

METHOD OF RECORDING DATA ON AN OPTICAL RECORDING MEDIUM

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

The present invention relates to a method and apparatus for recording data on an optical recording medium, and more particularly, to a method and apparatus in which digital data is recorded on an optical disc by forming a mark on the optical disc.

10 2. Description of the Related Art

Recording data on an optical disc which is one of optical recording media means that a mark is formed on a track formed on the optical disc. A mark is formed as a pit in a read-only disc such as a Compact Disc-Read Only Memory (CD-ROM) and a Digital Versatile Disc-Read Only Memory (DVD-ROM). In a
15 recordable disc such as a CD-R/RW and a DVD-R/RW/RAM, a phase-change film which changes into a crystalline phase or an amorphous phase is formed in the recording layer, and a mark is formed by a phase change of the phase-change film.

Methods for recording data can be divided into a mark edge recording method and a mark position recording method. According to the mark position
20 recording method, the sign of the amplitude of a detected Radio Frequency (RF) signal changes from negative to positive or from positive to negative at a location on which a mark is recorded. According to the mark edge recording method, the signal of the amplitude of a detected RF signal changes from negative to positive or from positive to negative at both edges of a mark. Therefore, recording the edges
25 of a mark is an important factor in improving the quality of a reproducing signal.

However, in a disc on which a phase-changing film is coated, it is shown that the shape of a trailing edge of a mark recorded according to the prior art recording method changes according to the length of a mark or an interval between marks, i.e., the space. That is, the trailing edge of a mark is formed greater than
30 the leading edge of the mark such that the characteristics of recording/ reproducing are degraded. If a recording mark is relatively long, the characteristics are more degraded.

FIG. 1 is a reference diagram of a recording waveform according to prior art.

Referring to FIG. 1, a variety of recording waveforms (a), (b) and (c) for

recording Non Return to Zero Inverted (NRZI) data are shown. Recording waveform (a) is for a DVD-RAM, recording waveforms (b) and (c) are for a DVD-RW. Here, T denotes the cycle of a reference clock. According to the mark edge recording method, the high level of NRZI data is recorded as a mark and the low level of NRZI data is formed as a space. A recording waveform used in recording a mark is referred to as a recording pattern, and a recording waveform used in forming a space (in erasing a mark) is referred to as an erase pattern. The prior art recording waveforms (a), (b) and (c) use a multi-pulse as a recording, and the power of an erase pattern is maintained in a predetermined DC level as shown in interval E.

Since the erase pattern included in the prior art recording waveform is maintained as the DC level for a predetermined time, 0~200° C heat is applied to the corresponding area continuously. Therefore, if recording is repeated multiple times, the shape of a mark is degraded and distorted such that the characteristics of recording/reproducing are degraded. In particular, development toward high density and high line speed for recording more data on a disc makes clock cycle T shorter and therefore heat interference between pulses forming a recording waveform increases to cause more degradation.

Meanwhile, in the prior art, different recording waveforms are used according to the kinds of optical discs and the specifications such as DVD-RAM and DVD-RW, because the characteristics of recording films are different. In particular, the fact that different recording waveforms should be used for each kind of discs means a problem in manufacturing a multi-drive which can record/reproduce all specifications of discs, because the multi-drive should accommodate a variety of recording waveforms. The problem causes an increase in cost.

SUMMARY OF THE INVENTION

To solve the above problems, it is a first objective of the present invention to provide a recording method and apparatus in which the distortion of the shapes of the leading edge and trailing edge of a mark and degradation by repeated recording can be prevented.

It is a second objective of the present invention to provide a recording method and apparatus in which data is recorded by a recording waveform having an erase pattern which can improve the shape of a mark.

It is a third objective of the present invention to provide a recording method
5 and apparatus in which data is recorded by a recording waveform which can be applied to a disc having a recording film with a variety of characteristics.

To accomplish the above objectives of the present invention, there is provided a method for recording data on an optical recording medium, which includes forming a mark or a space by using a recording waveform having an erase
10 pattern containing a multi-pulse.

Preferably, data is recorded according to Run Length Limited (RLL)(2, 10), a first level of predetermined Non Return to Zero Inverted (NRZI) data is recorded as a mark, and a second level of predetermined NRZI data is recorded as a space.

