J. Magn. Soc. Japan, 25, 441–444 (2001)

Burst Cutting Area (BCA) Technology, A Recording Method for Disc Unique ID on ROM type DVD Disc

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(Received October 20, 2000; Accepted December 21, 2000)

Abstract- A new method for recording tamper-resistant and disc unique information to each ROM disc is proposed. A pulsed beam of the CW-Q switch type YAG laser is irradiated to a ROM disc. A laser spot is formed like a rectangular shape on a reflective film of the disc and removes it to form a stripe of 10μm width overlapping on pre-pits. By forming a series of the stripe on the disc circumference according to the phase encoded signal, 188-bytes information can be recorded. The recording method has been adopted as BCA (Burst Cutting Area) in the DVD standards [1].

Key words: Optical Disc, BCA, YAG, DVD, ROM, Disc ID, Tamper, Tamper-resistance

1. Introduction

Read-only type optical discs such as Compact discs are spread widely because they are mass-produced at low cost by using a stamper. On the other hand, since ROM discs are easily produced from a stamper, illegal copies or unauthorized use of contents is the matter. In the background of growing number of illegal copies or unauthorized use of contents, the protection technology of copyright and security become more important. To protect the copyright of contents and maintain the security, it is required to record identification information such as the ID of the credit cards for identifying the individual disc. However, aluminum film is generally used for information layer of Read only type optical disc, it has been difficult and not practical to record the unique ID information in the information layer. We have developed a new recording technology of the unique ID information on a completed disc by using YAG laser of short pulse width. And we successfully established the mass production technology.

Requirements for Disc unique ID are summarized as follows.

(1) Tamper-resistance of ID (over 128bytes for cipher)
(2) Same durability as disc
(3) No additional process after recording
(4) Production cycle of 4 seconds or less
(5) No extra parts at drive side (readable with a pickup)
(6) Non-recordable with a user drive.

Conventional Disc unique ID recording method for re-writable disc, write once disc, or single-substrate type ROM disc, all of them, do not necessarily satisfy whole above required items[2]. In this paper we propose a tamper-resistant new recording method called Burst Cutting Area (BCA) technology for bonded type ROM discs such as DVD. Table 1 shows the specification of BCA, the data capacity, the location and the modulation method.

2. Outline of BCA

BCA is the area in which unique information is recorded by partially removing the Al-alloy reflective film on DVD disc. BCA is recorded using YAG laser, the laser spot is formed like a rectangular shape, and the marks are formed as stripe. Figure 1 shows the location of BCA, formed along the innermost circumference of a DVD disc as barcode like form. Figure 2 shows the readout signal waveform of both BCA and the pre-pits by using a conventional optical head. The intensity of reflected light drops nearly to zero level in the stripe region, and is different from the signal reproducing an ordinary pre-pit. Accordingly, the waveform from the BCA area shows larger amplitude and longer period and the pre-pits shows the conventional signal waveform. The BCA signal can be easily distinguished from the pit signal of DVD.

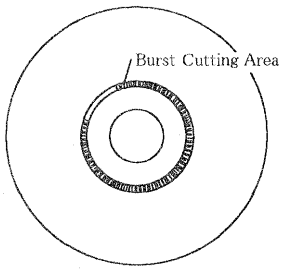

Fig.1 Appearance of BCA (188 bytes)

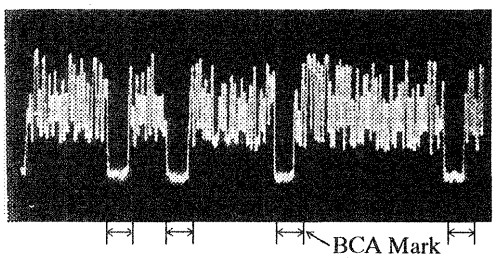

Fig.2 Waveform of BCA signal

Table 1 Specification of BCA

Capacity	Min.12 bytes, Max.188 bytes
Location of BCA	Between 22.3 (+0, -0.4)mm 23.5 (±0.05)mm
Modulation method	RZ recording after Phase Encoding (PE)
Error Correction Code	Reed Solomon type

3. Results of BCA recording experiment

BCA recording was experimented by using a test apparatus. Results and consideration of the experiment is described below.

