"Method of recording a digital information signal on a record carrier having a radiation-sensitive information layer, apparatus for carrying out the method, and optical record carrier provided with such a digital information signal".

The invention relates to a method of recording a binary information signal on a record carrier having a radiation-sensitive information layer, a recording pattern corresponding to said information signal being formed in the information layer of the record carrier by the generation of radiation pulses of fixed duration and intensity at selected instants of the sequence of instants corresponding to the bit cells, which radiation pulses have such an energy that unitary recording marks are formed on the record carrier, the information signal comprising a sequence of bit cells of which at least n consecutive bit cells are of the same first type, n being ≥ 2.

The invention also relates to a record carrier provided with a digital information signal stored in an information track, which information signal comprises a sequence of bit cells, of which at least n consecutive bit cells are of the same type, a sequence of bit cells of a first type always being represented by a plurality of unitary recording marks in the information track.

The invention also relates to apparatus for carrying out the method, which apparatus comprises a radiation source, an optical system for focusing a radiation beam emitted by the radiation source onto a radiation-sensitive information layer of a record carrier, and a control device for controlling the radiation source depending on an applied binary information signal, which information signal comprises a sequence of bit cells, of which at least n consecutive bit cells are of the same type, n being ≥ 2.

To date record carriers with radiation-sensitive information layers command much interest. This is mainly because such record carriers have a very high storage capacity, enabling a very large amount of information, for example data information and digitized video and/or audio information, to be recorded on such record carriers.

The information layer of such a record carrier comprises a material which exhibits a physical reaction upon exposure to a radiation beam of suitable intensity, so that by modulating this recording beam a corresponding recording pattern is formed on the record carrier. The information layer may, for example, consist of a metal, inter alia tellurium, which locally melts by heating upon exposure to said radiation beam. Alternatively, this information layer may, for example, comprise a double-layer structure of materials which react chemically under the influence of the incident beam of radiation, for example, on ion or bismuth on tellurium. Other suitable materials are, for example, magneto-optical materials such as Gd-Fe and cobalt ferrites. In itself the material selected for the information layer is irrelevant to the present invention, provided that upon exposure to a modulated radiation beam a recording pattern corresponding to the information signal is formed in this material.

For an optimum use of the storage capacity of the record carrier the information signal is generally modulated in a special manner, i.e. the source coding of the information signal is converted into a channel coding, which channel coding is adapted to suit the specific properties of the channel, in the present case the record carrier.

Parameters which are important in this respect are inter alia

(1) the maximum frequency of the recorded information signal is in view of the limited transmission bandwidth of the record carrier and the recording and reproducing apparatus,

(2) the low-frequency signal content of the information

signal; this is in view of cross-talk between the information signal and the low-frequency servo signals which are frequently used in read apparatuses for optical record carriers for centring the read spot on the information track and for focusing this read spot,

(3) the maximum number of consecutive bit cells of the same type; this is because it is frequently required that the clock information can be divided from the information signal during read-out of the record carrier.

Netherlands Patent Application 80 00 121 (PHN 9666) describes a method of the type mentioned in the opening paragraph and also describes some channel codings. Furthermore, said Patent Application describes two methods of recording the information signal on the record carrier in accordance with the channel coding.

In accordance with the first method a light beam is modulated exactly in accordance with the digital signal, so that recording marks of variable length are recorded on the record carrier, which marks correspond to the periods that the information signal assumes one of the digital values.

In accordance with the second method the light beam is pulsed, that is, for each bit cell of one type in the information signal a radiation pulse of fixed length and magnetude is generated. On the record carriers these radiation pulses produce recording marks of constant dimensions, unitary recording marks, each unitary recording mark consequently representing a bit cell of one specific type. In comparison with the first method this second method has the advantage that the dissipation in the radiation source is smaller, which has also a favourable effect on the lifetime of this radiation source.