Also, to accomplish the above objectives of the present invention, there is
15 provided a method for recording data on an optical recording medium, which includes (a) generating channel modulated digital data; (b) generating a recording waveform having an erase pattern containing a multi-pulse and a recording pattern; and (c) forming a first level of the digital data as a mark and forming a second level of the digital data as a space by using the generated recording waveform.

20 Preferably, steps (a) through (c) are based on Run Length Limited (RLL)(2, 10) or RLL(1, 7).

Most preferably, the power level of the leading pulse of the erase pattern is the low level of the multi-pulse and the power level of the trailing pulse is the high level of the multi-pulse. Alternatively, the power level of the leading pulse of the
25 erase pattern may be the high level of the multi-pulse and the power level of the trailing pulse may be the high level of the multi-pulse. The power level of the leading pulse of the erase pattern may be the low level of the multi-pulse and the power level of the trailing pulse may be the low level of the multi-pulse. The power level of the leading pulse of the erase pattern may be the high level of the multi-
30 pulse and the power level of the trailing pulse may be the low level of the multi-pulse.

Preferably, the ratio of the duration time of the high level and the duration time of the low level of the multi-pulse is substantially 1:1, and the duration time of the high level is half of a clock cycle.

It is effective that in step (a) the first level of predetermined NRZI data is formed as a mark, and in step (b) the second level of predetermined NRZI data is formed as a space.

The recording waveform includes a cooling pulse, and the erase pattern
5 includes a part of the cooling pulse. It is effective that if the ending time of the cooling pulse is less than or greater than $0.5T_s$ from the trailing edge of the NRZI signal, the duration time of the leading pulse forming the erase pattern increases over $0.5T_s$.

Preferably, a unit pulse constituting or included in the multi-pulse has a high
10 level and a low level that are adjusted by the duration time of the leading pulse forming the recording pattern.

Preferably, the recording pattern has at least two power levels.

Also, to accomplish the above objectives of the present invention, there is provided an apparatus for recording data on an optical recording medium, which
15 includes a recording waveform generating unit which generates a recording waveform having an erase pattern containing a multi-pulse and a recording pattern; and a pickup unit which applies lights to the optical recording medium according to the generated recording waveform so that a mark or a space is formed.

Preferably, the apparatus also includes a channel modulation unit which
20 channel modulates data provided from the outside, and outputs thus generated NRZI data to the recording waveform generating unit.

Preferably, the pickup unit includes a motor which rotates the optical recording medium; an optical head which applies laser beams to the optical recording medium or receives laser beams reflected from the optical recording
25 medium; a servo circuit which servo controls the motor and the optical head; and a laser driving circuit which drives laser device installed in the optical head.

BRIEF DESCRIPTION OF THE DRAWINGS

The above objects and advantages of the present invention will become
30 more apparent by describing in detail preferred embodiments thereof with reference to the attached drawings in which:

FIG. 1 is a reference diagram of a recording waveform according to prior art;

FIG. 2 is a block diagram of a recording apparatus according to a preferred

embodiment of the present invention;

FIG. 3 shows an example of an implementation of the recording apparatus of FIG. 2;

FIG. 4 shows an example of a waveform generated by a recording
5 waveform generating circuit;

FIG. 5 shows another example of a waveform generated by the recording waveform generating circuit;

FIGS. 6a through 6d are waveforms for explaining four types of erase patterns according to a preferred embodiment of the present invention;

10 FIGS. 7e and 7f are other examples of LH of FIG. 6a;

FIGS. 8 through 10 are shapes of marks recorded in a simulation;

FIGS. 11 through 15 are graphs showing the characteristics of a DVD-RAM;

FIGS. 16 through 20 are graphs showing the characteristics of a DVD-RW;

and

15 FIG. 21 is a flowchart showing a recording method according to a preferred embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 2 is a block diagram of a recording apparatus according to a preferred
20 embodiment of the present invention. Referring to FIG. 2, the recording apparatus which forms a mark on an optical recording medium 200 has a pickup unit 1, a recording waveform generating circuit 2, and a channel modulation unit 3.

