



Optical record carrier recording method and apparatus

The invention relates to an optical record carrier recording method for forming pits and lands by directing a radiation beam onto a recording surface of an optical record carrier, the radiation beam for each pit to be recorded being set to at least one write power level capable of forming a pit during a write power irradiation period and for each land
5 between the pits to at least one bottom power level incapable of forming a pit during a bottom power irradiation period. The invention also relates to a corresponding optical record carrier recording device for carrying out such method.

Such a recording method is known from the Compact Disc Recordable (CD-R)
10 System Description (also known as the Orange-Book). A pit is formed by applying a radiation beam having a write power level to a recording surface of an optical record carrier during a write power irradiation period. The time length of the write power irradiation period depends on the length of the pit to be recorded. The length of a pit is represented by a parameter nT , where T represents the time length of one period of a reference clock in a data
15 signal and n represents a predetermined integer number. For a CD-R system n is in a range from 3 to 11. For forming a land the radiation beam is set to a bottom power level which is lower than the write power level during a bottom power irradiation period.

A method for embedding a stream of bits of a secondary channel in a stream of bits of a main channel is known from WO 00/57417 A1. Therein the bits of the secondary
20 channel are embedded in the main channel by Limited Multi Level (LML) coding. While the stream of bits of the main channel is encoded in the zero crossings of a reflection signal, the bits of the secondary (LML) channel are encoded in the amplitudes of reflection, i. e. the amplitude levels of the pits and of the lands are used for encoding the bits of the secondary channel.

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It is an object of the present invention to provide an optical record carrier recording method and a corresponding apparatus which allow the application of LML coding on recordable optical record carriers and satisfy the following criteria:



- an acceptable difference between a normal runlength modulation and its corresponding LML equivalent should be achieved, that is, preferably a reduction of 30% in the land modulations and an increase of 30% in the pit modulations, and

5 - the length of the reduced effect as seen in the high frequency signal should be equal to the length of an unmodified effect.

Preferably, the thermal cross-talk towards preceding and succeeding effects should be maintained with respect to cross-talk as observed with the unmodified effect. Furthermore the LML effects should preferably be fully exchangeable with normal effects without increasing
10 the overall jitter. The jitter is the standard deviation of the time difference between level transitions in a digitized read signal and the corresponding transitions in a clock signal, the time difference being normalized by the duration of one period of said clock.

This object is achieved by an optical record carrier recording method as
15 claimed in claim 1, which is characterized in that the bottom power level is temporarily raised to an LML land power level during an LML land irradiation period for forming an LML land, the LML land power level being close to the write power level, and that the write power level is temporarily lowered to an LML pit power level during an LML pit irradiation period for forming an LML pit, the LML pit power level being close to the bottom power
20 level. According to the invention the amplitude of reflection of a signal stored on the optical record carrier is influenced by controlling the power level of the radiation beam when forming pits and lands. Thus it can be decided if a "normal" pit or an LML pit having different amplitudes of reflection shall be written or if a "normal" land or an LML land having different amplitudes of reflection shall be written.

25 According to the invention the LML land power level and the LML pit power level are optimized for minimum jitter. The LML land power level is selected such that a less brighter land is written, while the LML pit power level is selected such that a less darker pit is written, that is, compared to "normal" lands and pits. Thus, for LML the envelope of the eye-patterns is reduced. For lands the relatively high reflection level is reduced, while it is
30 increased for the relatively low reflection level in the pits.

There are different parameters for optimization of said write strategy. In particular, the time length of the temporary raise of the bottom power level, the time length of the temporary lowering of the write power level as well as the levels of the LML land power and the LML pit power can be optimized to find a compromise where there is sufficient

reduction in amplitude while the lowest increase in cross-talk is observed and the increase in jitter is minimized. The LML land power level is at least controlled such that it is close to the write power level, and the LML pit power level is at least controlled such that it is close to the bottom power level, preferably higher than the bottom power level. Preferred ranges for said power levels are given in claim 2. The specific values for said power levels are achieved by optimizing the time duration of the temporary lowering or raising, respectively, of the power levels.

