Vol 12 No 11, November 2003
1009-1963/2003/12(11)/1241-05
Chinese Physics
© 2003 Chin. Phys. Soc.
and IOP Publishing Ltd

Multilevel optical data recording methods on phase-change media*

Xiao Jia-Xi(肖家曦), Qi Guo-Sheng(齐国生), She Peng(佘 鹏),
Liu Rong(刘 嵘), and Xu Duan-Yi(徐端颐)

Optical Memory National Engineering Research Center, Department of Precision Instrument and Mechanics, Tsinghua University, Beijing 100084, *China*

(Received 6 September 2003; revised manuscript received 30 September 2003)

Multilevel data storage (ML) is a new method in the optical storage field, which is also a trend for improving the capability of future optical discs. This article introduces several ML methods based on phase-change media including pit depth modulation (PDM) and mark radial width modulation (MRWM). In addition, some disadvantages and advantages concerning the principle of these methods will be discussed. Finally, a new ML method will be advanced, through which the levels in one recording pit will be increased evidently.

Keywords: multilevel optical data storage, phase-change media
PACC: 4230N, 4240H

1. Introduction

For a conventional disc, binary coding is widely used, in which mark and null states are realized by the high and the low levels of reflected light, which means that each mark length corresponds to one bit. To increase the density of the recorded information many technologies are used, such as near-field technology and blue-ray storage technology. But the ultimate intention of these methods is to minimize the size of the recording marks limited by the optical diffraction radius

$$r = k\frac{\lambda}{NA}. \tag{1}$$

The result is that one mark length still corresponds to one bit. Multilevel data storage (ML) can increase the spatial density of recorded information beyond that gained by the above technologies. ML always utilizes the large difference in refractive indices between the amorphous and crystalline states, so that each recording region corresponds to a different reflectance, then multiple levels are achieved. Using ML each recording region can correspond to

$$B = \log_2 M \tag{2}$$

bits (B is the number of recording bits, M is the number of levels). Therefore, the effective length for one bit will be much shorter than the actual mark length. Additionally this technology has the advantage of increasing the recording density without extensively altering the current optical configuration.

2. Principle and methods for multilevel optical data storage

The first ML method introduced here is called pit depth modulation (PDM).[1] This method works on CD-ROM systems to achieve a multilevel reflectivity response by varying pit depth from zero to approximately 1/4-wavelength depth in the medium, as shown in Fig. 1.

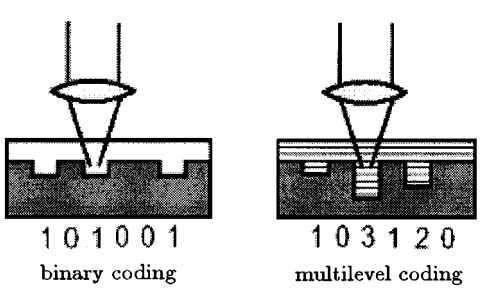


Fig.1. The principle of PDM.

*Project supported by the State Key Development Program For Basic Research of China (Grant No 19990330).

Actually, the PDM process is pit "volume" modulation. Proof of the feasibility of this technology has been demonstrated on DVD-ROM as well.

To develop rewritable ML discs, some techniques which can realize this ability are being studied. Ohta and Nishiuchi,[2] demonstrated a rewritable ML technology, that is, the mark radial width modulation (MRWM). As we know, there are two stable states in a phase-change material: the crystalline state and the amorphous state. The signal output comes from the difference in optical reflectivity between the amorphous and the crystalline states. According to this theory, we can subdivide the large signal output into multilevel signals on a phase-change optical disc using different mark radial widths.

High laser power irradiation P_ω forms amorphous marks and medium laser power P_e (around half the level of P_ω) crystallizes the amorphous marks on the phase-change optical disc. The idea of MRWM recording is to assign a specific laser pulse width and power level to each mark level to acquire different mark radial widths, then multilevel can be realized. Otherwise, the overwriting performance can be achieved by modulating the laser power between the P_ω and P_e levels.