The channel modulation unit 3 modulates data which is input from the outside into a channel bit stream. The recording waveform generating unit 2
25 receives the channel bit stream and generates a recording waveform for recording the received channel bit stream. The recording waveform generated according to the present invention has an erase pattern having an erase multi-pulse. The waveform will be explained later. The pickup unit 1 applies light to the optical recording medium 1 according to the generated recording waveform so as to form a
30 mark or a space.

FIG. 3 shows an example of an implementation of the recording apparatus of FIG. 2. The same blocks will be indicated by the same reference numerals and the same explanation will be omitted.

Referring to FIG. 3, the recording apparatus includes a pickup unit 1, a

recording waveform generating circuit 2, and a channel modulator 3. The pickup unit 1 has a motor 11 for rotating an optical disc 200, an optical head 13 for receiving laser light reflected onto the optical disc 200, a servo circuit 12 for servo control, and a laser driving circuit 14 for driving a laser device (not shown) installed
5 in the optical head 13.

The channel modulator 3 modulates input data into a channel bit stream, and outputs NRZI data. The recording waveform generating circuit 2 generates a recording waveform for recording NRZI data and provides the recording waveform to the laser driving circuit 14.

10 The laser driving circuit 14 forms a mark or a space by controlling laser with using the received recording waveform.

FIG. 4 shows an example of a waveform generated by a recording waveform generating circuit.

Referring to FIG. 4, NRZI data changes according to a modulation method
15 of the channel modulator 3. That is, if the modulation method is a Run Length Limited (RLL)(2, 10) series method, that is, according to Eight to Fourteen Modulation (EFM), Eight to Fourteen Modulation plus (EFM+), D(8-15), and Dual modulation, the minimum mark length is $3T_s$ and the maximum mark length is $11T_s$. Here, D(8-15) is a modulation method disclosed in "Optical Disc Recording System
20 of 25GB Capacity" announced by Matsushita in Optical Data Storage (ODS) 2001. Dual modulation is disclosed in Korea Patent Application No. 99-42032 "An RLL code allocation method, modulation and demodulation method, and demodulation apparatus having improved DC controlling capability," filed by the present applicant on 30, September, 1999, and laid open on 25, November, 2000. If data is
25 recorded using an RLL(1, 7) series method, the minimum recording mark is $2T_s$, and the maximum recording mark is $8T_s$.

When a high level is formed as a mark and a low level is formed as a space in NRZI data, the recording waveform include a recording pattern for recording a mark of a $7T$ length, an erase pattern for forming a space of a $3T$ length, and a
30 recording pattern for recording a mark of a $3T$ length.

The recording pattern is composed of a pulse train. Also, the erase pattern is formed with a pulse train as shown in interval F. T_{mp} indicates the width of a multi-pulse forming a recording pattern. Here, the multi-pulse indicates at least one pulse having the same width and power. In the present embodiment,

Tmp is $0.5T_s$. Tlp indicates the width of the last pulse forming a recording pattern. Tcl indicates the width (duration time) of a cooling pulse. The cooling pulse extends from a recording pattern to an erase pattern. Temp indicates the width of an erase multi-pulse forming an erase pattern. In the present embodiment, Temp is $0.5T_s$. Tsfp indicates a period from a point when NRZI data is transited from a low level to a high level to a point (start of first pulse) when a first pulse forming a recording pattern starts. Tsfp has an influence over the power level of an erase pattern. That is, as shown in FIG. 4, if Tsfp is greater than $0.5T_s$ and a multi-pulse contained in an erase pattern ends at low level Pb1, the next Tsfp starts from high level Pb2 of the multi-pulse. Meanwhile, if Tsfp is less than $0.5T_s$ and a multi-pulse contained in an erase pattern ends at low level Pb1, the next Tsfp maintains low level Pb1 of the multi-pulse.

FIG. 5 shows another example of a waveform generated by the recording waveform generating circuit.

Referring to FIG. 5, when the high level of NRZI data is formed as a mark, and the low level is formed as a space, the recording waveform includes a recording pattern for recording a mark of a $7T$ length, an erase pattern for forming a space of a $5T$ length, and a recording pattern for recording a mark of a $3T$ length.