3.1 Sample preparation

Sample disc has a four-layer structure comprising a 0.6 mm transparent substrate of polycarbonate, a 50nm reflective film of Al-alloy, a 50μm adhesion layer of acrylic UV curable resin, and a 0.6 mm transparent substrate of polycarbonate.

3.2 Experimental condition for recording

Figure 3 shows the test apparatus of BCA comprises a modulator and a recorder. First, in the modulator, as shown in Fig. 4, data bits are modulated by phase encoding (PE) rule, and this modulated signal is further modulated by return to zero (RZ) rule, and a PE-RZ signal is generated. That is, the data bit "0" is converted

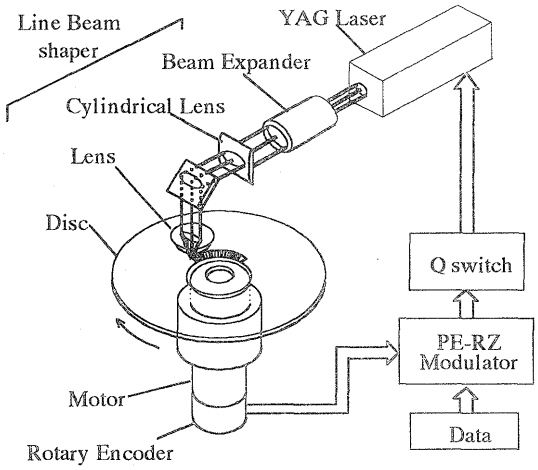

Fig.3 Construction of BCA recorder

into channel bit "10" and the data bit "1" into channel bit "01", and a stripe is recorded corresponding to this channel bit "1". In the recorder shown in Fig. 3, a signal corresponding to the rotation angle of the disc is obtained from the rotary encoder attached to the spindle motor of the disc. The modulated signal in synchronism with this rotation angle activates the Q switch unit of the YAG laser. Table 2 shows the recording conditions of the wavelength of 1067 nm, the laser pulses of short duration of 100 ns and the maximum frequency of 5 kHz. This laser light, first formed into a circular beam by a beam expander, and then it is further shaped into rectangular by a cylindrical lens. This beam is entered into an objective lens and the laser spot is formed like a rectangular shape on the reflective film of the disc. The reflective film is removed in a stripe shape, and one stripe is recorded with one pulse. Figure 5 shows the optical microscope observation of the formed BCA stripe. The sizes are about 1300 μm in the radial direction and about 10μm in the tangential direction. In the case of 188-byte BCA data, about 2000 stripes are recorded on disc like a barcode at intervals of 1T, 2T, 3T, and 4T (1T =about 15μm).

Table 2 Recording condition

Laser	YAG-CW-Q switch
Wave length	1067 nm
Laser output	0.5mJ/pulse
Pulse width	100 ns
Maximum frequency	5 kHz
Spot size	10 μ m × 1300 μ m
Recording time/ Disc	Less than 1 sec. (188bytes)

