



US008291286B2

(12) **United States Patent**  
**Wang**

(10) **Patent No.:** **US 8,291,286 B2**  
(45) **Date of Patent:** **Oct. 16, 2012**

(54) **DECODING SYSTEM AND METHOD FOR HIGH-DENSITY RECORDING MEDIUM**

(75) Inventor: **Sih-Kai Wang**, Tainan (TW)

(73) Assignee: **Sunplus Technology Co., Ltd.**, Hsinchu (TW)

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 559 days.

(21) Appl. No.: **12/591,814**

(22) Filed: **Dec. 2, 2009**

(65) **Prior Publication Data**

US 2010/0180177 A1 Jul. 15, 2010

(30) **Foreign Application Priority Data**

Jan. 13, 2009 (TW) ..... 98101013 A

(51) **Int. Cl.**  
**G06F 11/00** (2006.01)

(52) **U.S. Cl.** ..... 714/752

(58) **Field of Classification Search** ..... 714/752  
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,281,193	B2 *	10/2007	Wu et al.	714/758
7,877,661	B2 *	1/2011	Kahlman	714/752
8,069,398	B2 *	11/2011	Wu et al.	714/776
2003/0115529	A1 *	6/2003	Ohira et al.	714/752
2006/0069979	A1 *	3/2006	Wu et al.	714/758
2007/0277080	A1 *	11/2007	Wu et al.	714/758
2010/0017679	A1 *	1/2010	Kawamae et al.	714/752

\* cited by examiner

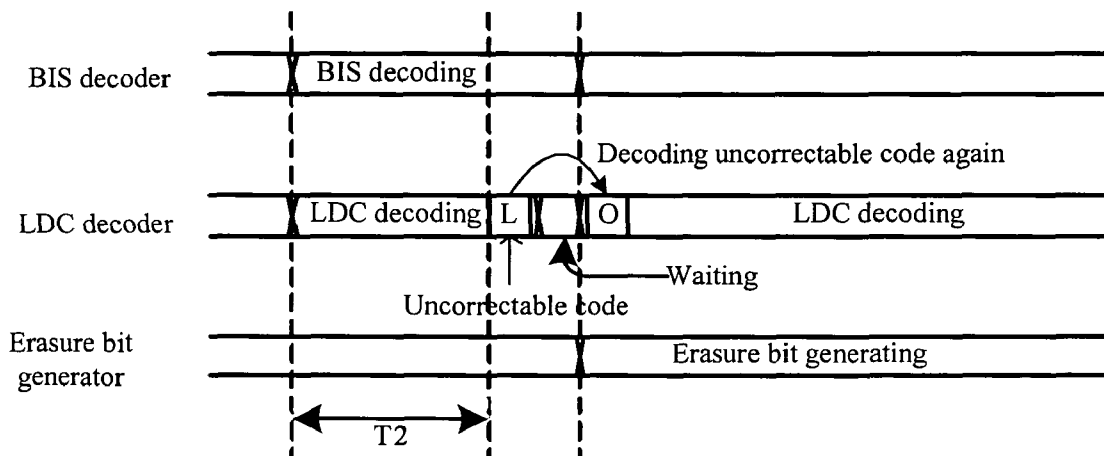
*Primary Examiner* — Bryce Bonzo

(74) *Attorney, Agent, or Firm* — Bacon & Thomas, PLLC

(57) **ABSTRACT**

In a decoding system and method for a high-density recording medium, a high protective codeword decoder decodes a burst indicator subcode (BIS) while a low protective codeword decoder decodes a long distance code, so as to eliminate the waiting time required for completely decoding all burst indicator subcodes (BISs) and starting the long-distance code (LDC) decoding. In addition, a first memory having a high access speed is implemented to store the BISs and corresponding BIS erasure indicators, and the access to a second memory have a lower access speed relative to the first memory is relatively reduced such that the bandwidth can be effectively used to thereby increase the decoding efficiency on the high-density recording medium.

**19 Claims, 11 Drawing Sheets**



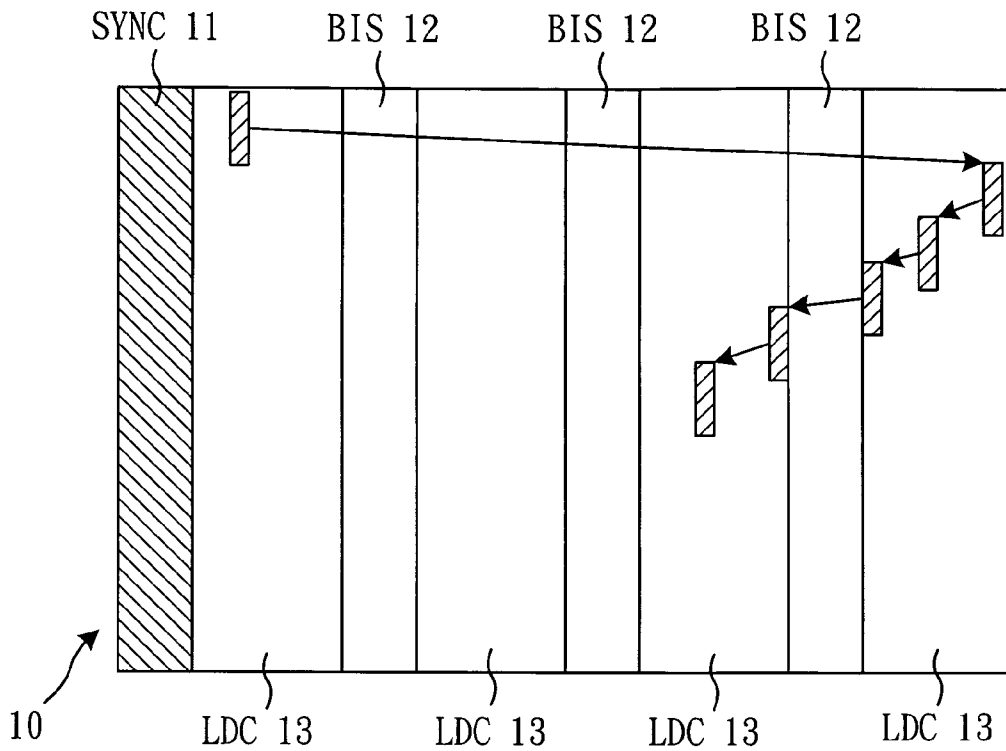


FIG. 1 (Prior Art)

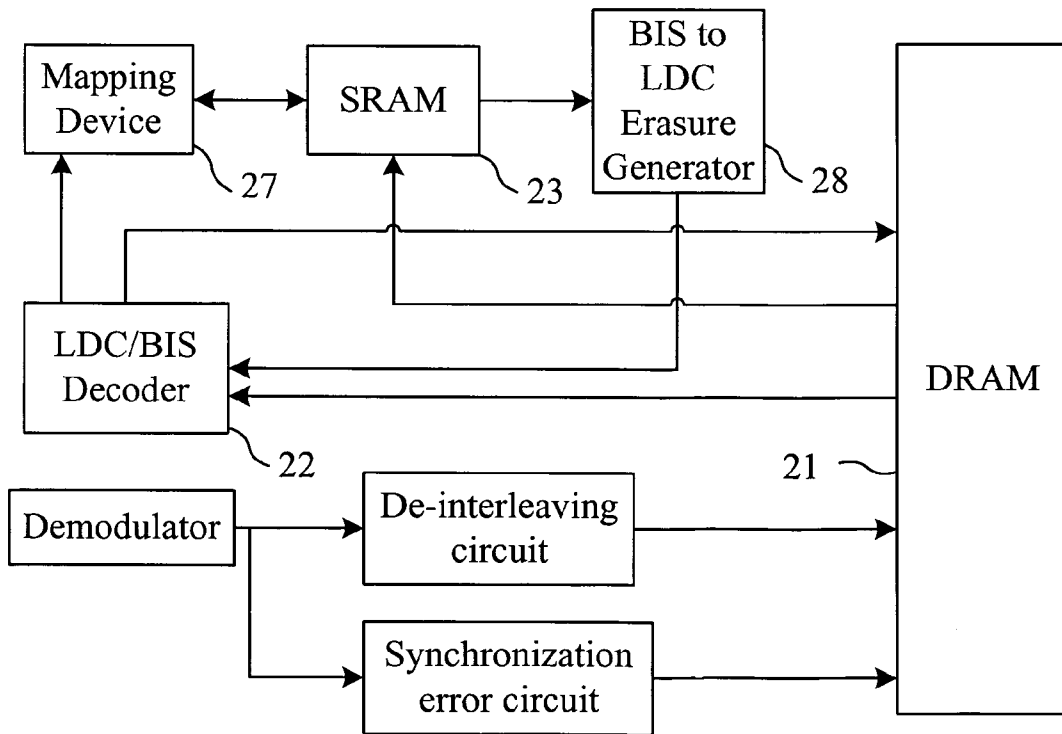


FIG. 2 (Prior Art)