Furthermore, said Netherlands Patent Application describes a channel coding in which at least two consecutive bit cells are always of the same type. As the minimum number of consecutive bit cells of the same type, i.e. n, increases, the maximum frequency of the binary information signal decreases. It is obvious that this has a

favourable effect on the attainable storage capacity and the required bandwidth of the recording and reproducing apparatus.

It is an object of the invention to provide a method of the type mentioned in the opening paragraph which enables a very high information density on the record carrier to be achieved without the need to impose extremely stringent requirements on the recording equipment and which also enables the dissipation of the radiation source to be reduced even further.

To this end the invention is characterized in that the radiation pulses are dimensioned so that the unitary recording marks formed by said radiation pulses represent m consecutive bit cells of the same first type, for which $1 < m \leq n$ (m and n being integers), and in that a greater number of consecutive bit cells of the same first type is represented by a plurality of unitary recording marks which are at least contiguous and which are produced by a plurality of consecutive radiation pulses.

The invention is based on the recognition of the fact that in practice the minimum size of the unitary recording marks is subject to limits. This depends on material parameters of the information layer and on the properties of the optical components by which the radiation beam in the recording apparatus is focused onto the information layer. If in encoding systems in which the number of consecutive bit cells of the same type is greater than one bit cell, said unitary recording mark is not related to one bit cell but to m bit cells, for which $1 < m \leq n$, the storage capacity of the record carrier can be increased substantially. The increase obtained by means of the invention then depends on the value of m. A preferred embodiment of the method in accordance with the invention is characterized in that $m = n$. This provides a maximum increase in storage capacity.

A record carrier in accordance with the present invention is characterized in that one unitary recording mark represents m consecutive bit cells of the first

type, for which $1 < m \leq n$ (m and n being integers), and in that a greater number of consecutive bit cells of said first type is represented by a plurality of unitary recording marks which are at least contiguous.

Finally, a recording apparatus in accordance with the invention is characterized in that the control device is adapted to supply control pulses to the radiation source and said radiation source is adapted to produce such a radiation pulse, in response to a control pulse that on the record carrier a unitary recording mark is formed which corresponds to m consecutive bit cells of the same first type in the information signal, for which $1 < m \leq n$.

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

Figures 1, 2 and 3 represent signal waveforms and the associated recording marks to illustrate the method in accordance with the invention,

Figure 4 shows an example of a device for obtaining the radiation pulses required for the method in accordance with the invention, and

Figure 5 shows the signal waveforms appearing in said device.

Figure 1 schematically represents a first version of the method in accordance with the invention, using the so-called Miller modulation.

Figure 1a represents a bit sequence of a digital signal, comprising a sequence of logic zeros and ones. In accordance with the Miller modulation this digital signal is converted into a binary information signal as shown in Figure 1b.

In accordance with the Miller modulation the binary information signal then exhibits a transition halfway a logic "1" of the applied digital signal and transition between two consecutive "0"'s of this signal.

A characteristic feature of this Miller modulation is that the length of time in which the binary signal continuously has one of the two values can assume

only a specific number of discrete values, which values comply with the formula nT. T is the greatest common divisor of these possible discrete values and in the Miller Modulation it corresponds to half the bit length of the original digital signal. In this Miller modulation the paramater n may assume the value 2, 3 or 4, as will be apparent from the Figure. Hereinafter the time interval T will be referred to as bit cell, as is customary.

For recording the binary information signal on a record carrier having a radiation-sensitive layer a radiation beam must be modulated in such a way that on this record carrier recording marks are formed whose sequence represents the binary information signal. For this purpose this radiation beam may, of course, be modulated directly with the binary information signal to be recorded. In addition, the said Netherlands Patent Application 80 00 121 (PHN 9666) describes the possibility of recording unitary recording marks on the record carrier by the pulsed operation of the radiation source. For this purpose a radiation pulse as shown in Figure 1c is generated for each bit cell T, which represents a logic "1". Each of the radiation pulses has a sufficiently high energy to produce a unitary recording mark corresponding to one bit cell on the record carrier. Thus, a pattern of recording marks S (shown in Figure 1d) of fixed dimensions is formed on said record carrier, which marks are referred to as unitary recording marks and whose pattern represents the binary information signal.