The temporary lowering of the LML pit power level should preferably be slightly shifted to the second half or the end of the write power irradiation period. Correct positioning of the location of the temporary lowering is essential to have a symmetrical lowering of the modulation. Similarly the temporary raise to the LML land power level is preferably located slightly in the first half of the bottom power irradiation period.

To ensure some peak temperatures which determine the thermal cross-talk the write power level is temporarily raised to an LML pit correction power level during a write power irradiation period, the LML pit correction power level being higher than the write power level according to a preferred embodiment. An advantageous range for the LML pit correction power level is given in claim 6.

In order to control the effect length in pits or lands, respectively, the write power irradiation period and/or the bottom power irradiation period are increased by an additional write power irradiation period or additional bottom power irradiation period, respectively, according to the preferred embodiments of claims 7 and 9. The thermal cross-talk towards the preceding pit may appear to be too much, particularly when temporarily raising the write power level to an LML pit correction power level during said LML pit irradiation period. Increasing the pulse length enables the nominal power to be lowered, resulting in lower thermal cross-talk to neighboring pits.

Preferred ranges for the LML pit increase power level and the LML land increase power level are given in claims 8 and 10. The additional write power irradiation period and/or the additional bottom power irradiation period has preferably a time length of 0.2 to 0.7T, in particular 0.5T or 0.25T, respectively.

The LML land irradiation period and/or the LML pit irradiation period has preferably a time length of 0.5T to 2T, in particular 1T to 1.25T. Such periods are preferably short, but the shorter such periods, the higher the power levels will have to be during said periods. In general, the longer the runlength of a pit or a land is, the longer can the LML pit irradiation period or the LML land irradiation period, respectively, be selected.

As an alternative write strategy for recordable optical media use can be made of a pulsed strategy according to which for recording pits the radiation beam is set to the write power level in the form of write pulses and that for forming an LML pit by temporary lowering of the write power level at least one write pulse is left out. Preferably, the write power level of the remaining write pulses is then increased compared to the normal write power level of the write pulses for forming a "normal" pit.

The invention also relates to an optical record carrier recording device as claimed in claim 15, comprising a radiation source and control means for carrying out the method according to the invention. Preferably, said device also comprises jitter control means for measuring and minimizing the jitter by controlling the power of the radiation beam and the duration and time length of the power levels as explained above.

Although the invention is explained by using a CD-R system as an example, it will be apparent to a person skilled in the art that the invention may also be applied to alternative optical recording systems.

The invention will now be explained in more detail with reference to the drawings in which

Fig. 1 shows a diagram illustrating multi level coding,

Fig. 2 shows an embodiment of a recording device according to the invention,

Fig. 3 shows a diagram illustrating writing of an I7 pit,

Fig. 4 shows a diagram illustrating writing of an I5 pit,

Fig. 5 shows a diagram illustrating writing of an I7 land,

Fig. 6 shows a diagram illustrating writing of an I5 land, and

Fig. 7 shows a diagram illustrating writing of an I6 pit using a pulsed strategy.

Figure 1 illustrates the concept of Limited Multi Level (LML) coding. A reflection signal 1 is shown into which a stream of data of a main channel is encoded using a Run Length Limited (RLL) code and a stream of data of a secondary channel (LML channel) is encoded using LML coding. While RLL coding uses a spatial modulation of the zero crossings of the signal 1 with a slicer level 2 as indicated by an arrow 3, LML coding uses an amplitude modulation of the reflection amplitude as indicated by an arrow 4. The runlength, i. e. the length of pits and lands, is represented by a parameter $n \cdot T$, where T represents the time length of one period of a reference clock in a data signal and n represents a

predetermined integer number. For a CD-R system the runlength is limited to a range from 3 to 11, i. e.

$$3 \leq n \leq 11.$$

The LML modulation is primarily introduced for longer runlengths, for example, in CD-R systems for runlengths equal to or greater than 5T. By controlling the reflection amplitude of each pit and land for such longer runlengths an additional bit value can be embedded into each such longer runlength. A "normal" pit 5 and a "normal" land 6, both having normal amplitudes of reflection, can then be interpreted as bits having bit value zero while an LML pit 7 or an LML land 8, each having a reduced amplitude of reflection, can be interpreted as bits having a bit value 1 or vice versa.