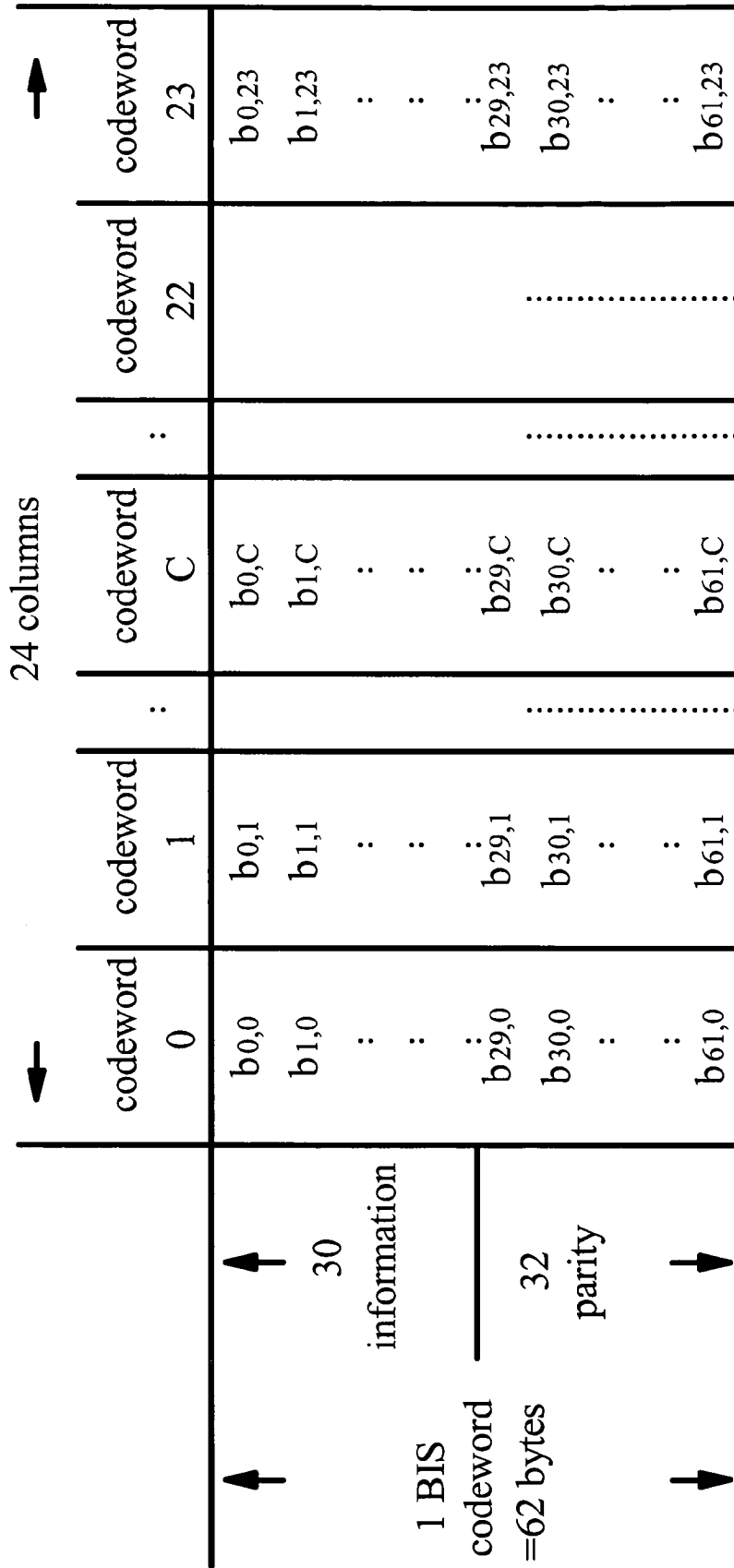


FIG. 3

unit u	row r	byte number N, C from BIS Block			shift right (=mod (r, 3))	filling in upward direction
		0	1	2		
0	0	0, 0	0, 1	0, 2	0	start of Block row N=0
	1	2, 5	2, 3	2, 4	1	↑ continuation of Block row N=2
	2	4, 7	4, 8	4, 6	2	
	3	6, 9	6, 10	6, 11	0	
	:					
	7	14, 23	14, 21	14, 22	1	
	8	16, 1	16, 2	16, 0	2	start of Block row N=16
	:					
	30	60, 18	60, 19	60, 20	0	
1	0	0, 21	0, 22	0, 23	0	start of Block row N=0
	1	2, 2	2, 0	2, 1	1	start of Block row N=2
	2	4, 4	4, 5	4, 3	2	
	3	6, 6	6, 7	6, 8	0	
2	0	0, 18	0, 19	0, 20	0	
	1	2, 23	2, 21	2, 22	1	end of Block row N=2
	2	4, 1	4, 2	4, 0	2	start of Block row N=4
	3	6, 3	6, 4	6, 5	0	
3	0	0, 15	0, 16	0, 17	0	
	1	2, 20	2, 18	2, 19	1	
	2	4, 22	4, 23	4, 21	2	
	3	6, 0	6, 1	6, 2	0	start of Block row N=6
4	0	1, 12	0, 13	0, 14	0	
	1	2, 17	2, 15	2, 16	1	
	2					
5	0	0, 9	0, 10	0, 11	0	
	1	2, 14	2, 12	2, 13	1	
	2					
6	0	0, 6	0, 7	0, 8	0	
	1	2, 11	2, 9	2, 10	1	
	2	4, 13	4, 14	4, 12	2	
7	0	0, 3	0, 4	0, 5	0	↑ continuation of Block row N=0
	1	2, 8	2, 6	2, 7	1	↑ continuation of Block row N=2
	2	4, 10	4, 11	4, 9	2	
	:					
	7	14, 2	14, 0	14, 1	1	start of Block row N=14
	30	60, 21	60, 22	60, 23	0	end of Block row N=60

