprise means for supplying a radiation beam by means of which the track pattern is inscribed on the

substrate, a modulation device for modulating the inscribing radiation beam in order to produce said periodic track modulation on the substrate, and means for applying said radiation sensitive information layer on the inscribed substrate, said modulation being
5 optically readable via said layer.

In this manufacturing apparatus said modulation device may be an intensity modulator or may be a focusing modulator for modulating the diameter of the radiation beam at the surface of the record carrier.

10 Alternatively, said modulation device is adapted to make the radiation beam oscillate in a radial direction at the surface of the record carrier.

An apparatus for recording information on a record carrier in accordance with the invention, may comprise a radiation source, an
15 optical system for directing a radiation beam to the information areas of said record carrier, a recording circuit for modulating the radiation beam depending on the digital signal to be recorded, an optical system with a detector for detecting the radiation received from said periodic track modulation via said radiation
20 sensitive recording layer, a band-pass filter for extracting the clock signal from the detector output and means for applying the clock signal to the recording circuit to synchronise the digital signal to be recorded with the periodic track modulation so that the digital information is recorded in a fixed phase relationship
25 with said periodic track modulation and has said power spectrum.

A preferred embodiment of this apparatus may comprise optical means for directing a radiation beam modulated with information to be recorded to the information areas and for directing an auxiliary beam to the information areas behind the modulated beam for reading
30 the information recorded by the modulated radiation beam, means for generating the clock signal from a signal derived from the auxiliary beam, and means for synchronizing the information recording process of the modulated beam with said generated clock signal.

28

An apparatus for reading a record carrier in accordance with the invention in whose information areas digital information has been recorded, which apparatus comprises an optical system for scanning said information areas with a radiation beam, a detector for detecting the radiation received from said periodic track modulation via said radiation sensitive layer and radiation received from said layer in said information areas, a read circuit for extracting the recorded information signal from the detected radiation, and a band-pass filter for extracting the clock signal from the detector output at a frequency at which the power spectrum of the recorded digitally coded information exhibits a zero point, and means for applying the clock signal to the read circuit for synchronisation during read-out of the recorded digital information.

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

Figure 1 shows a possible embodiment of a record carrier to which the inventive principle may be applied, Figure 1a being a plan view of the record carrier, Figure 1b showing a part of a track 4 of said record carrier on an enlarged scale, and Figure 1c showing a synchronization area of said part on an enlarged scale.

Figure 2 shows a small part of the cross-section taken on the line II-II in Figure 1a.

Figure 3, in Figures 3a to 3d inclusive, schematically shows a cross-section in the longitudinal direction through a part of the track 4, Figure 3a showing such a cross-section for a blank disc prepared in accordance with a known technology, Figure 3b showing said cross-section of Figure 3a after information has been recorded in the information area 9, Figure 3c showing such a cross-section of a blank disc prepared in accordance with the invention, Figure 3d showing the cross-section of Figure 3c after digital information has been recorded, Figure 3e schematically representing the signal obtained when reading the part of the track 4 shown in cross-section in Figure 3d, and Figure 3f schematically representing a plan view of a part of the track 4 after digital information has been recorded in a manner other than in Figures 3b and 3d,

Figure 4 shows the average power spectra of three digital information signal modulations,

Figure 5 is a diagrammatic representation of said modulations,

Figure 6 in Figure 6a schematically represents an apparatus for manufacturing a record carrier in accordance with Figure 3c, Figure 6b schematically represents an apparatus for inscribing information in the record carrier of Figure 3c, and Figure 6c represents an apparatus for reading an inscribed record carrier,

Figure 7 shows a number of examples of a periodic track modulation in accordance with the invention,

Figure 8a illustrates the principle of a read section of an apparatus for reading and/or recording a digital signal on a record

carrier in accordance with the invention, Figure 8b representing the frequency spectrum of the signal detected by the detector 27,

Figure 9a shows an apparatus in accordance with Figure 8a, which is also suitable for generating a radial tracking signal, Figure 9b representing the average power spectrum of the signal detected by the detector 27.

Figure 10 shows a variant of the apparatus of Figure 9a,

Figure 11a shows an apparatus in accordance with Figure 9a adapted to read a record carrier with a radial track modulation of substantially the same period as the periodic track modulation, Figure 11b representing the average power spectrum of the signal detected by the detector 27,

Figure 12 shows an apparatus adapted to read a record carrier with a radial track modulation of the same period as the periodic track modulation, and

Figure 13 shows a part of an apparatus for recording an information signal on a record carrier in accordance with the invention for generating a clock signal during recording, use being made of an auxiliary laser beam.

Figure 1 shows a possible embodiment of a record carrier to which the inventive principle may be applied, Figure 1b showing a plan view of this record carrier, Figure 1b showing a part of a track of said record carrier on an enlarged scale, and Figure 1c showing a synchronization area of said part on an enlarged scale. The record carrier body 1 is provided with a spiral track 4. This track 4 is divided into a multitude of sectors 7, for example 128 per revolution. Each sector 7 comprises an information area 9, intended for recording digitally coded information, and a synchronization area 8.

In order to ensure that the digital information is recorded in an accurately defined path the track 4 is employed as servo track. For this purpose the information areas 9 of the sectors 7 exhibit an amplitude structure, as is shown in Figure 2. This Figure 2 shows a small part of the cross-section taken on the radial line II-II in Figure 1a and thus shows a number of adjacent track portions, specifically information areas, of the servo track 4. The direction of the servo tracks 4 is thus perpendicular to the plane of drawing.