Figure 2 shows an outline diagram of MRWM recording marks on a phase-change optical disc. The mark radial widths are 1/3, 2/3, 1 for level 1, level 2 and level 3 respectively, while the assigned laser power is low for level 1 mark and the assigned laser pulse width is long for this mark.

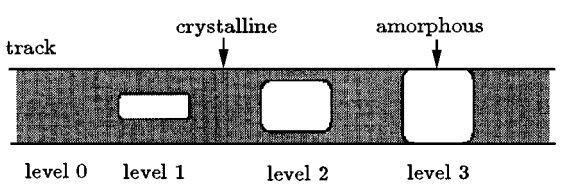


Fig.2. Outline diagram of MRWM 4-level recording on a phase-change optical disc.

The remarkable virtue of this technology is that it has a high C/N ratio because it uses low power laser and long pulse width to create low level marks. This measure can avoid the decrease in C/N ratio and can improve the poor recording stability.

In a word, MRWM realizes ML by controlling the molten area size with write power and duration. Different from MRWM, mark size modulation on a growth-dominant phase-change material realizes multilevel by controlling the cooling pulse duration.[3]

The principle of this method is that several reflectivity levels could be attributed to crystallization ratio or amorphous mark size in the recording layer of conventional GeTe-Sb_2Te_3 alloy, which is called a growth-dominant (GD) material. In a GD material the size of amorphous mark can be formed via two factors: one is the molten area and the other is the speed of re-crystallization which can occur below the melting point. The melting process and the re-crystallization process occur simultaneously and competitively. For this reason we can intentionally enhance the re-crystallization ability of the recording layer so that it can overcome competing amorphization, and then the molten area can be completely re-crystallized by consecutive irradiation of the write power P_ω without a cooling pulse. This enhanced re-crystallized behaviour in a GD material is utilized to realize precise amorphous mark-size control for multilevel reflection modulation where the amorphous mark size is controlled not by molten area but by re-crystallized area.

In Fig.3 the lower-half area of the oscilloscope screen shows a diagram of light intensity modulation as a function of time, while the upper-half shows the reflectivity change ($R_{\rm top}$) caused by each light intensity modulation. P_ω is basically the continual irradiation to melt the recording layer with an intermission for a cooling pulse period of τ_b at time t, when the cooling power P_b irradiates to implement a cooling rate high enough for amorphization. With varying the duty ratio of $\frac{\tau_b}{T}$, the size of the mark will be different and the "$R_{\rm top}$" will present multilevel.

Figure 4 gives an explanation for all the steps of forming a mark.

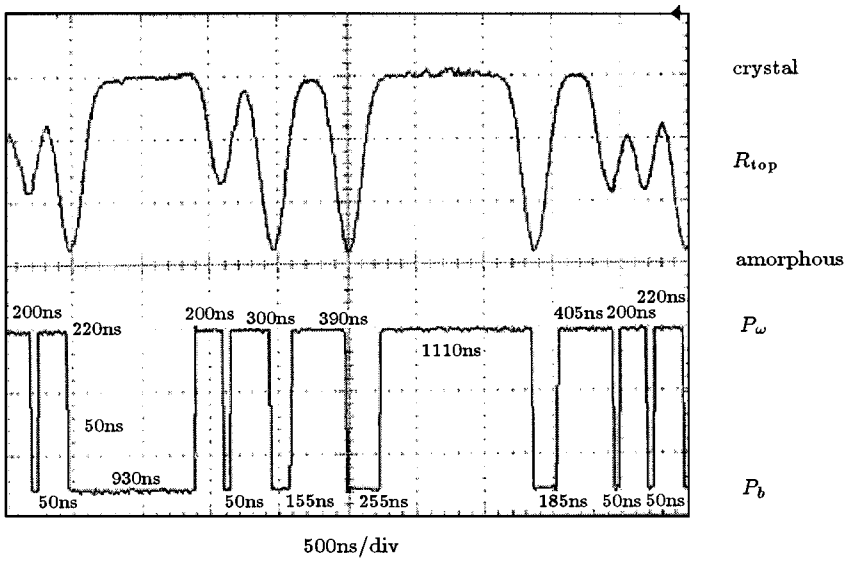


Fig.3. ML recording by cooling pulse duration control.