FIG. 4

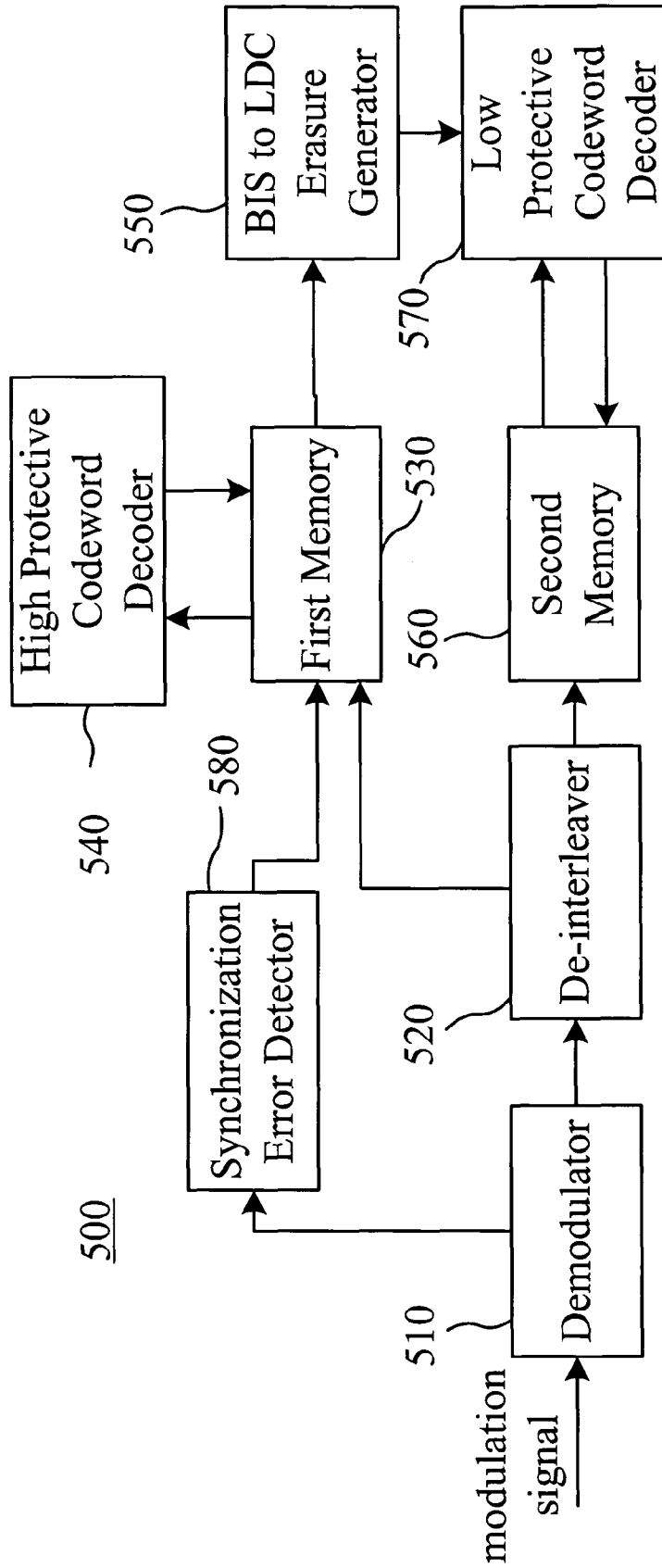


FIG. 5

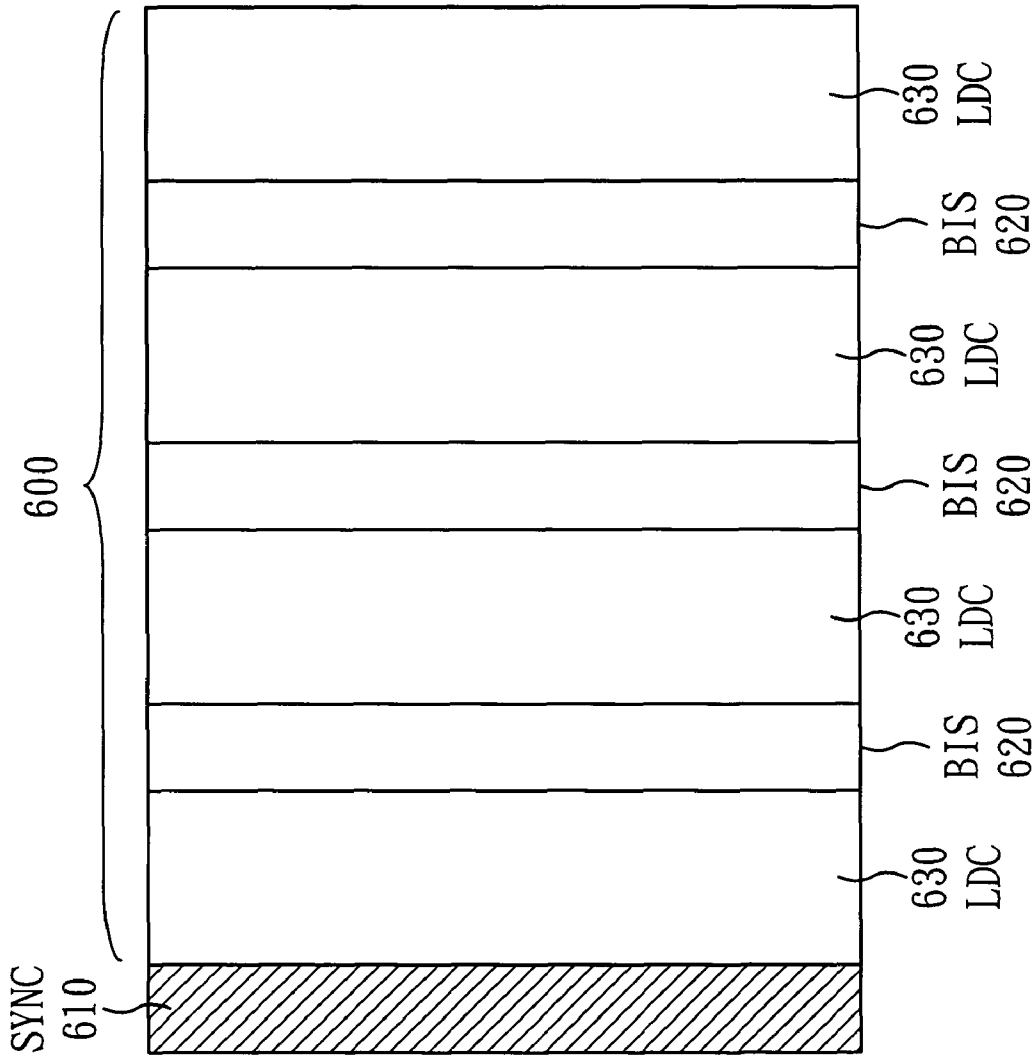


FIG. 6

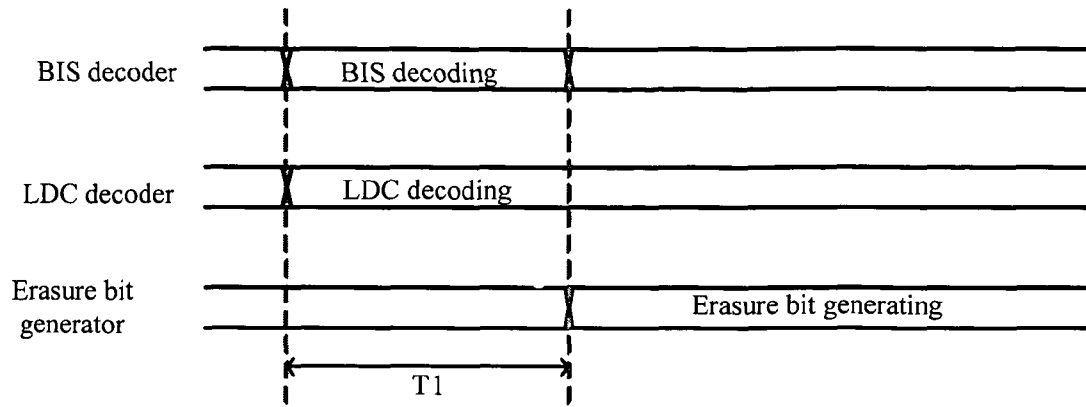


FIG. 7

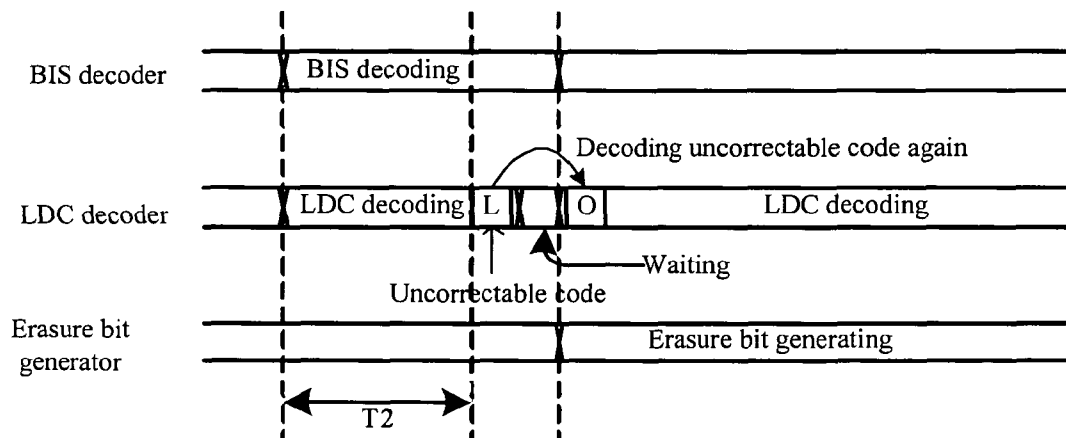


FIG. 8

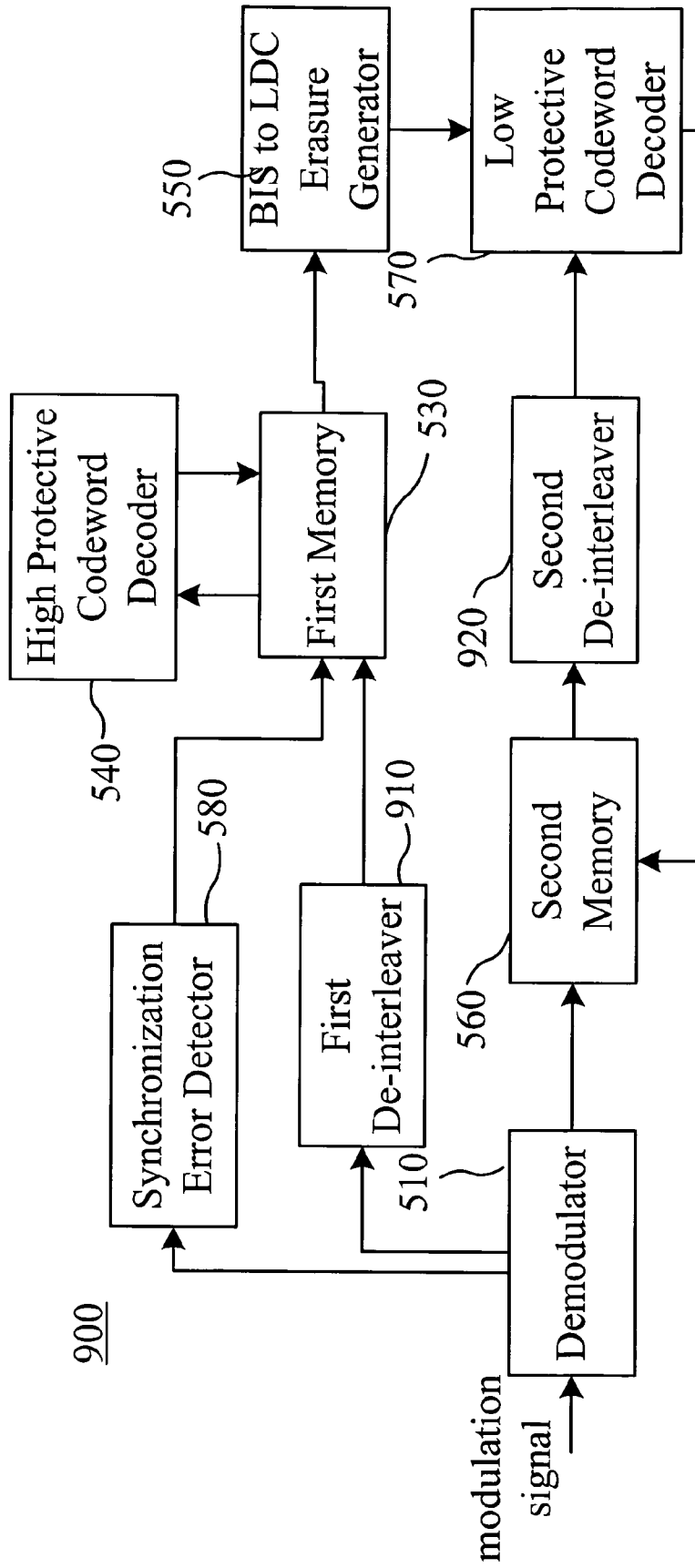


FIG. 9



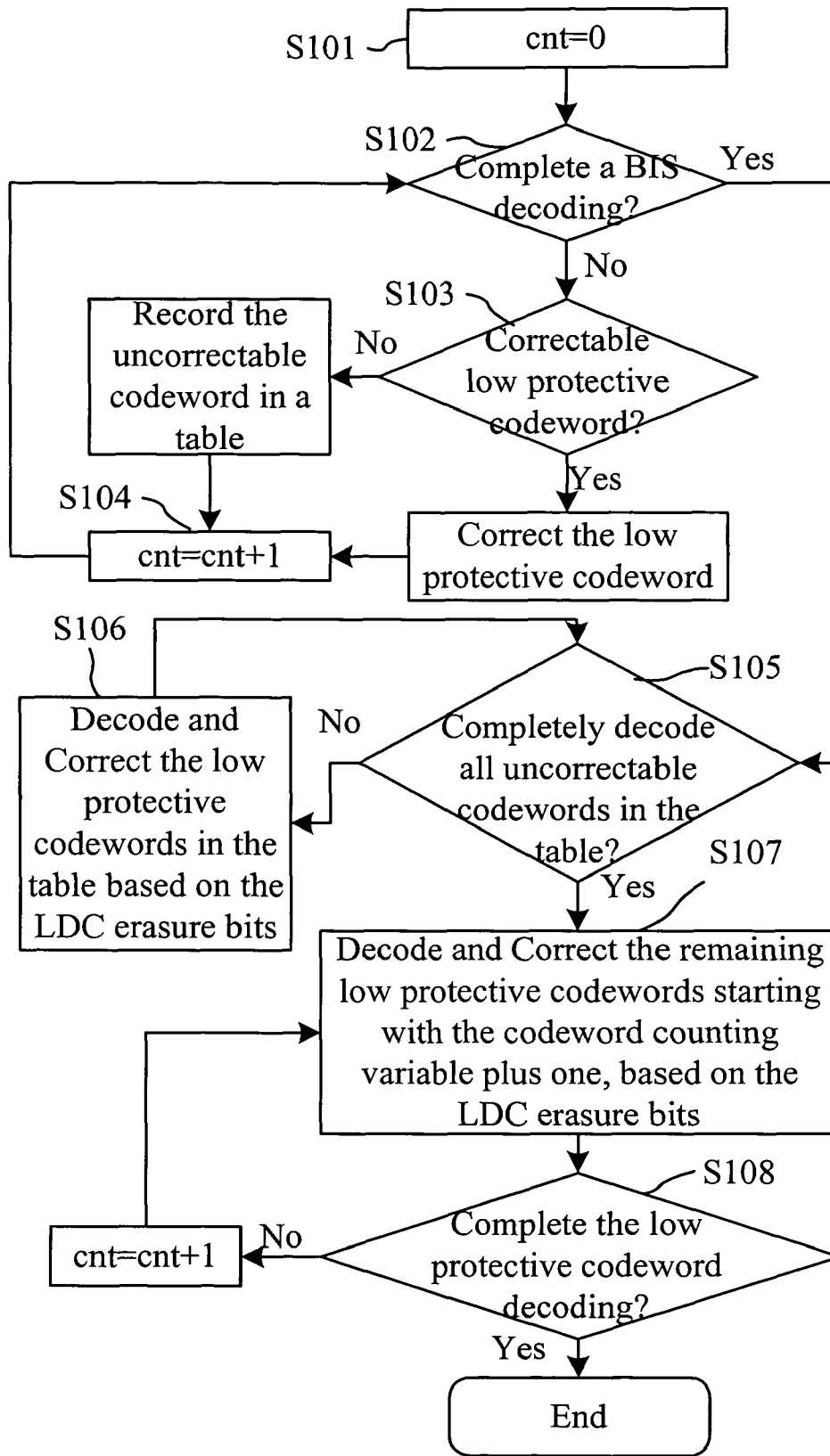


FIG. 10

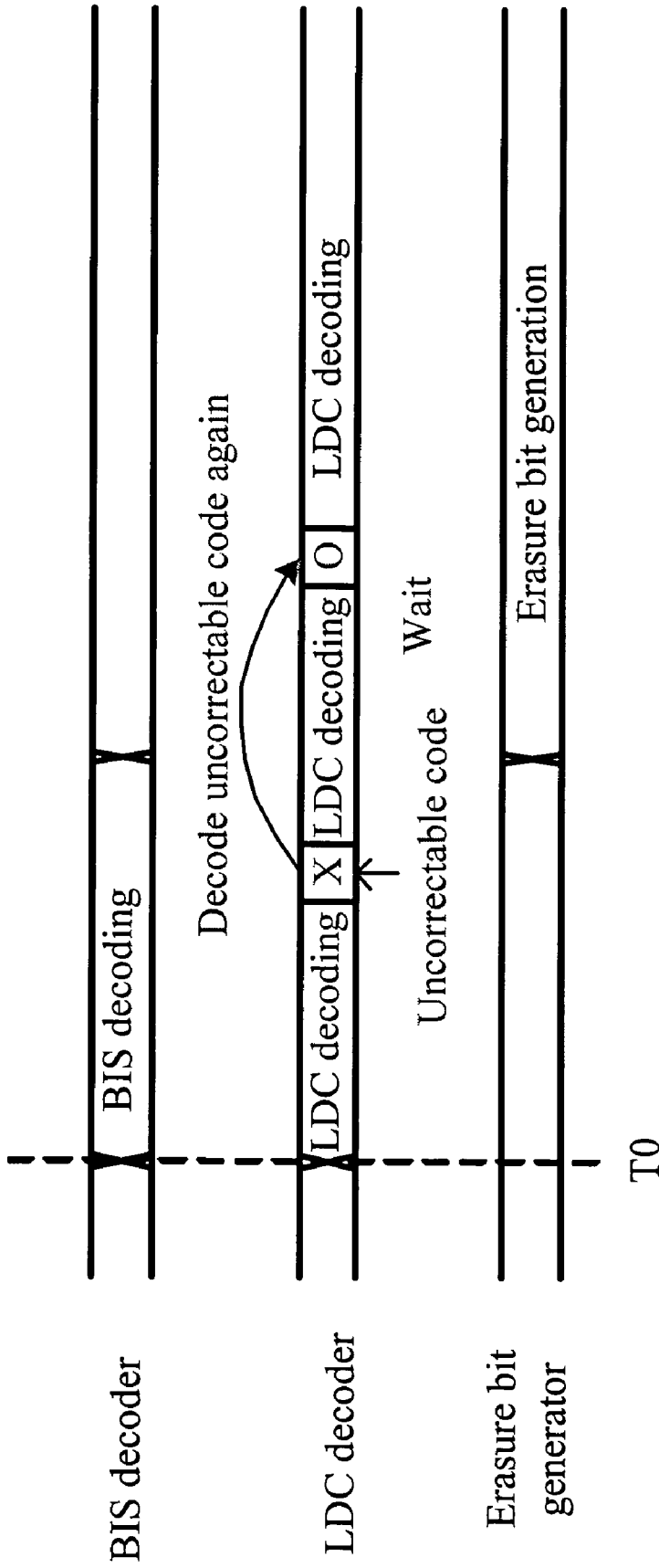


FIG. 11



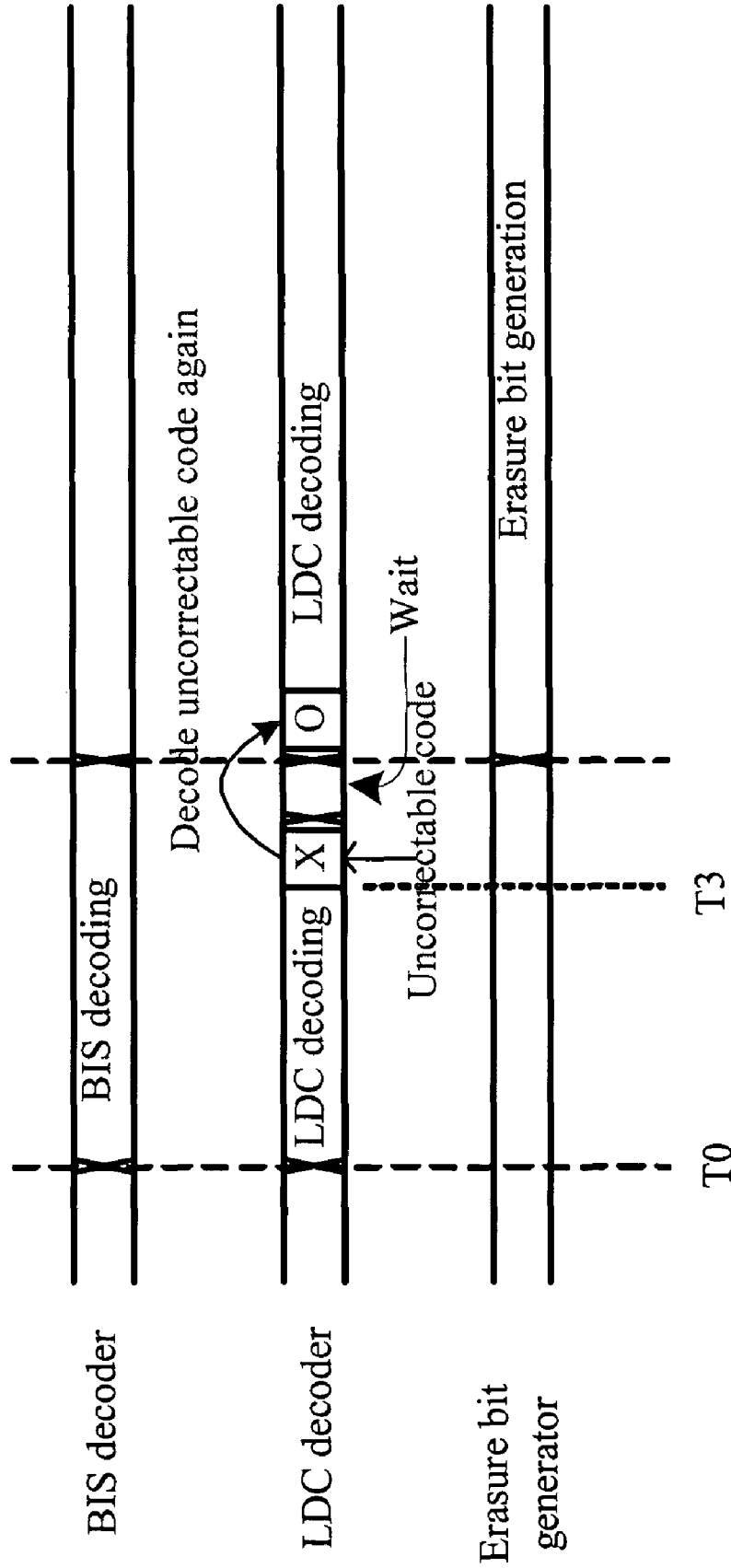


FIG. 13

## DECODING SYSTEM AND METHOD FOR HIGH-DENSITY RECORDING MEDIUM

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to the technical field of optical storage media decoding and, more particularly, to a decoding system and method for high-density recording medium.

#### 2. Description of Related Art

As shown in FIG. 1, an error correction code (ECC) cluster **10** has 152 long distance code (LDC) data columns, a synchronization data column and three burst indicator subcode (BIS) data columns **12**. The LDC data columns are divided into four LDC blocks **13** by the synchronization data column **11** and the BIS data columns **12**. The original LDC data is discontinuous and interleaved into the different LDC blocks **13**. Some ECC coding or decoding techniques are disclosed in U.S. Pat. No. 6,378,100, granted to Van Dijk, et al. for a "Method and apparatus for encoding multiword information with error locative clues directed to low protectivity words", U.S. Pat. No. 6,367,049, granted to Van Dijk, et al. for an "Encoding multiword information by wordwise interleaving", U.S. Pat. No. 6,604,217, granted to Kahlman for a "Multiword information encoded by wordwise interleaving and wordwise error protection with error locative clues derived from synchronizing channel bit groups and directed to target words", U.S. 2003/0208714, published Nov. 6, 2003, entitled "Method for encoding multiword information by wordwise interleaving and wordwise error protection with error locative clues derived from synchronizing channel bit groups and directed to target words, a method for decoding such information, a device for encoding and/or decoding such information, and a carrier provided with such information", and U.S. Pat. No. 7,281,193, granted to Wu, et al. for a "Method and apparatus for decoding multiword information". U.S. Pat. No. 6,378,100 discloses a decoding method in which the synchronization codes, the BIS codes or their dynamic or static combination is used as an erasure, and U.S. 2003/0208714 (a continuation application of U.S. Pat. No. 6,378,100) further discloses a method using a synchronization code as an erasure indicator.