38

Said servo tracks 4, in particular the information areas 9, thus take the form of grooves in the substrate 5. This makes it possible to control a radiation beam, which is directed at the record carrier in order to record digital information, to accurately coincide with said servo track 4, in other words to control the position of the radiation beam in a radial direction via a servo system which employs light reflected by the record carrier. The measurement of the radial position of the radiation spot with respect to the track on the record carrier may be in accordance with systems similar to those employed in conjunction with optical record carriers provided with a video signal and as inter alia described in "I.E.E.E. Transactions on consumer electronics", Nov. 1976, page 307.

For the recording of digital information the record carrier body is provided with a layer of a material 6 which, if exposed to suitable radiation, is subject to an optically detectable change. In principle only the information portions 9 of the sectors need be provided with such a layer. However, for reasons of manufacturing technology it is simpler to provide the entire record carrier surface with such a layer. This layer 6 may for example comprise a thin layer of a metal, such as tellurium. This metal layer can be melted locally by laser radiation of sufficiently high intensity, so that locally this information layer 6 is given a different reflection coefficient. When an information track thus inscribed is scanned by a read beam the reflected radiation beam is amplitude-modulated in accordance with the recorded information.

Alternatively, the layer 6 may take the form of a double layer of materials, for example aluminium on iron, which react chemically to incident radiation. At the location where a high-power radiation beam is incident on the disc FeAl_6 is formed, which is a poor reflector. A similar effect is obtained in the case of a double layer of bismuth on tellurium, Bi_2Te_3 being formed.

Since the write radiation spot is made to coincide accurately with said servo track of groove form, in particular when an information area is being scanned, the digital information modulating the write beam is recorded exactly in the information area coinciding with said

servo track.

As is apparent from the foregoing, unrecorded record carriers as supplied to the user have a groove structure in said information areas within the sectors. Moreover, within each sector such a record carrier has a synchronization area 8 in the form of an optically detectable relief structure. Figure 1b on an enlarged scale shows a part of a track 4, from which the sequence of a number of information areas 9 and synchronization areas 8 is apparent. In this case the synchronization areas 8 comprise a relief structure constituted by a sequence of recesses alternating with intermediate areas.

The depth of the recesses in the synchronization area is greater than the depth of the servo track in the information area 9. The depth of these recesses is selected in accordance with general optical rules and, by selecting the shape of said recesses in relation to the read system, an optimum read-out of the information represented by the structure is obtained. In the case of a read system in which the radiation beam reflected by the record carrier is detected by a single photo-detector, $1/4\lambda$ may be selected as depth for the recesses, λ being the wavelength of the radiation used. If the depth of the servo track in the information area 9 is selected to be $1/8\lambda$ or less, this servo track will hardly affect the amount of light detected by the detector.

In order to further illustrate the structure of the synchronization area, Figure 1c shows such a synchronization area on a more enlarged scale, the information layer 6 being omitted for the sake of simplicity. Such a synchronization area 8 comprises two portions, namely an indication portion 10 and an address portion 11. The address portion 11 contains all the information required for controlling the recording process. When recording digital information, this information is converted into a so-called word-organized bit series. This address portion contains information about the word organization, so that during recording the location of the bit words is defined and during reading the bit words are suitably decoded. Furthermore, this address portion 11 contains information about the relevant track number. This information takes

the form of a relief structure in accordance with a digital modulation technique suitable for the recording medium. As, in addition to the servo track in the form of a groove in the information portions 9, the record carrier therefore already contains in the synchronization area all the information required for positioning information in the form of a bit-word-organized bit series in said information areas, the requirements imposed on the write and read apparatus employed by the user may be less stringent. As furthermore this fully prerecorded information is formed in the record carrier as a relief structure, said record carrier is particularly suitable for mass-production, enabling the customary pressing techniques to be used.

Figure 3, in Figures 3a to 3d inclusive, schematically represents a part of such a servo track 4 in a cross-section in the longitudinal direction of said servo tracks 4 with a part of the synchronization area 8 and a part of the information area 9. Figure 3a shows such a cross-section of a blank prepared disc using a known technique, and Figure 3b shows such a cross-section after digital information 14 has been recorded in the information area 9. Figure 3c shows such a cross-section of a blank prepared disc provided with clock information in accordance with the invention, and Figure 3d represents the cross-section of Figure 3c after information 14 has been recorded in the information area 9. Figure 3e schematically represents the signal obtained when reading the part of the track 4 shown in cross-section in Figure 3d and Figure 3f schematically shows a plan view of a part of the track 4 after information has been recorded in a manner other than represented in Figure 3b and 3d.

The servo track 4 is formed in a substrate 5, for example by means of a laser beam. By modulating the intensity of the laser beam it is possible to form a relief structure of "pits" 13 containing information in the synchronization area 8. Subsequently, the entire disc, including for the sake of simplicity the portion of the record carrier 1 outside the grooves 4, may then be coated with the reflecting information recording layer 6. In the record carrier thus prepared information can be recorded in the information area 9 by forming holes 14 in the reflecting information layer 6,

for example by means of a laser beam. Such an inscribed record carrier is shown in Figure 3b. When information is written, i.e. the holes 14 are formed, and when the information is read, for example by means of a laser beam, it is of importance that this information writing or reading process is synchronized with the aid of a clock signal, which may be derived from the synchronization areas 8. In order to ensure that during writing and reading a suitable synchronous clock signal is available continuously, i.e. during writing or reading in the information areas 9 as well, the servo groove 4 is provided in accordance with the invention, with a first periodic structure which produces a modulation of the light reflected by the information carrier when the servo track 4 is followed during reading or writing.

However, this structure should be such that it does not disturb the read-out of information. That this is possible is explained with reference to Figures 4 and 5, Figure 4 representing the power spectra of three possible binary information signal modulations averaged over a large sample and Figure 5 being a diagrammatic representation of said modulations.