The recording pattern is composed of a pulse train. Also, the erase pattern is formed with a pulse train as shown in interval G. Tmp indicates the width of a multi-pulse forming a recording pattern. Here, the multi-pulse indicates at least one pulse having the same width and power. In the present embodiment, Tmp is $0.5T_s$. Tlp indicates the width of the last pulse forming a recording pattern. Tcl indicates the width (duration time) of a cooling pulse. The cooling pulse extends from a recording pattern to an erase pattern. Temp indicates the width of an erase multi-pulse constituting an erase pattern. In the present embodiment, Temp is $0.5T_s$. Tsfp indicates a period from a point when NRZI data is transited from a low level to a high level to a point (start of first pulse) when a first pulse constituting a recording pattern starts. Tsfp has an influence over the power level of an erase pattern. That is, as shown in FIG. 4, if Tsfp is greater than $0.5T_s$ and a multi-pulse contained in an erase pattern ends at low level Pb1, the next Tsfp starts from high level Pb2 of the multi-pulse. Meanwhile, if Tsfp is less than $0.5T_s$ and a multi-pulse contained in an erase pattern ends at low level Pb1, the next Tsfp maintains low level Pb1 of the multi-pulse.

FIGS. 6a through 6d are waveforms for explaining four types of erase patterns according to a preferred embodiment of the present invention.

Referring to FIGS. 6a through 6d, the erase patterns according the present invention are divided into four types: (a) LH, (b) HH, (c) HL, and (d) LL. The differences of erase patterns are marked by circles so that the differences can be easily understood. First, (a) LH indicates that the power of the leading pulse forming an erase pattern is the same as the low level Pb1 of the following erase multi-pulse and after the last erase multi-pulse forming the erase pattern ends at the low level Pb1, the power level of the following Tsfp is the same as the high level Pb2 of the erase multi-pulse. (b) HH indicates that the power of the leading pulse forming an erase pattern is the same as the high level Pb2 of the following erase multi-pulse and after the last erase multi-pulse forming the erase pattern ends at the high level Pb2, the level of the following Tsfp continues to be as the high level Pb2 of the erase multi-pulse. (c) HL indicates that the power of the leading pulse forming an erase pattern is the same as the high level Pb2 of the following erase multi-pulse and after the last erase multi-pulse forming the erase pattern ends at the high level Pb2, the level of the following Tsfp is the same as the low level Pb1 of the erase multi-pulse. Finally, (d) LL indicates that the power of the leading pulse forming an erase pattern is the same as the low level Pb1 of the following erase multi-pulse and after the last erase multi-pulse forming the erase pattern ends at the low level Pb1, the level of the following Tsfp continues to be as the low level Pb1 of the erase multi-pulse.

FIGS. 7e and 7f are other examples of LH of FIG. 6a. Referring to FIGS. 7e and 7f, (e) LH2 is the same as (a) LH of FIG. 6, except that Temp1, the duration time of the high level Pb2 of an erase multi-pulse forming a cycle, is $0.7T_s$ and Temp2, the duration time of the low level Pb1 of the erase multi-pulse, is $0.3T_s$. Also, (f) LH3 is the same as (a) LH of FIG. 6, except that the duration time of the high level Pb2 or the low level Pb1 of the erase multi-pulse is $1.0T$. Here, the ratio of Temp1 and Temp2, that is, the ratio of the duration time of the high level Pb2 and that of the low level Pb1 of the erase multi-pulse forming a cycle can be changed as m:n in a variety of ways. (Here, m, n are integers.) Thus, the recording waveform according to the present invention has an erase pattern containing an erase multi-pulse of which power is high level Pb2 or low level Pb1, and therefore distortion of the trailing edge of a mark is prevented and the characteristic of reproducing is

improved. In particular, in the recording waveforms shown in the embodiments described above, the duration time of the high level Pb2 and the low level Pb1 of the erase multi-pulse is adjusted within a scope between $0.25T_s$ and $0.75T_s$ for clock cycle T , and a duration time appropriate to the heat characteristic of the disc 5 200 is selected. Therefore, the characteristic of reproducing is more improved.

Meanwhile, information on the four types of erase patterns (type information) may be recorded in a lead-in area of a recordable disc or may be included in a wobble signal as one of header information items. In this case, when data is recorded, recording apparatus reads type information from the lead-in area 10 or from the wobble signal, and forms a mark or a space by generating a corresponding waveform.