However, the aforementioned patents only disclose a concept for the method of decoding ECC data, i.e., they do not explicitly disclose practical implementation methods. To overcome this, U.S. Pat. No. 7,281,193 discloses a decoding method in which the synchronization and BIS codes are combined as a tactic and the tactic can be switched automatically. FIG. 2 is a block diagram disclosed in U.S. Pat. No. 7,281,193 in which the demodulated and de-interleaved BIS and LDC codes are stored in the DRAM **21**. The LDC/BIS decoder **22** reads a BIS from the DRAM **21** for decoding and subsequently recording the BIS error flag in the SRAM **23**. Next, the LDC/BIS decoder **22** reads an LDC from the DRAM **21** to decode, and the BIS to LDC erasure generator **28** reads the BIS error flag from the SRAM **23** to thereby produce an LDC erasure flag to the LDC/BIS decoder **22** for the LDC decoding. Thus, the LDC decoding performance of the LDC/BIS decoder **22** is increased.

In decoding of a typical high-density recording medium, it firstly completes the BIS decoding in order to obtain the BIS error flag and then decodes the LDC in order to produce the LDC erasure flag based on the BIS error flag, thereby increasing the LDC decoding performance, as cited in the decoding disclosed by U.S. Pat. No. 7,281,193. Such a decoding has a disadvantage that the LDC decoding is not performed unless the BIS decoding is complete. For a future high-speed high-

density recording medium, decoding must be performed with high speed and high efficiency. Accordingly, the time waiting for completing the BIS decoding is a waste.

FIG. 3 is a schematic diagram of a data format of BIS blocks. FIG. 4 is a schematic graph of a table of interleaved mapping of partial BISs. As shown in FIGS. 3 and 4, the coordinates of the de-interleaved BISs are not successive (not following the direction of each codeword). Therefore, the demodulated and de-interleaved BISs are stored in the DRAM **21** and the DRAM **21** are then accessed for decoding, which are inefficient and occupy the bandwidth of the DRAM **21**. Accordingly, the disclosed method is not suitable for a complicated system application or a high-density recording medium to meet the system performance requirement of high-speed reading.