The reduction of the amplitude is preferably realized in the middle area of the runlength. For short runlengths, the reduced middle area is close to the leading and trailing edges of the runlength. The impulse response of the channel causes an increase in the jitter of the leading and trailing edges. Furthermore, for straightforward detection of the LML-information a single slicer level shall be used for all possible runlengths. Therefore, LML coding is limited to those runlengths that reach full modulation in the eye-pattern.

Fig. 2 shows an optical record carrier recording device according to the invention for recording a data signal 10 onto the recording surface 21 of a disc-shaped optical record carrier 20. The optical record carrier 20 is rotated around its center by a motor 11. A radiation beam 12 is generated by a radiation source 13 and focussed onto the recording surface 21 by a lens 14.

The data signal 10 is applied to control means 15. Therein the data signal 10 is converted into a control signal 16 by a conversion unit 17 which is applied to a control unit 18. Therein, a radiation control signal 19 is generated for controlling the radiation power to be generated by the radiation source 13.

In order to control the power of the radiation beam and the duration and time length of the power levels such that the resultant jitter is minimized, a jitter control unit 22 is provided for measuring the jitter after the writing of signals on the optical record carrier 20. Said measurement and control by the jitter control unit 22 take place during the writing of the signal on the optical record carrier 20, that is, by generating a jitter control signal 23 which is also applied to said control unit 18.

The method according to the invention will now be explained in more detail with reference to several examples as shown in the Figures 3 to 7 which show several write signals for writing pits, lands, LML bits or LML lands.

Figure 3A shows a write signal 30 for forming a normal pit having a runlength of 7T (often referred to as an I7 pit) on the record carrier. In order to form a preceding land the power of the radiation beam is set to a bottom power level P_0 which is preferably identical to a read power level. For writing the I7 pit thereafter, the power level is raised to a write power level P_W for a write power irradiation period 31 which equals 6.5T in this particular embodiment. Before forming a subsequent land, the power level is first lowered to zero and subsequently set to the bottom power level P_0 for forming the land.

Figure 3B shows a write signal 32 for forming an I7 LML pit having the same runlength of 7T. For forming said LML pit the power level is first raised to the write power level P_W after the writing of the previous land for a very short period 33. Subsequently, the power level is further raised to an LML pit power level P_{p2} during a first pit correction period 34 which is almost half of the write power irradiation period 31. After that the power level is drastically reduced to an LML pit power level P_{p1} during an LML pit irradiation period 35 before it is again raised to the LML pit correction power level P_{p2} for a second pit correction period 36 until the LML pit is completed.

As can be seen from Figure 3B, the LML pit correction power level P_{p2} is higher than the write power level P_W . Generally speaking, the LML pit correction power level P_{p2} is set within a range of 1.01 to 1.30 times the write power level P_W . In the specific embodiment for writing an I7 LML pit as shown the LML pit correction power level P_{p2} is set to 1.1 times the write power level P_W .

The LML pit power level P_{p1} is generally set within a range of 0.05 to 0.5 times the write power level P_W . In the specific embodiment shown in Figure 3B it is preferably set to 0.1 times the write power level P_W . In general, the LML pit power level P_{p1} is close to the bottom power level P_0 , preferably higher than the bottom power level P_0 .

The temporary lowering of the power level during the LML pit irradiation period 35 is preferably shifted to the end of the write pulse. Correct positioning of the location of the LML pit irradiation period 35 is essential to achieve symmetrical lowering of the modulation. The duration of said period 35 and the power level P_{p1} itself can be used to find a compromise where there is sufficient reduction in amplitude and the lowest increase in cross-talk is observed. In the example shown in Fig. 3B the period has a duration of 1.25T.