In practice, the dimensions of these unitary recording marks, in general the diameter of the round marks, is subject to a minimum limit. This minimum depends on the parameters of the radiation-sensitive material and on the properties of the optical components used for recording. If the radiation-sensitive material is, for example, a material which melts upon exposure to a radiation beam of sufficient intensity, a specific minimum radiation energy will be required because of the reliability of the write process, which radiation energy forms a unitary

recording mark of specific dimensions via heating of the material. If even smaller unitary recording marks are required the recording process will become unreliable. The optical components employed in the recording apparatus inter alia determine the diameter of the write spot projected onto the information layer. This write spot can be given a very small diameter by focusing, which results in the high storage capacity of these optical record carriers, but in practice this is also subject to limits. Indeed, regardless of, for example, flatness defects of the information layer this write spot diameter must always be maintained, which inter alia imposes stringent rewuirements on the flatness of the information layer and the focusing control of the recording apparatus.

Moreover, it should be borne in mind that even if unitary recording marks of very small dimensions can be formed on the record carrier by means of sophisticated techniques, this also has consequences for the read apparatus with which this record carrier is to be read. The read apparatus should then be capable of reliably reading these unitary recording marks, which imposes very stringent requirements on the optical components and control systems used therein, for example the tracking system and the focusing system. Especially if this read apparatus is a consumer product, for example for reading digital video and/or audio information, the requirements that may be imposed are subject to limits.

As a result of this the diameter of the unitary recording marks S shown in Figure 1d is limited to specific minimum dimensions in practice. This diameter in conjunction with the modulation system then determines the storage capacity of the record cartier.

The present invention aims at increasing this storage capacity in a simple manner. Instead of recording unitary recording marks which correspond to one bit cell it is proposed, in accordance with the invention, to record unitary recording marks which correspond to m consecutive bit cells of the same type in the binary in-

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formation signal, for which $1 < m \leq n$. As already stated, $n = 2$ in the case of Miller modulation, so that in accordance with the invention it follows automatically that for this modulation system $m = n = 2$ and consequently one unitary recording mark S' corresponds to two bit cells. Moreover, in accordance with the invention, a greater number of consecutive bit cells of the same type are represented by a plurality of unitary recording marks which are at least contiguous.

When the method in accordance with the invention is applied to the binary information signal represented by Figure 1b, this yields for example the pattern of unitary recording marks as shown in Figure 1f, for which radiation pulses as shown inFigure 1e are required. Comparing the patterns of unitary recording marks shown in Figure 1d and 1f then shows for example that the first two unitary recording marks S of Figure 1b are replaced by single unitary recording marks S' in Figure 1, that the next three consecutive unitary recording marks of Figure 1d are replaced by two partly overlapping unitary recording marks S' as shown in Figure 1f, etc.

The dimensions of the unitary recording marks shown in Figure 1f are selected so that a direct comparison with the pattern shown in Figure 1d is possible. In reality the unitary recording mark S' will be selected to be identical to the marks S of Figure 1d. The pattern shown in Figure 1f is then reduced to the pattern shown in Figure 1g, from which it is evident that the method in accordance with the invention leads to an increase in the storage capacity of the record carrier by a factor 2.

In addition to the Miller coding described in the foregoing several other codes exist in which the minimum number of consecutive bit cells of the same type is greater than one. These codes include serial codes (amongst them the Miller code) in which data bits of the digital source signal are consecutively transformed into bit cells of the binary information signal and so-called block codes, in which words of the digital signal are con-

verted into an unambiguous pattern of bit cells of the binary information signal. An example of such a code is the so-called EFM (Eight to Fourteen Modulation), described in Netherlands Patent Application 80 04 028, which code is employed as a modulation for recording audio information on an optical disc in the so-called Compact Disc Audio System. In the case of this EFM modulation the resulting binary information signal is characterized in that at least 3 consecutive bit cells are of the same type (n = 3), whilst the maximum is 11. A number of alternatives to the method in accordance with the invention will be described with reference to Figure 2 which represents a signal obtained by means of this EFM modulation.