Therefore, it is desirable to provide an improved decoding system and method to mitigate and/or obviate the aforementioned problems.

### SUMMARY OF THE INVENTION

An object of the present invention is to provide a decoding system and method for high-density recording medium, which can eliminate the waiting time required for completely decoding all burst indicator subcodes (BISs) and starting the long-distance code (LDC) decoding to thereby increase the decoding speed.

Another object of the present invention is to provide a decoding system and method for high-density recording medium, which essentially performs accesses to a high-speed first memory and reduces accesses to a second memory having a lower speed relative to the first memory to thereby increase the use efficiency of the bandwidth of the second memory and further the system decoding performance.

According to a feature of the invention, a decoding system for a high-density recording medium is provided. The decoding system includes a first memory, a high protective codeword decoder, a burst indicator subcode (BIS) to long distance code (LDC) erasure generator, a second memory and a low protective codeword decoder. The first memory stores a high protective codeword. The high protective codeword decoder is connected to the first memory in order to decode and correct the high protective codeword to the first memory to thereby produce a BIS erasure indicator with a position information. The BIS to LDC erasure generator is connected to the first memory in order to, based on the BIS erasure indicator, produce an LDC erasure bit for a low protective codeword. The second memory stores the low protective codeword. The low protective codeword decoder is connected to the second memory and the BIS to LDC erasure generator in order to decode and correct the low protective codeword to the second memory. In decoding, the low protective codeword decoder first directly decodes and corrects the low protective codeword, and then decodes and corrects the low protective codeword based on the LDC erasure bit when the low protective codeword exceeds a decoding capability of the low protective codeword decoder.