The reference a in Figure 5 designates a modulation known by the name of "biphase" modulation in which the applied digital signal is converted into a binary signal which for a logic "one" of the applied digital signal the modulation binary signal is positive during the time interval $T/2$ and negative during the next time interval $T/2$, T being the bit length of the applied digital signal. A logic "zero" of the applied digital signal yields exactly the opposite binary signal, i.e. negative for the time interval $T/2$ and positive for the next time interval $T/2$. This modulation technique yields a binary signal which has a power spectrum represented by a in Figure 4. The frequency f_0 then corresponds to $\frac{1}{T}$.

The reference b in Figure 5 represents the modulation known by the name of "Miller" modulation. The binary signal generated by means of this modulation has a transition from positive to negative or vice-versa at the centre of a logic "one" of the applied digital signal and also such a transition at the junction of two consecutive

logic "zeros". The power spectrum of the binary signal obtained by means of this modulation technique has the designation b in Figure 4.

Finally, the reference c in Figure 5 represents a modulation known by the name of "quadphase" modulation, the applied bit series
5 of the digital signal first of all being divided into consecutive groups of two bits. From each two-bit group having a duration of $2T$ a binary signal is derived which in a first time interval T has the same sequence of bits as the original two bits in the group and in the next time interval T repeats the sequence inverted in sign. The bit
10 combinations 11, 00, 01 and 10 which are possible are thus converted into the bit combinations 1100, 0011, 0110 and 1001 respectively. The binary signal obtained by means of this modulation technique has a power spectrum represented by c in Figure 4.

It is evident from Figure 4 that these modulation techniques
15 have the common property that the resulting binary signal exhibits no strong frequency components at comparatively low frequencies, for example frequencies below $0.2 f_0$. This is very useful when an optical record carrier is used with the associated write and read systems. As stated previously, such systems employ both a servo
20 control in order to keep the scanning spot accurately focussed on the record carrier and a servo control which controls the radial position of the scanning spot and ensures that said scanning spot accurately coincides with the information track. As the control
25 signals required for these servo controls are derived from the radiation beam which is reflected by the record carrier, which is also modulated by the relief structure of the synchronization area, it is essential that the frequency spectrum of the binary signal stored in the address portion does not contain any strong frequency
30 components within the frequency band intended for the control signals. Figure 4 thus shows that the frequency band below approximately $0.2 f_0$ is suitable for such control signals. The control signals for the said servo systems may for example extend to a maximum frequency of 15 kHz. If the frequency $f_0 = \frac{1}{T}$ is, for example, selected to be
35 500 kHz, it will be evident from Figure 5 that the binary signals a, b or c only exhibit very weak frequency components at frequencies of

15 kHz and lower. Furthermore it is apparent from Figure 4 that at the frequency $2 f_0$ and in the case of modulation method c the spectrum also has zero points at the frequency f_0 . Thus, it is possible to provide the record carrier with a clock structure of the frequency $2 f_0$ without interference with the information signal. Zero points at the frequency $2 f_0$ also occur in the case of other modulation methods.

When quadphase modulation (modulation c) is used and also in the case of some other modulation methods, the frequency f_0 is highly suitable for this purpose, said frequency corresponding to the bit frequency $1/T$, so that quadphase modulation becomes very attractive. Also in the case of modulation method b a structure with the frequency f_0 may be used in some cases because the components of the spectrum of modulation b are comparatively small at said frequency. Furthermore, it is theoretically possible to give the structure a modulation corresponding to a frequency higher than $2 f_0$, but in practice this is generally not feasible. Indeed, in order to obtain a maximum information density, the dimensions of the pits 13 and 14, which at a specific speed of rotation of the disc 1 at least correspond to a bit length of $1/2T$, are selected near the limit of resolution of the write/read system used, so that the surface structure corresponding to frequencies higher than $2 f_0$ will hardly be detectable. By means of special modulation techniques it is also possible to obtain zero points in the power spectra at frequencies other than f_0 or $2 f_0$, for example at $1/2 f_0$.

Figure 3c shows a cross-section of a record carrier in accordance with the invention corresponding to the cross-section of Figure 3a, whose surface at least at the location of the track 4 has been provided with a relief structure having a height d. A possible way of realizing this structure is to modulate the laser by means of which the synchronization area 8 and the groove 4 of the information area 9 is formed. In the present example this has only been done in the synchronization area 8 between the pits 13 by limiting the intensity of the laser beam. However, in principle it is also possible to provide the bottoms of the pits with a relief structure.

As is shown in Figure 3d the disc in accordance with the invention can also have information written in to it by forming holes 14 in the reflecting layer 6 covering the relief structure. Figure 3e shows an example of a signal obtained when reading a relief structure in accordance with Figure 3d. This signal exhibits minima at the location of the pits 13 or the holes 14 and an amplitude modulation corresponding to the relief structure having a height d in Figure 3c having the frequency f_0 at the maxima. The modulation structure of the bottoms of the holes 14 hardly contributes to the signal, because it hardly reflects any light owing to the removal of the reflecting layer 6. In this respect it is to be noted that it is, for example, also possible to provide a non-reflecting layer 6 on a reflecting substrate 5, which layer is locally removed. As a result of this the modulation of the frequency f_0 will be read satisfactorily at those locations 14 where the non-reflecting layer has been removed.