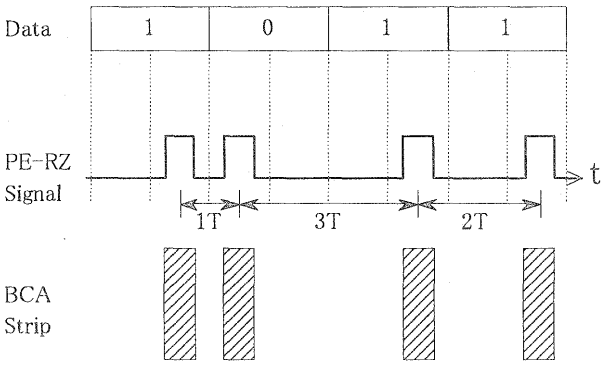

Fig.4 Phase encoding and RZ recording signal for BCA

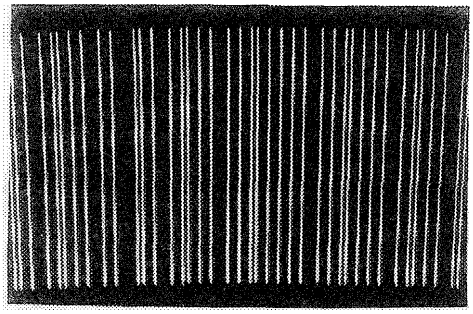

Fig.5 BCA stripe (x50)

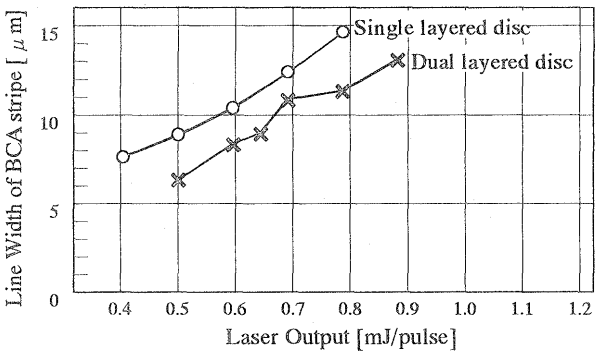

Fig.6 Laser output vs. Stripe width

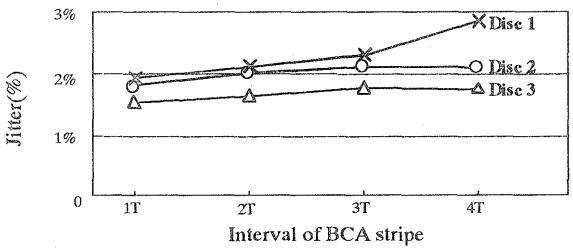

Fig.7 Jitter of BCA signal

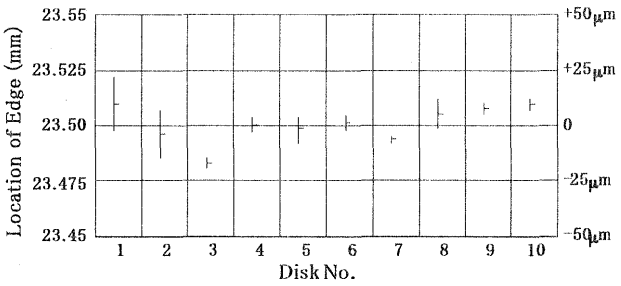

Fig.8 Radial accuracy of BCA stripe

3.3 BCA recording characteristics

Figure 6 shows the relation between the laser output and the line width of the recorded stripe on DVD disc. The line width increases as the output is raised. When the YAG laser recording output power increases too much, the adhesion layer is broken, but at the maximum processing line width of about 15 μm of the DVD standard, no damage of the adhesion layer was observed. The power control of the CW-Q switch type YAG laser at low level is unstable, and the minimum line width for DVD standard is designed at about 5 μm where the power control is stable. In the case of Dual-layer disc, the line width is narrower if the laser output is the same. This is because the absorption rate of the semitransparent layer for the Dual-layer disc is 20 to 30%. The reflectivity of the BCA recorded area is important for focusing and is estimated as follows. The reflectivity of the portion where the aluminum film is removed in the BCA recorded region is low. As the duty ratio of the BCA stripe recording is 25%, the drop of the reflectivity of the BCA recorded region becomes around 25% from the reflectivity of the mirror portion. Therefore the reflected light intensity is sufficient for focus control for existing DVD optical head. Figure 7 shows the result of jitter measurement of BCA, jitter values are between 1% to 3% for the interval 1T to 4T, and the jitter value width has a sufficient allowance.