According to another feature of the invention, a decoding system for a high-density recording medium is provided. The decoding system includes a demodulator, a first de-interleaver, a first memory, a high protective codeword decoder, a burst indicator subcode (BIS) to long distance code (LDC) erasure generator, a second memory, a second de-interleaver and a low protective codeword decoder. The demodulator receives a modulation signal and performs a demodulation operation on the modulation signal to thereby produce a demodulation signal, wherein the demodulation signal has

high and low protective codewords. The first de-interleaver is coupled to the demodulator in order to receive the demodulation signal and perform a de-interleaving operation on the high protective codeword of the demodulation signal to thereby produce a de-interleaved high protective codeword. The first memory is coupled to the first de-interleaver in order to store the de-interleaved high protective codeword. The high protective codeword decoder is connected to the first memory in order to decode and correct the de-interleaved high protective codeword to the first memory to thereby produce a BIS erasure indicator with a position information. The BIS to LDC erasure generator is connected to the first memory in order to depend on the BIS erasure indicator to produce an LDC erasure bit for a low protective codeword. The second memory is connected to the demodulator in order to store the low protective codeword of the demodulation signal. The second de-interleaver is coupled to the second memory in order to perform a de-interleaving operation on the low protective codeword to thereby produce a de-interleaved low protective codeword. The low protective codeword decoder is connected to the second memory and the BIS to LDC erasure generator in order to decode and correct the low protective codeword to the second memory. In decoding the low protective codeword decoder first directly decodes and corrects the low protective codeword, and then decodes and corrects the low protective codeword based on the LDC erasure bit when the low protective codeword exceeds a decoding capability of the low protective codeword decoder.

According to a further feature of the invention, a decoding method for a high-density recording medium is provided, which decodes a signal with high and low protective codewords. The decoding method includes the steps: (A) initializing a codeword counting variable; (B) determining whether a high protective codeword decoding is complete, and executing step (E) when the high protective codeword decoding is complete and otherwise step (C); (C) determining whether a low protective codeword is correctable, and correcting the low protective codeword when the low protective codeword is correctable and otherwise recording the low protective codeword in a table as an uncorrectable codeword; (D) increasing the codeword counting variable by one, and executing step (B); (E) determining whether all uncorrectable codewords in the table are completely decoded; and (F) producing an LDC erasure bit for a corresponding low protective codeword based on a BIS erasure indicator of the high protective codeword when the corresponding low protective codeword recorded in the table as an uncorrectable codeword is not decoded, and then decoding and correcting the corresponding low protective codeword based on the LDC erasure bit, and executing step (E).

According to another feature of the invention, a decoding method for a high-density recording medium is provided, which decodes a signal with high and low protective codewords. The decoding method includes the steps: (A) initializing a codeword counting variable; (B) determining whether a high protective codeword decoding is complete, and executing step (D) when the high protective codeword decoding is complete and otherwise step (C); (C) determining whether a low protective codeword is correctable, and waiting when the low protective codeword is not correctable, until the high protective codeword decoding is complete; (D) producing an LDC erasure bit for the low protective codeword based on a BIS erasure indicator of the high protective codeword, and decoding and correcting the low protective codeword based on the LDC erasure bit; and (E) determining whether a low protective codeword decoding concurrently activated with

the high protective codeword decoding is complete, and ending when the low protective codeword decoding is complete.

Other objects, advantages, and novel features of the invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a typical error correction code (ECC) cluster of a high-density recording medium;

FIG. 2 is a block diagram of a typical decoding system for a high-density recording medium;

FIG. 3 is a schematic diagram of a typical data format of burst indicator subcode (BIS) blocks;

FIG. 4 is a schematic graph of a table of interleaved mapping of partial BISs;

FIG. 5 is a block diagram of a decoding system for a high-density recording medium according to an embodiment of the invention;

FIG. 6 is a schematic diagram of an error correction code (ECC) cluster according to an embodiment of the invention;

FIG. 7 is a decoding timing according to an embodiment of the invention;

FIG. 8 is another decoding timing according to an embodiment of the invention;

FIG. 9 is a block diagram of a decoding system for a high-density recording medium according to another embodiment of the invention;

FIG. 10 is a flowchart of a decoding method for a high-density recording medium according to an embodiment of the invention;

FIG. 11 is a decoding timing of FIG. 10 according to an embodiment of the invention;

FIG. 12 is a flowchart of a decoding method for a high-density recording medium according to another embodiment of the invention; and

FIG. 13 is a decoding timing of FIG. 12 according to another embodiment of the invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 5 is a block diagram of a decoding system 500 for a high-density recording medium according to an embodiment of the invention. In FIG. 5, the decoding system 500 includes a demodulator 510, a de-interleaver 520, a first memory 530, a high protective codeword decoder 540, a burst indicator subcode (BIS) to long distance code (LDC) erasure generator 550, a second memory 560, a low protective codeword decoder 570 and a synchronization error detector 580.

The demodulator 510 receives a modulation signal and performs a demodulation operation on the modulation signal in order to produce a demodulation signal. The demodulation signal is an error correction code (ECC) cluster and has eight bits.

The de-interleaver 520 is coupled to the demodulator 510 in order to receive the demodulation signal and perform a de-interleaving operation on the demodulation signal to thereby produce the high and low protective codewords. The high protective codewords are a burst indicator subcode (BIS), and the low protective codewords are a long distance code (LDC).

FIG. 6 is a schematic diagram of an error correction code (ECC) cluster 600 according to an embodiment of the invention. As shown in FIG. 6, the ECC cluster 600 includes three BIS data columns 620 and four LDC data blocks 630. A

synchronization data column **610** is prefixed to the ECC cluster **600**. Each LDC data block **630** has 38 LDC data columns, and in this case one ECC cluster **600** contains 152 (=38×4) LDC data columns. In addition, each ECC cluster **600** also contains 496 rows.

The LDC and BIS data in the ECC cluster **600** is demodulated into 8 bits by the demodulator **510** and subsequently de-interleaved by the de-interleaver **520**. Accordingly, the high protective codewords (i.e., the BIS data) and the low protective codewords (i.e., the LDC data) are obtained. The LDC data is de-interleaved into 304 low protective codewords, each having a length of 248 bytes, and the BIS data is de-interleaved into 24 high protective codewords, each having a length of 62 bytes. Also, the synchronization code is sent to the synchronization error detector **580** in order to perform a synchronization error detection to thereby produce a synchronization erasure indicator.

The first memory **530** is coupled to the de-interleaver **520** in order to store the high protective codewords. Preferably, the first memory **530** is a static random access memory (SRAM).

The high protective codeword decoder **540** is connected to the first memory **530** in order to decode and correct the high protective codewords to the first memory **530** to thereby produce a BIS erasure indicator with a position information for each high protective codeword. For example, during decoding, the high protective codeword decoder **540** sets the BIS erasure indicator of the high protective codeword to "1" when an error is detected, and otherwise to "0". The BIS erasure indicator is positioned in a suitable place to thereby indicate the BIS data of the wrong ECC cluster corresponding to the BIS erasure indicator and further find the position relationship between the BIS erasure indicator and LDC data of the wrong ECC cluster **600**.

The BIS to LDC erasure generator **550** is connected to the first memory **530** in order to produce the LDC erasure bits for the LDC data of the wrong ECC cluster **600** according to the BIS erasure indicator.

While the low protective codeword decoder **570** decodes the LDC data, the BIS to LDC erasure generator **550** can extract the BIS erasure indicators of a BIS data nearby the LDC data of the wrong ECC cluster **600** from the first memory **530**. Thus, the BIS to LDC erasure generator **550** can produce the LDC erasure bits based on the BIS erasure indicators and send the bits to the low protective codeword decoder **570**.

The second memory **560** is connected to the de-interleaver **520** in order to store the low protective codewords. The second memory **560** is a dynamic random access memory (DRAM).

The low protective codeword decoder **570** is connected to the second memory **560** and the BIS to LDC erasure generator **550** in order to decode and correct the low protective codeword to the second memory **560**. On decoding, the low protective codeword decoder **570** first decodes and corrects the low protective codeword. When the low protective codeword exceeds a decoding capability of the low protective codeword decoder, the low protective codeword decoder **570** further decodes and corrects the low protective codeword based on the LDC erasure bit.

The synchronization error detector **580** is coupled to the demodulator **510** and the first memory **530** in order to detect the errors on the synchronization codes of the demodulation signal. When the errors of the synchronization codes of the demodulation signal are detected, the synchronization error detector **580** produces the synchronization erasure indicators and stores them in the first memory **530**. The BIS to LDC

erasure generator **550** is based on the BIS erasure indicators and the synchronization erasure indicators to produce the LDC erasure bits.

Upon the synchronization erasure indicators, the LDC erasure bits are produced. When the synchronization error detector **580** detects an error of a synchronization code, a synchronization erasure indicator corresponding to the erroneous synchronization code is set to "1", and otherwise to "0".

Since the synchronization data column **610** is not modulated in coding, for determining the errors of the synchronization codes, the demodulator **510** detects the positions of the erroneous synchronization code and sends all synchronization codes, which are not demodulated, directly to the synchronization error detector **580**, and the synchronization error detector **580** analyzes the synchronization codes sent by the demodulator **510**, groups them into legal and illegal ones, determines the illegal ones as the erroneous synchronization codes, sets the synchronization erasure indicators corresponding to the erroneous synchronization codes to "1" and otherwise to "0", and stores all synchronization erasure indicators in the first memory **530**.

When the low protective codeword decoder **570** decodes an LDC data, the BIS to LDC erasure generator **550** can extract the BIS erasure indicator of a BIS data or the synchronization erasure indicator of a synchronization codeword nearby the LDC data of the wrong ECC cluster **600** from the first memory **530**. Thus, the BIS to LDC erasure generator **550** can produce the LDC erasure bit based on the synchronization erasure indicator or the BIS erasure indicator.