Figure 2a represents the binary signal. The radiation pulse used for recording is such that a unitary recording mark S is obtained which corresponds to 3 bit cells, the minimum number of consecutive bit cells of type "1", i.e. m = n = 3. A greater number of bit cells of type "1" can be recorded in the same way as illustrated by Figure 1 by means of a number of consecutive radiation pulses spaced at time intervals of one bit cell, which results in the pattern shown in Figure 2c, generated by the radiation pulses shown in Figure 2b. The Figure shows that this results in a substantial overlap of the unitary recording marks.

In the pattern of radiation pulses shown in Figure 2d every second radiation pulse of the sequence, by means of which a plurality of consecutive bit cells of type "1" should be recorded, is suppressed, except for the last radiation pulse of such a sequence. From the pattern of unitary recording marks corresponding to these radiation pulses, shown in Figure 2c, it appears that this pattern still unambiguously represents the binary signal. The advantage thus obtained is of course that the dissipation of radiation source is reduced.

In addition to the first and the last radiation pulse whose presence and position are compulsory the pattern of radiation pulses shown in Figure 2f, only com-

prises the minimum number of intermediate radiation pulses in order to obtain a sequence of partly overlapping unitary recording marks (Figure 2g), which is achieved by positioning the intermediate radiation pulses at equal time intervals relative to the first and the last radiation pulse.

Finally, in the pattern of unitary recording marks shown in Figure 2i, a sequence of consecutive bit cells of type "1" may be represented by a plurality of non-overlapping but contiguous unitary recording marks, so that the required number of radiation pulses (Figure 2h) is reduced even further.

It will be evident that by means of logic circuitry the desired pattern of radiation pulses can be derived from the binary information signal in a simple manner. Apart from the said dissipation the choice of this pattern of radiation pulses also depends on the desired reliability. When the number of unitary recording marks is reduced this will ultimately also lead to a reduction of the reliability.

Figure 3 represents an alternative to the method represented in Figure 2. Figure 3a again represents the binary signal shown in Figure 2a. However, in contradistinction to the situation of Figure 2, the unitary recording marks S now correspond to two bit cells, hence m = 2. The sequence of radiation pulses shown in Figure 3b then results in a pattern of unitary recording marks S' as shown in Figure 3c. This alternative method also allows a number of radiation pulses to be suppressed, for example every second radiation pulse (except the last one) of each sequence, which results in the sequence of radiation pulses shown in Figure 3d and the pattern of unitary recording marks shown in Figure 3e.

Figure 4 by way of example shows a logic circuit for deriving the radiation pulses from the binary information signal, whilst Figures 5a to 5d show the corresponding signals.

This example is based on a binary information

signal I in which at least 3 consecutive bit cells are of the same type, so that unitary recording marks which correspond to 3 bit cells can be recorded.

In the logic circuit shown in Figure 4 the binary information signal I (Figure 5a) is applied to a device 1 in which this information signal is delayed by two bit cells (Figure 5a). The delayed information signal I' and the information signal I are applied to two inputs of an AND-gate 2. A third input of this AND-gate 2 receives a clock signal k (Figure 5c) comprising pulses halfway every bit cell. At the output of this AND-gate 2 this yields the pulse train shown in Figure 5d, which pulse train is applied to a radiation source 3. This radiation source 3 then produces radiation pulses for forming a unitary recording mark corresponding to 3 bit cells on the record carrier.