3.4 Positional accuracy of BCA

The end portion of the stripe in the radial direction is shaped like an arrowhead of about 20 μm in length, and this length is difficult to control. To satisfy the DVD standard, the absolute position of the end portion including this arrowhead must be recorded at a precision of ±50 μm. In the BCA recording experiment, the positional precision of the end portion in the radial direction was measured. Figure 8 shows the result of the measurement of the stripe position and it satisfied the specified value of 23.5 ± 0.05 mm with a sufficient allowance. In mass production, considering the effect of arrowhead in the end portion, it is expected possible to settle within the standard.

3.5 Observation of cross sectional image of stripe

By cutting the BCA stripe portion in the circumferential direction to the disc, cross section samples were prepared, and first observed by optical microscope. Figure 9 shows the cross-sectional optical microscope observation result of the BCA recorded disc. The reflective film is removed in a width of 10 μm by BCA stripe recording. However, damage on the adhesion layer or transparent substrate was not observed. In comparison, for reference, similar BCA recording experiment was attempted on the single-substrate type disc such as CD-ROM disc, in the course of recording, the reflective film was removed by sublimation. But the protective layer formed on the reflective film was also broken by recording, and the part of the reflective film become bare, which suggested necessity of the formation of protective layer after BCA recording. In the DVD, the reflective layer and the protective adhesion layer are formed in the middle of the sandwich structure composed of two substrates bonded together. That is, in a polycarbonate "enclosed container", melting or sublimation of the metal reflective film of aluminum, and mechanical deformation due to thermal recording are suppressed by the two substrates. Therefore it seems that the damage matter of the protective adhesion layer is resolved.

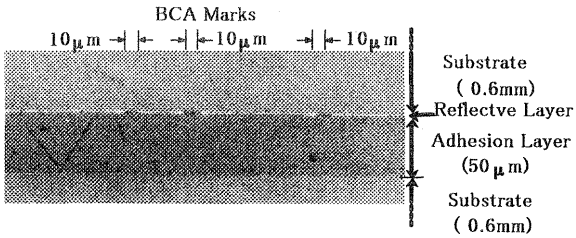

Fig. 9 Cross-sectional view of Adhesion layer near BCA

3.6 Observation by transmission electron microscope

The cross section of the BCA recorded portion was sliced in a thin film, and a cross sectional sample for a transmission electron microscope (TEM) was prepared, and observed by TEM. Figure 10 is a TEM image of the cross section of the sample magnified by about 20,000 times. Figure 11 shows schematic views of a part of cross section corresponding to Fig. 10. The reflective film of about 50nm in thickness was almost completely removed in a width of 10 μm. In the adjacent area of the stripe, aluminum aggregated in a thickness of 150 to 200nm and in a width of several μm. The volume of each part was calculated by using the results of TEM observation, and it shows that the volume of the aluminum removed from the stripe-forming portion was nearly equal to the volume of the aluminum increasing in this aggregation area.

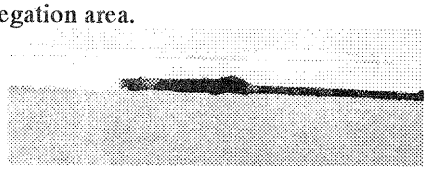

Fig.10 TEM image of BCA (x20000)

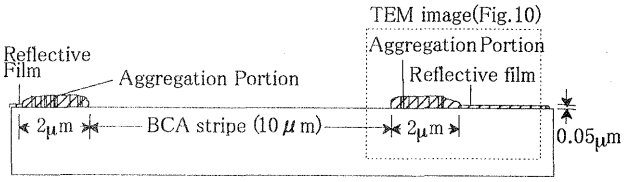

Fig.11 Cross sectional view of BCA (explanatory figure)