In Figures 3a-3d the pits 13 or the holes 14 are shown as continuous holes or pits i.e. in the case of more than one bit as an elongate slot having a length corresponding to the number of consecutive bits. However, it is alternatively possible to provide a separate pit or hole for each bit. Figure 3f illustrates this and shows a track 4 in which the clock modulation structure is represented by different types of hatching. In the synchronization area 8 the pits 13 may for example be formed in the centre of the maxima or minima of the structure and are also coated with a reflecting layer 6, which is symbolized by the hatching through said pits 13. In the information portion 9 the information holes 14 may be formed in the reflecting layer 6 at the maxima and minima of the clock information structure. Alternatively, as is represented by the information area 9 in Figure 3f, holes 14' may be formed at the transition points of the clock information structure. In this respect the location of the pits 13 or holes 14 is not essential, provided that the phase relationship with the clock information structure is fixed and known. Neither is the shape of the information structure of great significance. Instead of the rectangular shape shown in Figure 3 it may well have a sinusoidal shape, which is

readily possible in the case of manufacture by means of a modulated laser beam. It is of importance only that said clock synchronization structure exhibits a frequency component which can readily be detected at the frequency f_0 or $2 f_0$ and which exhibits no strong components within the spectrum of the synchronization or digital-information signal recorded or to be recorded, which is generally the case when the clock information structure d has a fundamental frequency f_0 or $2 f_0$ with higher order harmonics only. The next harmonic is then $2 f_0$ or $4 f_0$, which as is shown in Figure 4 falls beyond the part of the information power spectrum which is of interest.

In order to illustrate how structures in accordance with Figure 3 can be realized Figure 6, in this order, schematically shows in Figure 6a an apparatus for manufacturing a record carrier in accordance with Figure 3c, Figure 6b an apparatus for inscribing information in the record carrier of Figure 3c, and Figure 6c an apparatus for reading such an inscribed record carrier.

In the apparatus of Figure 6a the beam 16 from a laser 15 is projected at a rotating disc 1 via, for example, an intensity modulator 57, a mirror 17 and a focusing optic 18, in order to form the spiral groove 4 (Figure 1). The laser 15 is controlled by a circuit 20 for pulsing the laser 15 so as to form the pits 13 (Figure 3) in the synchronization area 8. The modulator 57 is controlled by a source 19 having a frequency f_0 (or $2 f_0$) in order to realize a clock modulation structure in the groove 4. Alternatively, it is possible to modulate the laser 15 itself. The disc 1 is driven by a motor 21 which for the purpose of speed control is provided with a servo control, which may for example comprise a tachogenerator 22, a speed-reference source 24, and a servo-amplifier 23. In order to ensure that the recording areas 8 are situated at the correct locations on the disc in the track 4 and, as the case may be, to obtain a correct tangential distribution of the modulation f_0 on the disc, the circuit 20 and, as the case may be, the source 19 of the frequency f_0 may be locked to the servo control.

Furthermore the circuit 20 is controlled by the source 19 in order to guarantee a correct phase relationship of the synchronization

pits 30 with the clock modulation structure. After this process the disc 1 may be provided with the said layer 6.

Figure 6b schematically represents an apparatus for providing the prepared disc 6 with information and simultaneously reading the clock modulation structure. This apparatus comprises the rotating disc 1, and a laser 15 whose beam 16, via a semitransparent mirror 17 and a focusing optic 18, is projected onto the disc 1. A reflected beam 30 is detected by means of a cell 27, for example a photodiode, and converted into an electric signal from which by means of the band-pass filter 28 the component of the frequency f_0 (or $2 f_0$) is extracted, which component is mainly produced by the clock modulation structure formed in the track 4. As the case may be, this signal may also be applied to a phase-locked loop 29, which improves the filtration, which increases the constancy of the clock signal, and as the case may be, compensates for brief signal dropouts. The clock signal is then available on output 31. Data can be recorded by pulse modulation of the laser beam 16, directly by including a modulator in the beam or, as is shown in Figure 6b, by modulating the laser 15 itself with a write modulator circuit 25, to which the information is applied via an input 26 and which is synchronized with the clock signal on output 31.

Via the light-sensitive element 27 and a read circuit 30 the information contained in the synchronization portions is recovered from the reflected beam 60, which information appears on an output 32. This read circuit 30 may also be synchronized with the clock signal on output 31. Said information may be used to synchronize the circuit 25 and to locate the correct position on the disc. This information is also used in a servo control, not shown in Figure 6b, for radially positioning the optic 18 and the mirror 17, for inscribing the desired portion of the track 4 and for controlling the drive of the disc 1, which is symbolically represented by the dashed line 62 in Figure 6b.

Furthermore, the apparatus may be provided with a tracking circuit 33 which derives a tracking signal from the signal supplied by the detector 27 in order to keep the beam 16 on the track 4 by

controlling the angle, relative to the beam 16, of the mirror 17, which control is symbolized by the dashed line 61 in Figure 6b.

Figure 6c shows an apparatus for reading an inscribed disc 1, which apparatus is generally combined with that of Figure 6b. The apparatus again comprises a laser 15, whose beam 16 is projected onto the disc 1 via a mirror 17 and the optic 18. The reflected beam 60 is detected with a photodiode 27 and the resulting electric signal is passed through a band-pass filter 28 having a pass frequency f_0 and onto a phase-locked loop 29 tuned to the frequency f_0 , so that the clock signal of the frequency f_0 (or $2 f_0$) is available on output 31. The information recorded on the disc is decoded from the electric signal supplied by the photodiode 27 by means of the read circuit 30, so that on an output 32 thereof the digital information and the information contained in the synchronization areas 8 is available. This read circuit is synchronized by means of the clock signal on output 31. In addition a tracking signal may be derived from the beam detected by a photodiode 27 by means of a tracking circuit 33, in order to control the mirror 17 in such a way that the beam 16 exactly follows the track 4. The disc drive motor 21 may be included in a servo control, for example comprising a tachogenerator 22, a reference source 24 and a servo amplifier 23, in order to control the speed, which control may be locked to the read circuit 30. Furthermore, the apparatus also comprises a control mechanism 35 for moving the optic 18 together with the mirror 17 and the detector 27 - the complete mechanism being designated 36 in Figure 6c - in a radial direction, so that at option a specific part of the disc can be read controlled by information applied to an input 37 of the control mechanism 35 and by the information produced by the synchronization areas and available on output 32 of the read circuit 30.