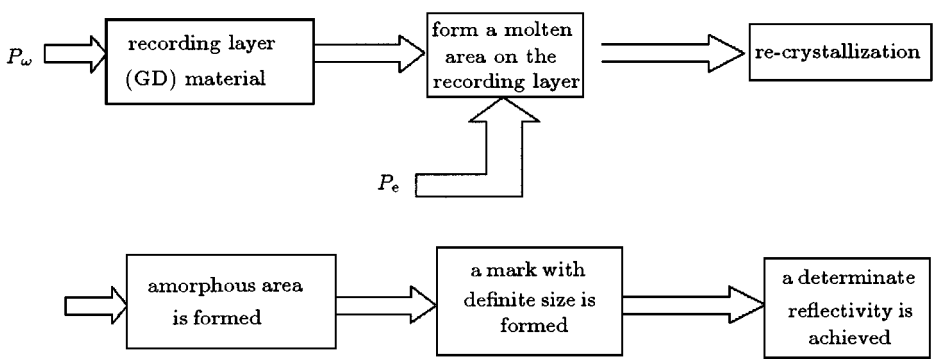


Fig.4. The steps of the mark-size modulation process.

3. A new method for multilevel recording on Phase-change optical discs

In this section a new four-level recording phase-change discs using three recording layers will be discussed.

Figure 5 shows the structure of the disc, which is composed of treble recording layers.[4] The active layers, which are in the same laser depth of focus, are composed of phase-change material (the grey layers). Four dielectric layers are used to control the optical reflectance and the thermal properties of the four-level disc. The total reflectance of the disc varies when the recording layers are in the different phases: amorphous state or crystalline state, or they are of different re-crystallized areas.

At first all the recording layers are initialized to the crystalline state. In the recording process the laser beam is incident on the substrate. By controlling the laser power the temperature of each layer varies, and marks can be chosen to make on any of the three recording layers. If the four recording regions on the second and third layers can be written in four states: AA, AC, CC, CA ("A" is an amorphous state, and "C" is a crystalline state) and the state of the first recording layer is the same, we can obtain four different reflectance: RAA, RAC, RCC, RCA. But there is a difficulty in obtaining a CA state by controlling the power of the layers because most of the energy is absorbed by the upper two recording layers, and the temperature of the irradiated region of the upper two recording layers is higher than that of the third layer. That means when the state of the third layer is A, the states of the upper two layers must be A. This is

also the reason why the first recording layer is used. Through the three recording layers we can have four recording regions by directly modulating the writing power. Then the four recording regions of CCC, ACC, AAC, AAA which correspond to different reflectance, RCCC, RACC, RAAC, RAAA, respectively, can be formed. Furthermore, if we can combine this technique with mark size modulation on a GD material, the amorphous marks of the four recording regions will be of different re-crystalline size, through which we can realize more than four levels (as shown in Fig.6 (a)). If this ML method comes true, it will be very attractive. The name of the new ML modulation is given as amorphous and crystalline marks on growth-dominant (ACGD) material.