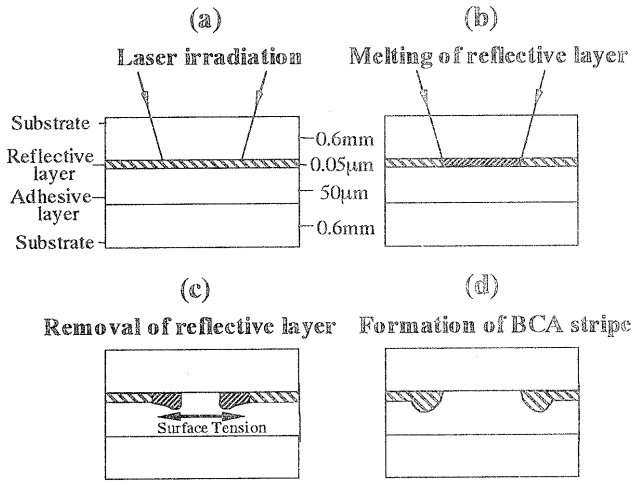

Fig.12 Recording process of BCA

4. Consideration of recording models

As a result of the experiment, the following two models are considered. As estimated in a first model, the removed portion of the aluminum reflective film irradiated with laser beam is in Fig. 12(a), the reflective film melted at the portion is in (b), and the molten aluminum moves to both edge sides by surface tension, which is shown in (c), the moved reflective film forms like ridges in (d), and hence the stripe is recorded. The second is the sublimation model, the initial process is the same as in (a) and (b), simultaneously the gas is generated, and the metal diffuses in the peripheral area due to gas pressure in (c), and the metal of the quenched reflective film is solidified mainly at both sides in the tangential direction of the BCA recorded portion in (d).

The result of the present experiment may be explained by the first model, but actually it seems to be a combined the result of two models. In the recorded portion, the characteristics of the "enclosed container" by 4-layer structure of DVD discs works for the stable BCA recording characteristics.

5. Results of Reliability Test

To estimate the reliability, accelerated life test was executed. After BCA recording with test condition (Table 2), the disc was presented for the environmental test for 96 hours. At first, disc distortion, disc birefringence, other characteristics of disc substrate, and signal jitter were measured on both the BCA recorded disc and unrecorded disc. These discs were exposed in the environment at 70 degree C and 95% R.H for 96 hours, and the same characteristics were measured again. Furthermore the discs were broken, and to investigate any oxidization and degradation, the BCA section was observed by TEM, scanning electron microscope (SEM) and the electron diffraction analysis to investigate oxidization and degradation.

Results of the 96-hour environmental test are summarized in Table 3. There was almost no degradation on the substrate of the disc, such as distortion of disc or increase of birefringence due to BCA recording. The pre-pit signal jitter at a position apart from the BCA recorded area by 100μm was negligibly small. From the result of TEM observation and electron diffraction analysis, no oxidation of aluminum in the edge part of the BCA mark was observed. As a result of the observation by SEM, there was no change in the adhesion layer of the BCA recorded area. BCA recording method in a completed DVD disc has been verified to satisfy the requirement of reliability for DVD. This is considered because the BCA is recorded in the enclosed structure of the disc composed of two substrates bonded together, by YAG laser of very short pulse width.

Table 3 Life test results

	BCA recorded disk	BCA non-recorded disk
Tilt angle change	+0.085°	+0.078°
Retardation change	-4.23 nm	-6.65 nm
Reflection layer change	None	None

Environmental condition : 70°C95%R.H. 96hrs

6. Conclusions

BCA recording characteristics shows sufficient property required for the unique ID recording technology of DVD. BCA recorded discs have been verified to satisfy the reliability of DVD. The result of the disc used in the present experiment can be explained by a BCA recording model.

New ID recording method by aluminum removal method has tamper resistant characteristic. Then it was first proposed by the authors and adopted for DVD-ROM standard in 1996. Afterwards, the importance of security has been enhanced, and at the present it is employed in many disc standards including DVD-RAM, DVD-R and DVD-RW standards, and is utilized as one of the copyright protection techniques for recordable discs. Using such security function of BCA, it is expected to be used in various systems, including the electronic distribution system combining the optical disc and the Internet.

References

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2) Hideaki Komoda et al.: "Hybrid CD", National Technical Report, vol.41 No.6, pp.52-59 (1995)