The clock information structure which is or has been recorded in track 4 may take various forms. Figure 7 shows a number of examples thereof. Figure 7a schematically represents a track 4 in which the clock information is formed by a height variation - symbolically represented by the interrupted hatching - for example by modulating the intensity of the laser beam that writes the track 4.

Figure 7b shows a track 4 in which the clock information is formed as a width variation of the track 4, for example by modulation of the laser-beam focusing, for which for example the objective 18 (Figure 6a) may be controlled by means of the device 59 (Figure 6a) - whilst a combination of width and depth variations is also possible, which in practice will frequently be the case when the intensity or focusing of the laser beam is modulated. Figure 7c shows a track 4 in which the clock information takes the form of a radial variation of the position of the track 4, for which purpose for example the angle of the mirror 17 (Figure 6c) relative to the beam 16 can be modulated by means of the device 58. All the variations shown then have a period length L_0 which is equal to $L_0 = \frac{V}{f}$, where V is the tangential speed of the disc 1 at said location and f the frequency of the desired clock signal, which frequency f corresponds to a zero point in the average power spectrum of the data to be recorded, for example the frequency f_0 (Figures 4c and 5c in the case of "quadphase" modulation).

One of the possible ways of obtaining a tracking signal is by providing a radial "wobble" in the groove shaped track, for example by controlling the mirror 17 (Figure 6a), to produce, for example, a sinusoidally varying radial excursion with a wavelength on the disc which during playback at the normal speed produces a light intensity variation detected by the detector 27 (Figure 6), whose frequency is situated outside the spectrum of the data, i.e. for example below the frequency $0.2 f_0$ (Figure 4).

For example by synchronous detection, a measure of the deviation of the centre of the detector relative to the centre of the track 4 may be derived from said signal component. Such a radial wobble may be combined with a clock modulation structure, for example the clock modulation structure shown in Figure 7a, which combination is shown in Figure 7d. A special combination is obtained when the wobble on the disc has a wavelength equal to that of the clock modulation structure with a fixed phase relationship, which makes synchronous detection superfluous.

Figure 7e shows such a structure, a depth modulation structure (represented by alternately hatched and non-hatched areas) in track 4 being combined with a radial positional variation which is 90° shifted

relative thereto (i.e. by a quarter of the period of said structure), which structure can be produced with the apparatus of Figure 6a by modulating the angle of the mirror 17 relative to the beam 16 with the aid of the device 58. If the depth modulation structure is
 5 then selected so that the "shallow" parts of these modulations coincide with the surface of the disc-shaped record carrier 1, the servo track 4 will take the form of a sequence of radially asymmetrical pits which are tangentially spaced from each other by distances equal to the said distance L_0 . Figure 7f shows an example of such a track 4.

10 Figure 8a illustrates the principle of the read section of an apparatus for writing data in or reading data from a record carrier in accordance with the invention, the power spectrum of the signal I detected by the detector 27 being shown in Figure 8b. The apparatus comprises a photodetector 27 which scans along the track 4. The
 15 signal which is supplied by the detector 27 has a power spectrum as shown in Figure 8b, in this present example having the spectrum of a quadphase modulated signal S_d and a clock signal S_c . The clock signal S_c is extracted with the aid of a band-pass filter 28, preferably followed by a phase-locked loop 29. The clock signal S_c is available
 20 on output 31. The digital signal S_d , i.e. the signal recorded in the synchronization areas 8 and, during reading, the signal recorded in the synchronization areas 8 and in the information areas 9, is detected with a read circuit 30, which read circuit 30 is synchronized with
 25 the clock signal S_c . The data signal read is available on output 32. Furthermore, a radial tracking signal can be derived from the signal from the detector 27. When information is to be recorded in information areas 9 the circuit 30 only detects the information contained in the synchronization areas 8, which together with the clock signal S_c is then applied to the write circuit 25 in order to
 30 modulate the beam of a write laser 15.

When a low-frequency radial wobble is used in order to obtain a radial tracking signal, the apparatus of Figure 9a may be used, Figure 9b showing the power spectrum of the signal detected by the detector 27. When a track 4 with a radial wobble is read a photo-
 35 detector 27 may be employed which is divided in two sections a and b

by a trackwise or tangential line. A differential amplifier 40, or equivalent means, forms the difference of the signals detected by sections a and b and a summing amplifier 41, or equivalent means, provides the sum of said signals. The power spectrum (Figure 9b) again contains the spectrum of a quadphase modulated signal S_d , the clock signal S_c and the low-frequency signal S_w produced by the wobble. In the sum signal the wobble manifests itself as an amplitude modulation with the clock signal S_c as a carrier wave, which in Figure 9b is represented as side bands S_{c-w} and S_{c+w} , which side bands produce, for example after synchronous detection, a radial tracking signal equal to zero when the detector 27 exactly follows the centre 45 of the track 4. Filtering the sum signal with the band-pass filter 28 yields the clock signal S_c and, if the filter is not too narrow-banded, also said side bands. The output signal of said band-pass filter 28 is applied to the phase-locked loop 29 and on an output 31 thereof the clock signal S_c is available. The output signal of this band-pass filter 28 is also applied to a synchronous demodulator 42 together with the clock signal S_c . This demodulator then produces the modulation S_w .