In addition, the four types of erase patterns may be used as a symbol indicating X times speed of a disc or the kind of a mark when data is recorded and reproduced. For example, the erase pattern may indicate information, "the speed 15 of a disc using LH type erase pattern is 20-multiple times speed."

In order to test the effect of the present invention, the shapes of a mark recorded in a simulation was observed. The structure used in the simulation is shown in table 1. The disc used in the simulation has a 4-layered film structure.

20

Table 1

	Substrate	Dielectric film	Recording film	Dielectric film	Reflecting film
Material	PC	ZnS-SiO ₂	Sb-Te eutectic	ZnS-SiO ₂	Ag alloy
Thickness	0.6mm	128nm	14nm	16nm	30nm

The conditions of the simulations includes a wavelength of 405nm, the Number of Apertures (NA) 0.65, and a linear velocity of 6 m/s. In order to observe the shape of a mark, after a recording mark of 8T is recorded, the next recording 25 mark of 8T is recorded by overlapping 4T of the previous recording mark of 8T. FIGS. 8 through 10 show the comparison results of the mark shapes when the prior art recording waveform was used and the mark shapes when the recording waveform according to the present invention was used. In FIG. 8, (a) shows a mark formed by the simulation, (b) shows a mark formed on (a) by a recording 30 waveform according to the present invention, and (c) shows a mark formed on (a)

by the prior art recording waveform. Likewise, in FIG. 9, (d) shows a mark formed by the simulation, (e) shows a mark formed by a recording waveform having a erase pattern according to the present invention, and (f) shows a mark formed by a recording waveform having the prior art DC erase pattern. In FIG. 10, (g) shows a mark formed by the simulation, (h) shows the result of erasing the mark of (g) by the erase pattern according to the present invention, and (i) shows the result of erasing the mark of (g) by the prior art DC erase pattern.

Table 2 shows the parameters of thin films used in a simulation for interpreting heat.

10

Table 4

Material	$\lambda = 405\text{nm}$		C(J/cm ³ K)	k(W/cmK)
	n	K		
ZnS-SiO ₂	2.300	0.000	2.055	0.0058
Sb-Te eutectic (Crystal)	1.650	3.150	1.285	0.0060
Sb-Te eutectic (Amorphous)	2.900	2.950	1.285	0.0060
Ag alloy	0.170	2.070	2.450	0.2000

Referring again to simulation results of FIGS. 8 through 10, it is shown that the trailing edge of the mark formed by the recording waveform having the erase pattern according to the present invention of (b) of FIG. 8 is better than the trailing edge of the mark formed by the recording waveform having the prior art DC erase pattern of the prior art method of (c) of FIG. 8. Like the trailing edges, the shape of the leading edge of the mark is better when the erase pattern according to the present invention is used as shown in FIG. 9. The results of the simulation shows that the shape of a mark when the recording waveform having the erase pattern formed with the erase multi-pulse is used is improved compared to the prior art. By adjusting the shape, width, and power level of the erase multi-pulse, distortion of the shape of a mark can be more reduced.

In order to experimentally verify the effect of the present invention, parameters needed in obtaining the recording waveforms shown in FIGS. 4 and 5, that is, the duration time and the power level, were obtained from 4.7GB DVD-RAM and 4.7GB DVD-RW disc, using a DVD evaluator of which the laser wavelength is 650nm and NA is 0.60. Then, the characteristics of repetitive

recording/reproducing according to the present invention were compared with the prior art method.

FIGS. 11 through 15 are graphs showing the characteristics of the DVD-RAM. FIGS. 11 through 13 show the features of power and time of recording using a recording waveform with a DC erase pattern of prior art, and FIGS. 14 and 15 show improved features of recording using a recording waveform of the present invention. In FIG. 11, (a) and (b) show jitter characteristics with respect to recording power and erase power, respectively, for the leading edge, trailing edge, and both edges of a mark in the prior art DC erase. Based on (a) and (b), 14.5mW recording power and 6mW erase power were selected for experiments.

FIGS. 12 and 13 show the measured results in the prior art DC erase.