Upon the ECC principles and algorithms, whether a codeword is correctable is known on decoding. Such a feature allows an LDC and a BIS to be concurrently decoded without the help of the LDC erasure bit, and the LDC decoding is paused until the LDC being decoded is an uncorrectable codeword. When the BIS decoding is complete, the BIS to LDC erasure generator **550** reads the BIS erasure indicator of a BIS from the first memory **530** to accordingly produce and transmit the LDC erasure bit to the low protective codeword decoder **570** for increasing the decoding performance of the low protective codeword decoder **570**, so as to complete the decoding of the LDC which is determined to be uncorrectable by the low protective codeword decoder **570**.

Referring to FIG. 7, the low protective codeword decoder **570** and the high protective codeword decoder **540** concurrently start to decode. In this case, the BIS to LDC erasure generator **550** has no erasure bit when the BIS is not decoded completely. During the BIS decoding, the low protective codeword decoder **570** does not detect an LDC uncorrectable, so it can eliminate the time T1 waiting for completely decoding the BIS by the high protective codeword decoder **540**. In this case, after the BIS is decoded completely, the BIS to LDC erasure generator **550** can obtain the BIS erasure indicator of the complete BIS. Next, the low protective codeword decoder **570** is based on the LDC erasure bit produced by the BIS to LDC erasure generator **550** to help the LDC decoding to thereby increase the decoding performance of the low protective codeword decoder **570** and eliminate the time T1.

The difference between FIGS. 7 and 8 is in that an uncorrectable LDC, numbered L, is seen by the low protective codeword decoder **570** during the time of a BIS decoding. Namely, the LDC L exceeds the decoding capability of the low protective codeword decoder **570**, which makes the decoding operation of the low protective codeword decoder **570** pause until the BIS decoding is complete. When the BIS is completely decoded, the BIS to LDC erasure generator **550** can obtain the BIS erasure indicator of the complete BIS and store it in the first memory **530**. In this case, the low protective

codeword decoder **570** re-start to decode the LDC L while the BIS to LDC erasure generator **550** reads the BIS erasure indicator of the BIS from the first memory **530** to thereby produce the LDC erasure bit to the low protective codeword decoder **570** for the LDC L. Thus, the decoding performance of the low protective codeword decoder **570** on the LDC L is relatively increased. The low protective codeword decoder **570** and the BIS to LDC erasure generator **550** go on the remaining decoding operations after the LDC L is completely decoded to thereby complete the entire LDC decoding. Accordingly, it is clear that the low protective codeword decoder **570** can save the time T2 waiting for the BIS decoding operation of the high protective codeword decoder **540**.

FIG. **9** is a block diagram of a decoding system **900** for a high-density recording medium according to another embodiment of the invention. In FIG. **9**, the decoding system **900** includes a demodulator **510**, a first de-interleaver **910**, a first memory **530**, a high protective codeword decoder **540**, a burst indicator subcode (BIS) to long distance code (LDC) erasure generator **550**, a second memory **560**, a second de-interleaver **920** and a low protective codeword decoder **570**.

The demodulator **510** receives a modulation signal and performs a demodulation operation on the modulation signal to thereby produce a demodulation signal. The demodulation signal has high and low protective codewords. Each high protective codeword is a BIS, and each low protective codeword is an LDC.

The first de-interleaver **910** is coupled to the demodulator **510** in order to receive the demodulation signal and perform a de-interleaving operation on the high protective codeword of the demodulation signal to thereby produce a de-interleaved high protective codeword.

The first memory **530** is coupled to the first de-interleaver **910** in order to store the de-interleaved high protective codeword, i.e., the BIS. Preferably, the first memory **530** is a SRAM.

The high protective codeword decoder **540** is connected to the first memory **530** in order to decode and correct the de-interleaved high protective codeword to the first memory **530** to thereby produce a BIS erasure indicator with a position information.

The BIS to LDC erasure generator **550** is connected to the first memory **530** in order to depend on the BIS erasure indicator to produce an LDC erasure bit for a low protective codeword corresponding to the de-interleaved high protective codeword.

The second memory **560** is connected to the demodulator **510** in order to store the low protective codeword of the demodulation signal. Preferably, the second memory **560** is a DRAM.

The second de-interleaver **920** is coupled to the second memory **560** in order to perform a de-interleaving operation on the low protective codeword to thereby produce a de-interleaved low protective codeword.

The low protective codeword decoder **570** is connected to the second de-interleaver **920**, the second memory **560** and the BIS to LDC erasure generator **550** in order to decode and correct the low protective codeword to the second memory **560**.

The low protective codeword decoder **570** first decodes and corrects the low protective codeword in decoding. When the low protective codeword exceeds a decoding capability of the low protective codeword decoder **570**, the low protective codeword decoder **570** then decodes and corrects the low protective codeword based on the LDC erasure bit.

The synchronization error detector **580** is coupled to the demodulator **510** and the first memory **530** in order to detect

the erroneous synchronization code or codes of the demodulation signal. When one or more erroneous synchronization codes of the demodulation signal are detected, the synchronization error detector **580** produces synchronization erasure indicators and stores them in the first memory **530**. The BIS to LDC erasure generator **550** is based on the BIS erasure indicators and the synchronization erasure indicators to produce the corresponding LDC erasure bits.

The difference between FIGS. **9** and **5** is in that the de-interleaver **520** in FIG. **5** is replaced with the first de-interleaver **910** and the second de-interleaver **920**, and the connection of the second memory **560** is accordingly changed to present a new configuration.

FIG. **10** is a flowchart of a decoding method for a high-density recording medium according to an embodiment of the invention. The decoding method decodes a signal with high and low protective codewords. Step **S101** initializes a codeword counting variable cnt and concurrently activates a BIS decoding and a LDC decoding.

Step **S102** determines whether the high protective codeword (BIS) decoding is complete. When the high protective codeword decoding is complete, step **S105** is executed, and otherwise step **S103** is executed.

Step **S103** determines whether a low protective codeword is correctable. When the low protective codeword is correctable, the low protective codeword is corrected, and otherwise it is recorded in a table as an uncorrectable codeword.

Step **S104** increases the codeword counting variable cnt by one, and executes step **S102**.

Step **S105** determines whether all uncorrectable codewords in the table are completely decoded. When all uncorrectable codewords in the table are completely decoded, step **S107** is executed, and otherwise step **S106** is executed.

When one or more uncorrectable codewords in the table are not decoded, step **S106** produces an LDC erasure bit based on the BIS erasure indicator of the high protective codeword for each low protective codeword in order to decode and correct the low protective codewords in the table based on the LDC erasure bits, and then step **S105** is executed.

When step **S105** determines that all uncorrectable codewords in the table are completely decoded, step **S107** is based on the LDC erasure bits to decode and correct the low protective codewords starting with the variable cnt plus one.

Step **S108** determines whether the low protective codeword (LDC) decoding is complete. When the low protective codeword decoding is not complete, the codeword counting variable is increased by one, and step **S107** is executed. Otherwise, the procedure ends.

FIG. **11** shows a decoding timing of FIG. **10** according to an embodiment of the invention. As shown in FIG. **11**, at T<sub>0</sub>, the BIS decoding and the LDC decoding are concurrently performed. At the position X, the low protective codeword is uncorrectable and recorded in a table as an uncorrectable codeword. Next, the following low protective codewords are proceeded. When the BIS decoding is complete, the BIS erasure indicator is used to produce the LDC erasure bit in order to help decoding the uncorrectable codeword (indicated by "O") in the table. When all uncorrectable codewords in the table are completely decoded, the remaining low protective codewords starting with the codeword counting variable plus one are decoded and corrected.

FIG. **12** is a flowchart of a decoding method for a high-density recording medium according to another embodiment of the invention. The decoding method decodes a signal with high and low protective codewords. Step **S201** initializes a codeword counting variable cnt and concurrently activates a BIS decoding and an LDC decoding.



Step S202 determines whether the high protective codeword (BIS) decoding is complete. When the high protective codeword decoding is complete, step S204 is executed, and otherwise step S203 is executed.

Step S203 determines whether a low protective codeword is correctable. When the low protective codeword is uncorrectable, the procedure is halted to wait for the completion of the high protective codeword decoding, i.e., the low protective codeword (LDC) decoding pauses until the high protective codeword decoding is complete and a BIS erasure indicator is produced.

Step S204 is based on the BIS erasure indicator to produce an LDC erasure bit to accordingly decode and correct the low protective codeword uncorrectable.

Step S205 determines whether the low protective codeword decoding is complete. When the low protective codeword decoding is complete, the procedure ends.

When step S203 determines that the low protective codeword is correctable, step S206 decodes and corrects the low protective codeword.

Step S207 increases the codeword counting variable by one, and executes step S202.

When step S205 determines that the low protective codeword decoding is not complete, step S208 increases the codeword counting variable by one, and executes step S204.