The reference frequency of the radial wobble is recovered from the difference signal from amplifier 40 with the aid of band-pass filter 38 and phase-locked loop 39, which reference frequency together with the output signal of the synchronous detector 42 is applied to a synchronous detector 43. On the output 44 thereof a signal is then available which may be used as a radial tracking signal and is representative of the deviation of the detector 27 relative to the centre of the track 4, which in Figure 9a is represented by the dashed line 45. Said radial tracking signal can then control the mirror 17 as is symbolically represented in Figures 6b and 6c.

The data contained in the track 4 is then recovered from the sum signal on the output of amplifier 41 in a similar way as in the apparatus of Figure 8a. For the purpose of information recording, similar steps may be applied as in the apparatus of Figure 8a, which are also valid for the apparatus of Figure 10, Figure 11a and Figure 12.

Figure 10 shows a variant of the apparatus in accordance with Figure 9, which yields better signal separation. The detector 27 has now also been divided by a radial line, so that four quadrants a, b, c and d are obtained, the sections a, b and c, d respectively being situated on either side of the tangential line, and the sections a, c and b, d respectively being situated on either side of the radial line. An amplifier 41, or equivalent means, determines the sum of the signals generated by the sections a, b, c and d, so that this amplifier is specifically sensitive to intensity variations of the beam reflected by the track 4, i.e. to the data signal Sd. An amplifier 421 determines the difference between the sections a+b and c+d situated on either side of the tangential line, so that said amplifier 421 is particularly sensitive to variations of the track 4 in a radial direction, i.e. to the wobble reference frequency. An amplifier 46 determines the difference between the sections a+c and b+d situated on either side of the radial line, so that this amplifier is particularly sensitive to variations of the track 4 in a tangential direction, i.e. to the signal Sc and to the signal corresponding to the wobble side bands.

In a similar way as in the apparatus of Figure 9a the clock signal Sc is recovered from the output signal of amplifier 46 by means of band-pass filter 28 and phase-locked loop 29 and the frequency of the wobble reference signal by means of band-pass filter 38 and phase-locked loop 39. The output signal of the band-pass filter 28, which contains the wobble signal Sw as an amplitude modulation of the clock signal Sc, is detected synchronously with the clock signal by means of synchronous detector 42 and yields the wobble signal Sw whose amplitude variation represents the deviation of the detector 27 relative to the centre 45 of track 4. Said signal Sw is detected synchronously with the output signal of phase-locked loop 39, i.e. with the wobble reference frequency, by means of synchronous detector 43, so that the radial tracking signal appears on output 44. The data signal is recovered from the output signal of amplifier 41 by means of the read circuit 30 which is synchronised by the clock signal Sc.

Mathematically, the operation of the apparatus of Figures 9a and 10 in respect of the recovery of the radial tracking signal may be explained as follows. The signal I detected by the detector 27 is a product of the clock modulation, the wobble modulation and the radial tracking error, which (when ignoring the data signal) may be expressed as:

$$I = A_r \sin(w_w t) \sin(w_c t)$$

where A_r is a function of the tracking error, w_w the angular frequency of the wobble signal S_w , w_c is the angular frequency of the clock signal S_c , and t the time. Synchronous detection with the clock signal S_c yields the term $A_r \sin(w_w t)$ and subsequent synchronous detection with the wobble frequency w_w yields the signal A_r .

Figure 11a shows a read section of an apparatus for reading data from a track 4 with a clock modulation structure and a wobble for deriving a radial tracking signal, the frequency of the wobble signal S_w being substantially, but not exactly, equal to the frequency of the clock signal S_c , and Figure 11b shows the frequency spectrum in which S_d represents the data signal and $S_c - w$ the term having a frequency equal to the difference between the frequencies of the clock signal S_c and the wobble signal S_w , which difference is for example 30 kHz, said term being obtained in that the photodiode 27 receives the product of the wobble modulation and the clock modulation. As a result of this, said term is situated in the low-frequency part of the spectrum and is hardly disturbed by the digital information. This term can be used to derive the radial tracking signal which is zero if the centre line 45 of the track is followed exactly. The wobble then yields a term of double the difference frequencies, which term is not used, and a term with the wobble frequency itself.

The apparatus, in a similar way as the apparatus of Figure 10, comprises an amplifier 41 for supplying the sum of the signals supplied by sections a, b, c and d of photodiode 27, from which sum the term of said difference frequency is extracted by means of the band-pass filter 48. With the aid of a synchronous detector 43, to which said difference frequency is applied, this term is demodulated with the wobble reference signal and, as the case may be via a low-pass

filter 49, the radial tracking signal appears on output 44.

The clock signal S_c is obtained in a similar way as in the apparatus of Figure 10 by determining the difference between the signals supplied by the two radial halves $a+c$ and $b+d$ of photodiode 27 with amplifier 46 and applying said difference to a phase-locked loop 29 after filtration with band-pass filter 28. In a similar way as in the apparatus of Figure 10 the wobble signal S_w is derived by determining the difference between the signals supplied by the two axial halves $a+b$ and $c+d$ of photodiode 27 with amplifier 421 and applying this to a phase-locked loop 39 via a band-pass filter 38. The difference frequency applied to the read circuit detector 43 is obtained by applying the clock signal S_c thus obtained and the wobble signal S_w to a synchronous detector 42, after which the resulting wobble reference signal of said difference frequency is applied to synchronous detector 43 via band-pass filter 47.