The power level set during the initial period 33 can be adapted to the heat stored in the record carrier after writing a previous land. After a short land is formed, residual heat of the previous pit will be present in the record carrier. In that case, the next pit should be written with a reduced initial power with respect to the case where this pit is preceded by a

long land. This method is called thermal balancing. The pit strategy then depends on the neighboring lands. This is also illustrated in Figures 3A, 3B. If the land before the pit or the LML pit, respectively, is a short land, in particular an I3 or I4 land, i. e. a land having a runlength of 3T or 4T, the power level should be set to an initial reduced write power level

5 P_{W3} (for I3-land) or P_{W4} (for I4-land) during the initial period 33.

Figures 4A, 4B show another embodiment for writing a normal I5 pit and an I5 LML pit. The write signal 40 for writing the I5 pit as shown in Figure 4A is substantially identical to the write signal 30 for writing the I7 pit as shown in Figure 3A, that is, except for the length of the write power irradiation period 41 which is shorter than the corresponding

10 period 31. The write signal 42 for forming an I5 LML pit as shown in Figure 4B is also quite similar to the write signal 32 as shown in Figure 3B for forming the I7 LML pit except for the certain power levels and the durations for which these power levels are set.

During the initial period 43 the power level is at first set to the write power level P_W or, if the previous land is quite short, to a reduced write power level as explained

15 above. Subsequently, during the first correction period 44 the power level is set to the LML pit correction power level P_{p2} which is preferably set to 1.07 times the write power level P_W in the present embodiment. After nearly half of the write power irradiation period 41, the power level is reduced to the LML pit power level P_{p1} during the LML pit irradiation period 45, the LML pit power level P_{p1} preferably being set to 0.35 times the write power level P_W .

20 Subsequently, the power level is again raised to the LML pit correction power level P_{p2} during a second pit correction period 46. The period 45 again has a duration of 1.25T.

Control of the side lobes, i.e. an increase in the normal write power, during the correction periods 44, 46 is essential to ensure peak temperatures which determine the thermal cross-talk. In the case of the I5 LML pit as shown in Figure 4B, the LML pit

25 correction power level P_{p2} used for the I7 LML pit as shown in Figure 3B appeared to be inadequate to compensate for the loss in pit length. First, the power level would be too large since a power level of more than 1.1 times the write power level P_W would increase the maximum required power and the thermal cross-talk towards the preceding pit also appeared to be too much. Therefore, in the present embodiment the length of the write pulse is

30 physically increased by an LML pit increase period 47 of 0.5T during which the power level is reduced to an LML pit increase power level P_{p3} . Said LML pit increase power level P_{p3} is generally set to within a range of 0.5 to 0.9 times the power level P_W . In the specific embodiment shown here it is set to 0.9 times the write power level P_W . Increasing the pulse

length of the signal 42 enables the nominal power to be lowered, resulting in less thermal cross-talk to neighboring pits.

Figures 5 and 6 show corresponding write signals for writing lands and LML lands. Figure 5A shows a write signal 50 for writing a normal land having a runlength of $7T$. As can be seen therein, at the beginning of the bottom power irradiation period 51 the power level is set to zero and after a short period it is raised to the bottom power level P_0 . In Figure 5B a write signal 52 for writing an LML land having the same runlength of $7T$ is shown. Again, during the initial period 53 the power level is set to zero, while it is subsequently raised to the bottom power level P_0 during a first land write period 54. The power level is subsequently raised to an LML land power level P_{11} during an LML land irradiation period 55 before the power level is again lowered to the bottom power level P_0 during the second land write period 56. In order to lower the nominal power, resulting in less thermal cross-talk to neighboring pits, the pulse length of the LML land pulse, i. e. the bottom power irradiation period 51, is increased by an additional bottom power irradiation period 57 during which the power level is raised to an LML land increase power level P_{13} .

Generally speaking, the LML land power level P_{11} is set to within a range of 0.7 to 1.3 times the write power level P_w . In the specific embodiment for forming an I7 LML land the LML land power level P_{11} is set to 1.1 times the write power level P_w . The LML land increase power level P_{13} is generally set to within a range of 0.03 to 0.75 times the write power level P_w . In the embodiment shown in Figure 5B it is preferably set to 0.5 times the write power level P_w . The period 55 has a duration of $1.25T$.