The optical components and the control systems, such as a focusing control system, used in this recording apparatus are of minor importance to the present invention. The same applies to the organisation structure on the record carrier, for example the presence of absence of a pre-recorded track on this record carrier. For an example of these aspects of the recording apparatus reference is made to the previously mentioned Netherlands Patent Application 80 00 121 (PHN 9666), which is herewith incorporated by reference.

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CLAIMS:

1. A method of recording a binary information signal on a record carrier having a radiation-sensitive information layer, a recording pattern corresponding to said information signal being formed in the information layer of the record carrier by the generation of radiation pulses of fixed duration and intensity at selected instants of the sequence of instants corresponding to the bit cells, which radiation pulses have such an energy that unitary recording marks are formed on the record carrier, the information signal comprising a sequence of bit cells, of which at least n consecutive bit cells are of the same first type, n being $\geq$ 2, characterized in that the radiation pulses are dimensioned so that the unitary recording marks formed by said radiation pulses represent m consecutive bit cells of the same first type, for which $1 < m \leq n$ (m and n being integers), and a greater number of consecutive bit cells of the same first type is represented by a plurality of unitary recording marks which are at least contiguous and which are produced by a plurality of consecutive radiation pulses.

2. A method as claimed in Claim 1, characterized in that m = n.

3. A method as claimed in Claim 1 or 2, characterized in that a number of consecutive bit cells of the same first type greater than n is represented by a plurality of partly overlapping unitary recording marks.

4. A method as claimed in Claim 2, characterized in that for recording (n + p) consecutive bit cells of the same first type (p + 1) radiation pulses are generated, which radiation pulses are spaced at time intervals of one bit cell from each other.

5. A record carrier provided with a digital information signal stored in an information track, which

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information signal comprises a sequence of bit cells, of which at least n ($n \geq 2$) consecutive bit cells are of the same type, a sequence of bit cells of a first type always being represented by a plurality of unitary recording marks in the information track, characterized in that one unitary recording mark represents m consecutive bit cells of the first type, for which $1 < m \leq n$ (m and n being integers) and a greater number of consecutive bit cells of said first type is represented by a plurality of unitary recording marks which are at least contiguous.

6. A record carrier as claimed in Claim 5, characterized in that one unitary recording mark represents n consecutive bit cells of the first type and a plurality of consecutive bit cells of the first type greater than n is represented by a plurality of partly overlapping unitary recording marks.

7. A record carrier as claimed in Claim 6, characterized in that the overlap of the partly overlapping unitary recording marks corresponds to n - 1 bit cells.

8. An apparatus for carrying out the method as claimed in Claim 1, which apparatus comprises a radiation source, an optical system for focusing a radiation beam emitted by the radiation source onto a radiation-sensitive information layer of a record carrier, and a control device for controlling the radiation source depending on an applied binary information signal, which information signal comprises a sequence of bit cells, of which at least n consecutive bit cells are of the same type, n being ≥ 2, characterized in that the control device is adapted to supply control pulses to the radiation source and said radiation source is adapted to produce such a radiation pulse, in response to a control pulse, that on the record carrier, a unitary recording mark is formed which corresponds to m consecutive bit cells of the same first type in the information signal, for which $1 < m \leq n$.

9. An apparatus as claimed in Claim 8, characterized in that the control device is adapted so that (n+p) consecutive bit cells of the same first type of the in-

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formation signal result in (p + 1) radiation-source control pulses which are spaced from each other by time intervals corresponding to one bit cell.

10. A method of recording a digital information signal on a record carrier having a radiation-sensitive information layer, substantially as hereinbefore described with reference to Figures 1e to 1g and 2 to 5 of the accompanying drawings.

11. A record carrier as claimed in claim 5, substantially as hereinbefore described with reference to Figures 1e to 1g and 2 to 5 of the accompanying drawings.

12. An apparatus as claimed in claim 8, substantially as hereinbefore described with reference to Figures 1e to 1g and 2 to 5 of the accompanying drawings.