With the read circuit 30, synchronized with the clock signal S_c , the data signal can be recovered from the output signal of amplifier 41.

If the frequency of the wobble signal S_w is selected to equal the frequency of the clock signal, it will be evident from Figure 11b that the term with the difference frequency directly constitutes the DC tracking signal. This tracking signal can then be obtained without synchronous detection.

The phase difference between the two track modulations should not be zero, because only one modulation can be distinguished when the two modulations are in phase. It is found that 90° is an optimum phase difference.

Figures 7e and 7d show such a structure which can be read with the simple read circuit of Figure 12.

In the apparatus of Figure 12 the photodiode 27 is divided into two radial halves a and b for an optimum detection of the clock signal S_c , which is obtained on output 31 by determining the difference between the signals supplied by the two halves a and b with amplifier 46, by filtering said signal with band-pass filter 28 and applying it to the phase-locked loop 29. By filtering the output signal of amplifier 46 with a low-pass filter 49 the radial tracking signal is

directly available on output 44. The digital signal is recovered from the difference signal with read circuit 30, which is synchronized with the clock signal Sc. Alternatively, it is possible to recover the data signal and the low-frequency tracking signal from the sum
5 of the two halves.

In respect of the tracking during the recording of data signals the apparatus in accordance with Figures 8a to 12 inclusive may be extended with a device modulating a laser beam 16, which device is synchronized with the clock signal Sc and the signal read from the
10 synchronization areas, as has been explained with reference to Figure 6b.

In the foregoing it has been assumed in each case that one detector 27 is used which detects the reflected beam 16 (Figure 6). Especially at high bit frequencies it may be problematic, when
15 recording data in the information areas 9 with a laser beam which is comparatively powerful relative to that used for reading, to recover the clock information from the beam which is reflected between every two write pulses. As in many cases a follower laser-beam is employed in order to enable the recorded data signal to be detected,
20 the apparatus of Figure 13 may be used in such cases, in which the track 4, which relative to the detector 27 travels in the direction of the arrow 63, is scanned by an information-writing beam 16a and a follower beam 16b, which beams can for example be obtained by means of a beam splitter 68, mirrors 17a and 17b and optical systems
25 18a and 18b. In order to modulate the beam 16a a modulator may be arranged in the beam 16a. Said apparatus comprises a photo-diode 27, which in respect of the reading of data signals and tracking signals fully corresponds to the apparatus in accordance with any of the Figures 8a, 9a, 10, 11a or 12a. Furthermore, the apparatus comprises
30 a photodiode 50 for detecting the reflection of the follower beam 16b which is projected at the track at some distance behind the beam 16a. During the read process and also when the synchronization areas 8 are being read the clock signal Sc is obtained by applying the signal detected by photodiode 27 to the phase-locked loop 29 via an
35 amplifier and a band-pass filter which for simplicity are not shown

in this Figure (for example 46 in Figure 11a and for example 28 in Figure 11a respectively). In addition, in particular during the writing process, said clock signal is also recovered in a similar way from the signal detected by photodiode 50, as the case may be
5 via a band-pass filter not shown and via a phase-locked loop 501, but this signal is delayed relative to the clock signal obtained via photodiode 27 by a delay device 51, the output signal of which supplies output 31. The phase of the delayed clock signal is then compared with the phase of the clock signal obtained by means of
10 the photodiode 27 in phase comparator 52 and via switch 53 the delay device 51 is adjusted so that the clock signal from photodiode 50, which has been delayed via delay device 51, is in phase with the signal obtained via photodiode 27. During the read-out of the synchronization areas 8 switch 53 is closed and the
15 delay device 51 is adjusted so that the clock signal from photodiode 50, which has been delayed by said delay device 51, is in phase with the clock signal obtained via photodiode 27. During the recording of data in the information areas 9 switch 53 is open and the clock signal is recovered from the reflected auxiliary beam
20 16b via photodiode 50 and is delayed with the delay device 51 by an interval adjusted during the read-out of the synchronization areas 8. The switch 53 is operated on command of the synchronization signals read from the synchronization areas by the read circuit 30.

The invention is not limited to the embodiments shown, which
25 relate to a data storage medium with a subdivision into sectors. The invention may also be used in prepared record carriers for the storage of digitally coded audio, video and other information in more or less continuous information areas.

Furthermore the invention is not limited to record carriers in
30 which the recorded information is detected via reflection of the laser beam, but may also be employed in record carriers where the recorded information is detected by detecting the radiation transmitted by the record carrier.

Although the description with reference to the Figures is
35 based on the use of laser beams, it is alternatively possible, in particular during reading, to employ focused non-coherent light beams.



CLAIMS:

1. A record carrier comprising a radiation-sensitive information layer upon a disc-shaped substrate, in which layer optically detectable changes can be produced by a radiation beam, said record carrier being provided with information areas arranged in accordance with a spiral or concentric track pattern, which record carrier is intended for the recording and/or reproduction, via the radiation beam, of digitally coded information having a fixed bit frequency in the information areas, wherein the substrate in the information areas has a periodic track modulation, which is optically detectable via the information layer and whose period corresponds to a frequency for which the power spectrum of the digitally coded information at least substantially exhibits a zero point, said periodic track modulation generating a clock signal corresponding to said fixed bit frequency, for synchronising the digitally coded information during recording and during reproduction to provide said power spectrum.

2. A record carrier as claimed in Claim 1, wherein the digitally coded information to be recorded is coded in accordance with a modulation whose power spectrum exhibits a zero point at the bit frequency and wherein the period of the periodic track modulation corresponds to the bit frequency.