Figures 6A, 6B show embodiments for forming an I5 land and an I5 LML land. The write signal 60 is shown therein for forming an I5 land which is identical to the write signal 50 shown in Figure 5A except for a shorter bottom power irradiation period 61. Figure 6B shows a write signal 62 which is also identical to the write signal 52 shown in Figure 5B except for the power levels P_{11} and P_{13} and the durations of the periods 63 to 67. In this embodiment the LML land power level P_{11} is set to 0.9 times the write power level P_w , and the LML land increase power level P_{13} is set to 0.03 times the write power level P_w . Here, the period 65 has a duration of $1T$.

The parameters described above with reference to the Figures 3 to 6 are used according to the invention to control the write signal such that there is an acceptable difference between a normal runlength modulation and its corresponding LML equivalent. When LML pits and lands have modulations which are 30% lower than the unmodified pits and lands, bit detection in the LML channel is still quite robust while the original main RLL

channel can be detected without any loss if the compensation levels are optimized correctly. Furthermore, by adjustment of these parameters enables the runlength of the pits and lands to be made equal to the unmodified case. Finally an optimization of the overall jitter, i. e. a minimization of the jitter, can be achieved.

5 A pulsed strategy can be an alternative write strategy for recordable optical media like CD-R. Pulsed strategies are known to require more power. However, the modulation level of the LML-effects appears to be very sensitive to variations in write power, particularly when using a method based on thermal balancing as explained above. When using a pulse-based strategy, this problem is mainly overcome.

10 Figure 7A shows a write signal 70 based on such a pulsed strategy for forming an I6 pit. During the write power irradiation period 71 a power level is switched five times between the write power level P_W and the bottom power level P_0 , i. e. the write signal 70 comprises five pulses 73 to form the I6 pit. Figure 7 shows a corresponding write signal 72 for forming an I6 LML pit. Said signal 72 comprises only four pulses 74, 75, i. e. the middle
15 one of the five pulses 73 shown in Figure 7A is missing. Furthermore, during the pulse periods the power level is raised to a higher level, that is, during the first two pulses 74 to a first LML pit power level P_{p11} and during the second two pulses 75 to a second LML pit power level P_{p12} . Preferably, in the present embodiment shown in Figure 7B the first LML pit power level P_{p11} is set to 1.1 times the write power level P_W and the second LML pit power
20 level P_{p12} is set to 1.15 times the write power level P_W .

Even though the invention has been explained with reference to a recordable CD (CD-R), it will be apparent to a person skilled in the art that the invention can also be applied to all other recordable or rewritable optical recording media such as rewritable CDs or DVDs like DVD-R, DVD+R, DVD-RAM. Furthermore the invention is not limited to
25 certain codes or codes underlying a certain runlength limitation. Moreover, the invention can be applied not only to pits or lands having a runlength as shown in the figures, but in general to all other runlengths as well.

CLAIMS:

1. An optical record carrier recording method for forming pits and lands by directing a radiation beam (12) onto a recording surface (21) of an optical record carrier (20), the radiation beam for each pit to be recorded being set to at least one write power level (P_w) capable of forming a pit during a write power irradiation period (31) and for each land
5 between the pits to at least one bottom power level (P_0) incapable of forming a pit during a bottom power irradiation period (51), characterized in that the bottom power level (P_0) is temporarily raised to an LML land power level (P_{l1}) during an LML land irradiation period (55) for forming an LML land, the LML land power level (P_{l1}) being close to the write power level (P_w), and that the write power level
10 (P_w) is temporarily lowered to an LML pit power level (P_{p1}) during an LML pit irradiation period (35) for forming an LML pit, the LML pit power level (P_{p1}) being close to the bottom power level (P_0).
2. An optical record carrier recording method as claimed in claim 1,
15 characterized in that the LML land power level (P_{l1}) is set to within a range of 0.70 to 1.30, in particular 0.90 to 1.1, times the write power level (P_w) and that the LML pit power level (P_{p1}) is set to within a range of 0.05 to 0.50, in particular 0.1 to 0.4, times the write power level (P_w).
- 20 3. An optical record carrier recording method as claimed in claim 1, characterized in that the LML pit irradiation period (35) is situated at least mainly in the second half of a write power irradiation period (31).
4. An optical record carrier recording method as claimed in claim 1,
25 characterized in that the LML land irradiation period (55) is situated at least mainly in the first half of a bottom power irradiation period (51).
5. An optical record carrier recording method as claimed in claim 1,

characterized in that the write power level (P_w) is temporarily raised to an LML pit correction power level (P_{p2}) during said write power irradiation period (31), the LML pit correction power level (P_{p2}) being higher than the write power level (P_0).