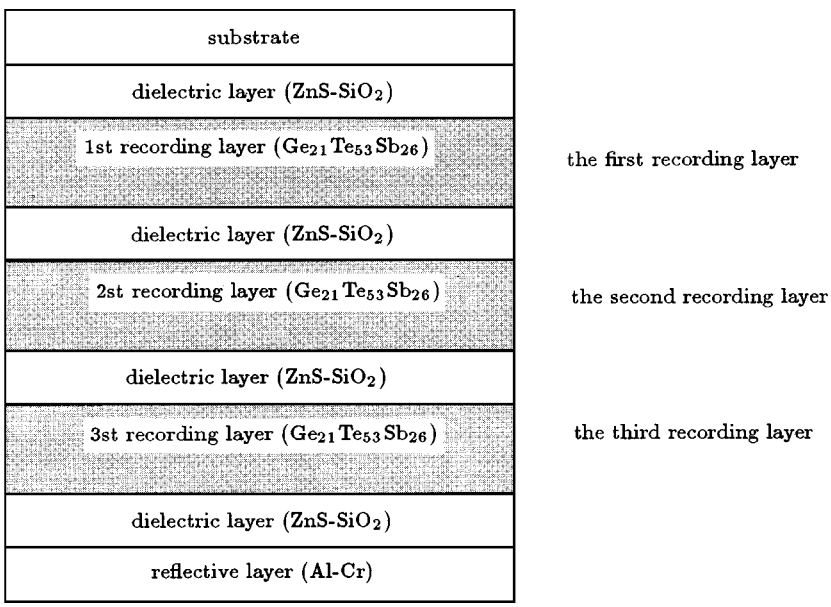


Fig.5. Four-level disc structure using three recording regions.

The writing strategy of ACGD method will be discussed as follows.

All of the recording layers are made of the same GD material. First we use a high laser power $P_{\omega 1}$ so that the temperature of the irradiated regions of the three recording layers are beyond the melting point and amorphous marks are recorded on all of the three recording layers, and we obtain the AAA state. At a lower laser power $P_{\omega 2}$ the temperature of the irradiated region of the upper two recording layers are still beyond the melting point, but that of the third recording layer is not, hence its crystalline state cannot be transformed to amorphous state, thus the marks are only recorded on the upper two recording layers and we have the AAC state. At a further lower laser power $P_{\omega 3}$ the temperature of the irradiated region of the first recording layers remains beyond its melting point, but that of the lower two recording layers are not, thus the marks are only recorded on the first recording layer, this time we may have the ACC state. At the lowest write laser power $P_{\omega 4}$, neither of the three recording layers will record, so the CCC state is formed.

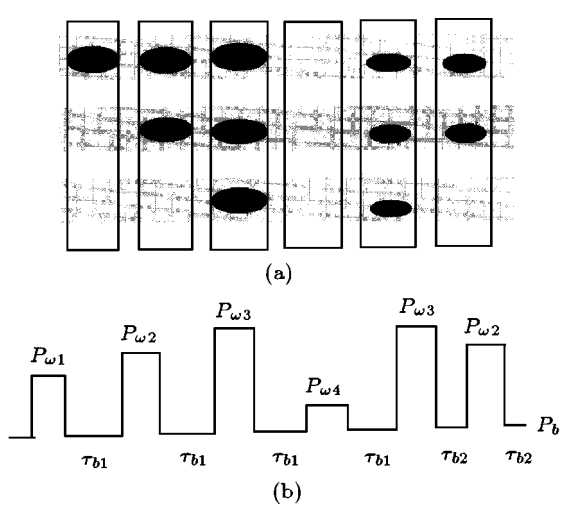


Fig.6. (a) recording marks of ACGD, (b) writing pulses of ACGD.

Besides the steps referred to, the cooling pulses of different duration τ_b with a power of P_b must be combined to control the re-crystallized area (the writing

pulses are shown in Fig.6 (b).) According to the principle of mark size modulation on a GD phase-change material, when the duty ratio of $\frac{\tau_b}{T}$ varies, the size of the marks will be different and the "$R_{\rm top}$" will present multilevel. With the different laser powers P_ω we can choose to record marks on different layers and with the different duty ratio of $\frac{\tau_b}{T}$ we can record marks with different areas. Then combining these two factors to control the recording marks, we can realize ACGD ML recording.

As an ideal result of ACGD we can make more than four levels in each mark length, and hence this method can improve the capability of optical data storage evidently. Though there are still many problems in this method like encoding, writing strategy, etc, it is a promising method for practical application.

References

[1] Hirofumi Haeiwa and Hisao Nakashima 2002 *Jpn J. Appl. Phys.* **41** 4841

[2] Takeo Ohta and Kenichi Nishiuchi 2000 *Jpn J. Appl. Phys.* **39** 770

[3] Kenjirou Kiyono and Michikazu Horie 2001 *Jpn J. Appl. Phys.* **40** 1855

[4] Han-Ping D. Shieh and Yen-Lin Chen 2001 *Jpn J. Appl. Phys.* **40** 1850