3. A record carrier as claimed in Claim 1 or Claim 2, wherein the information areas are spaced from each other by synchronisation areas, both types of area exhibiting the periodic track modulation, and wherein the period of the periodic track modulation corresponds to a frequency at which the digital information power spectrum of the synchronization areas substantially exhibits a zero point.

4. A record carrier as claimed in Claim 3, wherein in the synchronization areas, information is recorded in accordance with a digital modulation whose power spectrum exhibits a zero point at the bit frequency, and wherein the frequency corresponding to the period of the periodic track modulation is equal to the bit frequency of said modulation.

5. A record carrier as claimed in any one of the preceding Claims, wherein the information areas contain an optically



detectable continuous servo track, and wherein the periodic track modulation is constituted by a track-width modulation of the servo track.

5 6. A record carrier as claimed in any one of Claims 1 to 4 inclusive, wherein the periodic track modulation is constituted by a periodic radial undulation of the servo track.

7. A record carrier as claimed in any one of the Claims 1 to 4 inclusive, wherein the periodic track modulation is constituted by an optically detectable track-depth modulation.

10 8. A record carrier as claimed in Claim 7, wherein said track-depth modulation extends between the surface of said record carrier and a level situated below said surface.

9. A record carrier as claimed in any one of the preceding Claims, wherein the periodic track modulation is superimposed on a radial undulation having a wavelength which is long relative to the period of said modulation.

10. An apparatus for manufacturing a record carrier as claimed in any of the preceding Claims, comprising means for supplying a radiation beam by means of which the track pattern is inscribed on the substrate, a modulation device for modulating the inscribing radiation beam in order to produce said periodic track modulation on the substrate, and means for applying said radiation sensitive information layer on the inscribed substrate, said modulation being optically readable via said layer.

25 11. An apparatus as claimed in Claim 10, wherein said modulation device is an intensity modulator.

12. An apparatus as claimed in Claim 10, wherein said modulation device is a focusing modulator for modulating the diameter of the radiation beam at the surface of the record carrier.

13. An apparatus as claimed in Claim 10, wherein said modulation device is adapted to make the radiation beam oscillate in a radial direction at the surface of the record carrier.

35 14. An apparatus for recording information on a record carrier as claimed in any of the Claims 1 to 9, comprising a radiation source, an optical system for directing a radiation beam to the information areas of said record carrier, a recording



5 circuit for modulating the radiation beam depending on the digital
signal to be recorded, an optical system with a detector for
detecting the radiation received from said periodic track
modulation via said radiation sensitive recording layer, a
band-pass filter for extracting the clock signal from the detector
output and means for applying the clock signal to the recording
circuit to synchronise the digital signal to be recorded with the
periodic track modulation so that the digital information is
recorded in a fixed phase relationship with said periodic track
10 modulation and has said power spectrum.

15 15. An apparatus as claimed in Claim 14, comprising optical
means for directing an auxiliary beam to the information areas
behind the modulated beam for reading the information recorded by
means of the modulated radiation beam, means for generating the
clock signal from a signal derived from the auxiliary beam, and
means for synchronizing the information writing process of the
modulated beam with said generated clock signal.

20 16. An apparatus for reading a record carrier as claimed in
any one of Claims 1 to 9 inclusive, in whose information areas
digital information has been recorded by means of apparatus as
claimed in Claims 14 or Claim 15, which apparatus comprises an
optical system for scanning said information areas with a radiation
beam, a detector for detecting the radiation received from said
periodic track modulation via said radiation sensitive layer and
25 radiation received from said layer in said information areas, a
read circuit for extracting the recorded information signal from
the detected radiation, and a band-pass filter for extracting the
clock signal from the detector output at a frequency at which the
power spectrum of the recorded digitally coded information exhibits
30 a zero point, and means for applying the clock signal to the read
circuit for synchronisation during read-out of the recorded digital
information.

35 17. An optically readable disc record carrier having a
radiation sensitive layer on which digital information may be
recorded substantially as described with reference to Figures
1,2,3,4,5 and 7 of the accompanying drawings.

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18. An apparatus for manufacturing an optically readable disc record carrier having a radiation sensitive layer on which digital information may be recorded substantially as described with reference to Figure 6a of the accompanying drawings.
- 5 19. An apparatus for recording information on an optically readable disc record carrier having a radiation sensitive layer on which digital information may be recorded substantially as described with reference to Figure 6b of the accompanying drawings.
- 10 20. An apparatus for recording information on an optically readable disc record carrier having a radiation sensitive layer on which digital information may be recorded substantially as described with reference to Figures 6b and 13 of the accompanying drawings.
- 15 21. An apparatus for reading an optically readable disc record carrier having a radiation sensitive layer on which digital information has been recorded substantially as described with reference to Figure 6c of the accompanying drawings.
- 20 22. An apparatus for reading an optically readable disc record carrier having a radiation sensitive layer on which digital information has been recorded substantially as described with reference to Figures 6c and 8 of the accompanying drawings.
- 25 23. An apparatus for reading an optically readable disc record carrier having a radiation sensitive layer on which digital information has been recorded substantially as described with reference to Figures 6c and 9 of the accompanying drawings.
- 30 24. An apparatus for reading an optically readable disc record carrier having a radiation sensitive layer on which digital information has been recorded substantially as described with reference to Figures 6c and 10 of the accompanying drawings.
- 35 25. An apparatus for reading an optically readable disc record carrier having a radiation sensitive layer on which digital information has been recorded substantially as described with reference to Figures 6c and 11 of the accompanying drawings.
26. An apparatus for reading an optically readable disc record carrier having a radiation sensitive layer on which digital information has been recorded substantially as described with reference to Figures 6c and 12 of the accompanying drawings.