- 5 6. An optical record carrier recording method as claimed in claim 5,
characterized in that the LML pit correction power level (P_{p2}) is set to within a range of 1.01
to 1.30, in particular 1.01 to 1.10, times the write power level (P_w).
7. An optical record carrier recording method as claimed in claim 1,
10 characterized in that the write power irradiation period (41) is increased by an additional
write power irradiation period (47) and that the write power level (P_w) is lowered to an LML
pit increase power level (P_{p3}), the LML pit increase power level (P_{p3}) being higher than the
LML pit power level (P_{p1}).
- 15 8. An optical record carrier recording method as claimed in claim 7,
characterized in that the LML pit increase power level (P_{p3}) is set to within a range of 0.50 to
0.95 times the write power level (P_w), in particular to within a range of 0.80 to 0.90 times the
write power level (P_w).
- 20 9. An optical record carrier recording method as claimed in claim 1,
characterized in that the bottom power irradiation period (51) is increased by an additional
bottom power irradiation period (57) and that the bottom power level (P_0) is raised to an
LML land increase power level (P_{l3}), the LML land increase power level (P_{l3}) being lower
than the write power level (P_w).
- 25 10. An optical record carrier recording method as claimed in claim 9,
characterized in that the LML land increase power level (P_{l3}) is set to within a range of 0.03
to 0.70, in particular 0.03 to 0.50, times the write power level (P_w).
- 30 11. An optical record carrier recording method as claimed in claim 7 or 9,
characterized in that the additional write power irradiation period (47) and/or the additional
bottom power irradiation period (57) has a time length of 0.2 to 0.7T, in particular 0.5T or
0.25T, respectively, where T represents the time length of one period of a reference clock in a
data signal.

12. An optical record carrier recording method as claimed in claim 1,
characterized in that the LML land irradiation period (55) and/or the LML pit irradiation
period (35) has a time length of $0.5T$ to $2T$, in particular $1T$ to $1.25T$, where T represents the
5 time length of one period of a reference clock in a data signal.

13. An optical record carrier recording method as claimed in claim 1,
characterized in that for recording pits the radiation beam is set to the write power level in the
form of write pulses and that for forming an LML pit by temporarily lowering the write
10 power level at least one write pulse is left out.

14. An optical record carrier recording method as claimed in claim 13,
characterized in that the write power level of the remaining write pulses is increased.

15 15. An optical record carrier recording device for recording data in the form of
pits and lands by directing a radiation beam (12) onto a recording surface (21) of an optical
record carrier (20), the device comprising a radiation source (13) for providing the radiation
beam (12) and control means (15) for controlling the power of the radiation beam (12) such
that for each pit to be recorded the power is set to at least one write power level (P_w) capable
20 of forming a pit during a write power irradiation period (31) and for each land between the
pits the power is set to at least one bottom power level (P_0) incapable of forming a pit during
a bottom power irradiation period (51),
characterized in that the control means (15) are operative for controlling the power of the
radiation beam (12) such that the bottom power level (P_0) is temporarily raised to an LML
25 land power level (P_{ll}) during an LML land irradiation period (5) for forming an LML land,
the LML land power level (P_{ll}) being close to the write power level (P_w), and that the write
power level (P_w) is temporarily lowered to an LML pit power level (P_{pl}) during an LML pit
irradiation period (35) for forming an LML pit, the LML pit power level (P_{pl}) being close to
the bottom power level (P_0).

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16. An optical record carrier recording device as claimed in claim 15,
also comprising jitter control means (22) for measuring and minimizing the jitter by
controlling the power of the radiation beam and the duration and time lengths of the power
levels.