Referring to (a), (b), and (c) of FIG. 12 and (a) and (b) of FIG. 13, the most preferable jitter characteristics are shown when $T_{sfp} = 0.5T_s$ and when $T_{sfp} = 0.4T_s$. T_{le} didn't affect the jitter characteristics, and T_{lp} was good when the cycle is $0.7T_s$.

Based on the parameters experimentally obtained in this way, a mark was formed with the recording waveform having the four types of erase patterns described above, and the characteristics of the formed mark were measured as the following.

FIG. 14 shows the jitter characteristics of the four types according to the present invention shown in FIG. 6.

Referring to FIG. 14, it can be inferred that a jitter characteristic is good when recording using a recording waveform with an erase pattern, i.e., any one of four types of erase pattern shown in FIG. 6, of the present invention. Especially, referring to (a) of FIG. 14, it is shown that LH type is the best among the four types. Referring to (b) of FIG. 14, when the erase pattern formed with the erase multi-pulse according to the present invention is used in erasing a mark, the jitter characteristics of $\Delta Pb(Pb2 - Pb1)$ which is the difference between the high level and low level of the erase multi-pulse is shown. It is shown that up to 5mW there are no big difference.

FIG. 15 shows the jitter characteristics of the results of repetitive recording/reproducing using the recording waveform having the erase pattern according to the present invention compared to prior art.

Referring to FIG. 15, it is easily understood that when a mark is erased using the erase multi-pulse according to the present invention, the result is good,

especially in the repetitive recording characteristics aspect.

FIGS. 16 through 20 are graphs showing the characteristics of the DVD-RW. FIGS. 16 through 18 show the features of power and time of recording using a recording waveform with a DC erase pattern of prior art, and FIGS. 19 and 20 show improved features of recording using a recording waveform of the present invention.

In FIG. 16, (a) and (b) show jitter characteristics with respect to recording power and erase power, respectively, for the leading edge, trailing edge, and both edges of a mark in the prior art DC erase. Based on (a) and (b), 14.0mW recording power and 6mW erase power were selected.

FIGS. 17 and 18 show the measured results in the prior art DC erase.

Referring to FIGS. 17 and 18, the most preferable jitter characteristics are shown when $T_{sfp} = 0.3T_s$ and when $T_{sfp} = 0.05T_s$. T_{le} was good in $0.55T_s$, and T_{lp} was good in $1.0T$ and $1.1T_s$.

Based on the parameters experimentally obtained in this way, a mark was formed with the recording waveform having the four types of erase patterns described above, and the reproducing characteristics of the formed mark were measured as the following.

FIG. 19 shows the jitter characteristics of the four types shown in FIG. 6.

Referring to FIG. 19, it is shown that LH type is the best among the four types. When the erase pattern formed with the erase multi-pulse according to the present invention is used in erasing a mark, the jitter characteristics of $\Delta Pb(Pb2 - Pb1)$ which is the difference between the high level and low level of the erase multi-pulse is shown. Since the characteristics are suddenly degraded from 3mW, 1mW was selected as the condition for the repetitive recording/reproducing experiment.

FIG. 20 shows the jitter characteristics of the results of repetitive recording/reproducing using the recording pulse having the erase pattern according to the present invention.

Referring to FIG. 20, it is easily understood that when a mark is erased using the erase multi-pulse according to the present invention, the result is good, especially in the repetitive recording characteristics aspect. However, the jitter characteristics were suddenly degraded from 2,000 times. Therefore, it is shown that the pulse erase method according to the present invention is advantageous up to 1,000 times repetitive recording that is guaranteed in the normal DVD-RW.

Meanwhile, the above experiments followed the DVD formats and therefore

the EFM+ modulation method was used. However, if any of other modulation methods that are normally used, for example, RLL(1, 7), D(8 - 15), and Dual modulation, is used, the result will be the same.

A recording method according to a preferred embodiment of the present invention based on the structure described above will now be explained.

FIG. 21 is a flowchart showing a recording method according to a preferred embodiment of the present invention.

Referring to FIG. 21, the recording apparatus receives data from the outside, modulates the data, and generates NRZI data in step 1801. Then, the recording apparatus generates a recording waveform having an erase pattern containing an erase multi-pulse in step 1802. Using the generated recording waveform, a mark or a space is formed on the optical disc 200 in step 1803.