FIG. 13 is a decoding timing of FIG. 12 according to another embodiment of the invention. As shown in FIG. 13, at T0, the BIS decoding and the LDC decoding are concurrently performed. At T3, the low protective codeword is uncorrectable, so the LDC decoding pauses to wait for completing the BIS decoding. When the BIS decoding is complete, the LDC decoding is proceeded to decode and correct the remaining low protective codewords based on the LDC erasure bits.

As cited, a typical decoding flow of high-density recording medium includes demodulation, de-interleaving, BIS decoding and LDC decoding executed in sequence. An LDC decoding cannot have enough BIS indicators to set the LDC erasure bits and enhance the LDC decoding performance of the low protective codeword decoder 570 except when the BIS decoding is complete. However, the LDC decoding and the BIS decoding can be concurrently performed in the invention. Accordingly, the waiting time for completing the BIS decoding is reduced or eliminated.

In addition, for the format of BIS blocks in the prior art, the coordinates of the de-interleaved BISs are not successive, i.e., not following the direction of each codeword. When the BISs are stored in the DRAM in a form to be conveniently decoded, such as the BIS blocks follow the direction of each codeword, it is inefficient and time-wasting for the DRAM accesses in that the de-interleaved BISs are written to the DRAM, the decoded BISs are corrected by reading the error bit information from the DRAM, and the corrected BISs are written back to the DRAM.

Therefore, the invention provides a decoding system and method for a high-density recording medium to reduce the decoding time, efficiently use the DRAM, save the bandwidth of the DRAM, and increase the decoding performance of a high-density recording medium, so as to meet the requirement of high-speed reading of a future high-density recording medium.

The invention allows the high protective codeword decoder 540 and the low protective codeword decoder 570 to work concurrently, so the BIS decoding and the LDC decoding can be performed concurrently, thereby eliminating the time waiting for completing the BIS decoding in the prior art. In addition, the invention uses the first memory 530, which has a higher access speed than the second memory 560, to store the

BISs and BIS erasure indicators to thereby reduce the access to the second memory 560. Thus, the bandwidth of the second memory 560 can be used more efficient to thereby increase the decoding performance of the high-density recording medium and meet the requirement of high-speed reading of a future high-density recording medium.

Although the present invention has been explained in relation to its preferred embodiment, it is to be understood that many other possible modifications and variations can be made without departing from the spirit and scope of the invention as hereinafter claimed.

What is claimed is:

1. A decoding system for a high-density recording medium, comprising:

a first memory for storing a high protective codeword;  
a high protective codeword decoder connected to the first memory for decoding the high protective codeword and correcting the high protective codeword into the first memory to produce a burst indicator subcode (BIS) erasure indicator with a position information;  
a BIS to LDC erasure generator connected to the first memory for producing a long-distance code (LDC) erasure bit for a low protective codeword based on the BIS erasure indicator;

a second memory for storing the low protective codeword; and

a low protective codeword decoder connected to the second memory and the BIS to LDC erasure generator for decoding the low protective codeword and correcting the low protective codeword into the second memory;

wherein, during decoding, the low protective codeword decoder first decodes and corrects the low protective codeword, and then decodes and corrects the low protective codeword when the low protective codeword exceeds a decoding capability of the low protective codeword decoder.

2. The system as claimed in claim 1, further comprising a de-interleaver coupled to the first memory and the second memory for receiving a demodulation signal and de-interleaving the demodulation signal to produce the high protective codeword and the low protective codeword.

3. The system as claimed in claim 2, further comprising a demodulator coupled to the de-interleaver for receiving a modulation signal and demodulating the modulation signal to produce the demodulation signal.

4. The system as claimed in claim 3, further comprising a synchronization error detector coupled to the demodulator and the first memory for detecting an error in the synchronization codes of the demodulation signal, producing a synchronization erasure indicator when the error in the synchronization codes is detected, and storing the synchronization erasure indicator in the first memory, wherein the BIS to LDC erasure generator produces the LDC erasure bit based on the BIS erasure indicator and the synchronization erasure indicator.

5. The system as claimed in claim 4, wherein the demodulation signal is an error correction code (ECC) cluster, the high protective codeword is a BIS, and the low protective codeword is an LDC.

6. The system as claimed in claim 5, wherein the first memory is a static random access memory (SRAM).

7. The system as claimed in claim 6, wherein the second memory is a dynamic random access memory (DRAM).

8. A decoding system for a high-density recording medium, comprising:

a demodulator for receiving a modulation signal and demodulating the modulation signal to produce a

## 11

demodulation signal, wherein the demodulation signal has high and low protective codewords;

a first de-interleaver coupled to the demodulator for receiving the demodulation signal and de-interleaving the high protective codeword of the demodulation signal to produce a de-interleaved high protective codeword;

a first memory coupled to the first de-interleaver for storing the de-interleaved high protective codeword;

a high protective codeword decoder connected to the first memory for decoding the de-interleaved high protective codeword and correcting the de-interleaved high protective codeword in the first memory to produce a BIS erasure indicator with a position information;

a BIS to LDC erasure generator connected to the first memory for producing an LDC erasure bit, based on the BIS erasure indicator, for a low protective codeword;

a second memory connected to the demodulator for storing the low protective codeword of the demodulation signal;

a second de-interleaver coupled to the second memory for de-interleaving the low protective codeword to thereby produce a de-interleaved low protective codeword; and

a low protective codeword decoder connected to the second memory and the BIS to LDC erasure generator for decoding the low protective codeword and correcting the low protective codeword in the second memory;

wherein, in decoding, the low protective codeword decoder first decodes and corrects the low protective codeword, and then decodes and corrects the low protective codeword based on the LDC erasure bit when the low protective codeword exceeds a decoding capability of the low protective codeword decoder.

9. The system as claimed in claim 8, further comprising a synchronization error detector coupled to the demodulator and the first memory for detecting an error in the synchronization codes of the demodulation signal, producing a synchronization erasure indicator when the error in the synchronization codes is detected, and storing the synchronization erasure indicator in the first memory, wherein the BIS to LDC erasure generator produces the LDC erasure bit based on the BIS erasure indicator and the synchronization erasure indicator.

10. The system as claimed in claim 9, wherein the demodulation signal is an error correction code (ECC) cluster, the high protective codeword is a BIS, and the low protective codeword is an LDC.

11. The system as claimed in claim 10, wherein the first memory is a static random access memory (SRAM).

12. The system as claimed in claim 11, wherein the second memory is a dynamic random access memory (DRAM).

13. A decoding method for a high-density recording medium, which decodes a signal with high protective codewords and low protective codewords, the method comprising the steps of:

- (A) initializing a codeword counting variable;
- (B) determining whether a high protective codeword decoding is complete, and executing step (E) when the high protective codeword decoding is complete and otherwise step (C);
- (C) determining whether a low protective codeword is correctable, and correcting the low protective codeword when the low protective codeword is correctable or otherwise recording the low protective codeword in a table as an uncorrectable codeword;

## 12

- (D) increasing the codeword counting variable by one, and executing step (B);
- (E) determining whether all uncorrectable codewords in the table are completely decoded; and
- (F) if all uncorrectable codewords in the table are not completely decoded, producing an LDC erasure bit for a corresponding low protective codeword based on a BIS erasure indicator of the high protective codeword, then decoding and correcting the corresponding low protective codeword based on the LDC erasure bit, and executing step (E).

14. The method as claimed in claim 13, further comprising the steps of:

- (G) if all uncorrectable codewords in the table are completely decoded, increasing the codeword counting variable by one based on the LDC erasure bit of each low protective codeword to decode and correct remaining low protective codewords; and
- (H) determining whether a low protective codeword decoding concurrently activated with the high protective codeword decoding is complete, if the decoding is complete, increasing the codeword counting variable by one and executing step (G), or otherwise ending the decoding.

15. The method as claimed in claim 14, wherein the demodulation signal is an error correction code (ECC) cluster, the high protective codeword is a BIS, and the low protective codeword is an LDC.

16. A decoding method for a high-density recording medium, which decodes a signal with high and low protective codewords, the method comprising the steps of:

- (A) initializing a codeword counting variable;
- (B) determining whether a high protective codeword decoding is complete, if the decoding is complete, executing step (D), or otherwise executing step (C);
- (C) determining whether a low protective codeword is uncorrectable, if the low protective codeword is uncorrectable, continue decoding until the high protective codeword decoding is complete;
- (D) producing an LDC erasure bit for the low protective codeword based on a BIS erasure indicator of the high protective codeword, and decoding and correcting the low protective codeword based on the LDC erasure bit; and
- (E) determining whether a low protective codeword decoding is complete, and ending when the decoding is complete.

17. The method as claimed in claim 16, further comprising the steps of:

- (F) decoding and correcting the low protective codeword when it is determined that the low protective codeword is correctable in step (c); and
- (G) increasing the codeword counting variable by one, and executing step (B).

18. The method as claimed in claim 17, further comprising the step of:

- (H) increasing the codeword counting variable by one and executing step (D) when step (E) determines that the low protective codeword decoding is not complete.

19. The method as claimed in claim 18, wherein the demodulation signal is an error correction code (ECC) cluster, the high protective codeword is a BIS, and the low protective codeword is an LDC.