As described above, according the present invention, a method and apparatus for recording data in which the recording waveform which prevents distortion of the shape of a mark due to heat interference and heat accumulation when data is recorded and improves the shape of the mark is used are provided so that the characteristics of recording/reproducing are improved.

What is claimed is:

1. A method of recording data on an optical recording medium, the method comprising:

generating channel modulated digital data;

generating a recording waveform having an erase pattern containing a multi-pulse having a high level and a low level and a recording pattern in response to the channel modulated digital data; and

forming a first level of the channel modulated digital data as a mark and forming a second level of the channel modulated digital data as a space by using the generated recording waveform,

wherein the generating of the recording waveform comprises causing a power level of a leading pulse of the erase pattern to be the high level or the low level of the multi-pulse and a power level between the end of the erase pattern and start point of a leading pulse of the recording pattern to be the high level or the low level of the multi-pulse.

2. The method of claim 1, wherein the generating of the channel modulated digital data comprises:

performing a Run Length Limited (RLL)(2, 10) method.

3. The method of claim 1, wherein the generating of the channel modulated digital data comprises:

performing a Run Length Limited RLL(1, 7) method.

4. The method of claim 1, wherein the generating of the recording waveform comprises:

causing a power level of a leading pulse of the erase pattern to be a low level of the multi-pulse and a power level of a trailing pulse of the erase pulse to be a high level of the multi-pulse.

5. The method of claim 1, wherein the generating of the recording waveform comprises:

causing a power level of a leading pulse of the erase pattern to be a high level of the multi-pulse and a power level of a trailing pulse to be a high level of the multi-pulse.

6. The method of claim 1, wherein the generating of the recording waveform comprises:

causing a power level of a leading pulse of the erase pattern to be a low level of the multi-pulse and a power level of a trailing pulse to be a low level of the multi-pulse.

7. The method of claim 1, wherein the generating of the recording waveform comprises:

causing a power level of a leading pulse of the erase pattern to be a high level of the multi-pulse and a power level of a trailing pulse to be a low level of the multi-pulse.

8. The method of claim 1, wherein the generating of the recording waveform comprises:

causing a ratio of a duration time of a high level and another duration time of a low level of the multi-pulse to be substantially 1:1.

9. The method of claim 8, wherein the generating of the recording waveform comprises:

causing the duration time of the high level to be half a clock cycle.

10. The method of claim 8, wherein the generating of the recording waveform comprises:

causing the ratio of the duration time of the high level and the duration time of the low level of the multi-pulse to be $m:n$ where m and n are integers.

11. The method of claim 1, wherein the generating of the channel modulated digital signal comprises:

forming a first level of an NRZI data signal as the mark and a second level of the NRZI data signal as the space.

12. The method of claim 11, wherein the generating of the recording waveform comprises:

forming the cooling pulse as a part of the erase pattern.

13. The method of claim 12, wherein the generating of the recording waveform comprises:

upon determining whether an ending time of the cooling pulse is less than or greater than $0.5T_s$ from a trailing edge of the NRZI data signal, causing a duration time of a leading pulse forming the erase pattern to be over $0.5T_s$.

14. The method of claim 13, wherein the generating of the recording waveform comprises:

forming a unit pulse of the multi-pulse to have a high level and a low level that are adjusted by the duration time of the leading pulse forming the recording pattern.

15. The method of claim 1, wherein the generating of the recording waveform comprises:

forming the recording pattern having at least two power levels.

16. A method of recording data on an information storage medium, the method comprising:

generating channel modulated digital data;

generating a recording waveform comprising a recording pattern, an erase pattern having a multi-pulse having a high level and a low level, and a cooling pulse concatenating the recording and erase patterns, in response to the channel modulated digital data; and

forming a first level of the channel modulated digital data as a mark and forming a second level of the channel modulated digital data as a space by using the generated recording waveform,

wherein the generating of the recording waveform comprises causing a power level of a leading pulse of the erase pattern to be the high level or the low level of the multi-pulse and a power level between the end of the erase pattern and start point of a leading pulse of the recording pattern to be the high level or the low level of the multi-pulse.