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Parallel Writing and Detection for Two Dimensional Magnetic Recording Channel

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ABSTRACT

Two-dimensional magnetic recording (TDMR) is treated as the next generation magnetic recording method, but because of its high channel bit error rate, it is difficult to use in practices. In this paper, we introduce a new writing method that can decrease the nonlinear media error effectively, and it can also achieve 10 Tb/in^2 of user bit density on a magnetic recording medium with 20 Teragrains/in^2.

Key Words : Two-dimensional magnetic recording, non-linear media error, LDPC, shingled writing, two-dimensional detection

Ⅰ. INTRODUCTION

Because of super-paramagnetic limiting and thermal stability, conventional perpendicular magnetic recording is limited at about 1Tb/in^2. A new recording method is necessary to break through rhis limitation[1]. Bit patterned magnetic recording (BPMR)[2], heat assisted magnetic recording (HAMR), two-dimensional magnetic recording (TDMR) and microwave assisted magnetic recording (MAMR) are treated as the next generation magnetic recording technologies to achieve more than 1 Tb/in^2. Moreover, in theory, TDMR can even achieve 10Tb/in^2 [1,3].

TDMR combines two important technologies: shingled writing recording (SWR) and two-dimensional magnetic recording. For SWR, a wide write-pole is used, making heavily overlapped tracks. For this reason, the resulting tracks are much narrower than the original written width[1]. Only one corner of the write-head is important[3]. Moreover, the fields are constrained only on one edge of down-track and one edge of cross-track. The vertical fields will be more uniform through the thickness of the medium. Because of these two factors, high field levels can be maintained[1].

TDMR proposes to use revolutionary 2-D codes and detectors to retrieve the data in this low-SNR environment. The advantage is that the costs of researching, developing, and manufacturing systems are lower than in systems with completely new heads and media. The main challenges lie also in developing the required low SNR 2-D detectors and codes[4].

Even though designing a detector that accounts for the high 2-D correlation of the noise is a considerable challenge, there have already been some studies for TDMR detector and decoder. Some researchers have tried three-track Viterbi algorithm (3TVA) and decision feedback Viterbi algorithm (DFVA) and achieving a bit error rate (BER) in the range of 13%-16%[5], and 2-D MAP detector achieved 0.06-0.08 BER[6]. Usually, LDPC code is used for TDMR encoder. A BER of nearly 10^{-5} has been achieved at about 4Tb/in^2, as introduced in[7].

In this study, we proposed a parallel writing

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method for TDMR readback signal processing that would effectively reduce the nonlinear media noise. The rest of this paper is organized as follows: we present a way to build a four-grain media model in Section II. Then, in Section III, we give the details of our new writing method and contrast it with conventional TDMR signal processing. We show the simulation result in Section IV. In Section V, we provide our conclusion.

Ⅱ. FOUR-GRAIN MODEL FOR TDMR

The four-grain model is one model that is simplified by the discrete-grain model. This model attempts to model the recording medium by representing magnetic grains as random-sized tiles that predefine shapes before[5]. The variation in grain shapes and sizes can be modeled by letting the grains span over various adjacent cells with different probability, respectively[5]. In our four-grain model the grain shapes are defined as 1×1,1×2, 2×1, 2×2 four kinds of shapes with probability p_1, p_2, p_3, p_4, which will confirm that $p_1+p_2+p_3+p_4=1$[8].

We assume that the number of channel bits in the medium is *N*×*N*, and tiling the grains in this *N*×*N* area. The total numbers of tiles of size 1×1, 1×2, 2×1, and 2×2 are N_1, N_2, N_3, and N_4, respectively such that $N^2=N_1+2N_2+3N_3+4N_4$[8].

To create the medium with these four grain model, we utilize the following algorithm: first, randomly place 2×2 tiles in the medium. Then, randomly place 1×2 and 2×1 tiles, respectively, in the remaining slots of the square. Finally, place the remaining 1×1 tiles in the remaining slots.

Grains with only one cell are magnetized exactly, and grains with more than one cell will be written more than one times. The grain will be finally magnetized by the magnetization of the last constituent cells of each grain[5]. Here, in one grain, the cells are written in a row-by-row fashion starting from the top-leftmost cell of the medium and ending in the bottom-rightmost cell. Thus the magnetization of each grain will be the magnetized as its bottom-rightmost cell[4]. For example, let us have an ideal medium with 10×10 bits size and tiling the ideal medium with the four kinds of shape grains. Then, the bit in each grain will be rewritten as Fig. 1 shows.

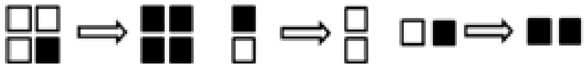

Fig. 1. writing style of one grain

The readback of TDMR can be obtained from scans of the medium. Actually, the TDMR bit cell size is comparable to the resolution of the read head, which adds a considerable amount of 2-D interference to the TDMR readback signal[6-9]. The readback signal can be calculated by the convolution of the recorded magnetization of the medium and the 2-D read sensitivity function given below:

$$h(x,y)=\exp\left(\frac{-1.34898^2(x^2+y^2)}{2(T_{50}/T)^2}\right)$$

Here T_{50} is the half pulse-width, and T is the length of the square bit cell[6,9]. x, y denote locations along down-track and cross-track directions, respectively. In our model, the position jitter is ignored[9]. Thus the TDMR channel output can be expressed as:

$$Y(x,y)=\sum_{i,j}X_{x-1,y-j}h_{i,j}+n$$

where $X_{x,y}$ denotes the medium data array, and n denotes the electronic noise[10].

Ⅲ. SIGNAL PROCESSING AND PARALLEL WRITING METHOD

In practice, there will be 20 teragrains/in^2 in TDMR medium, with the expectation of recording for about 10 Tb/in^2 (on average, each user bit is

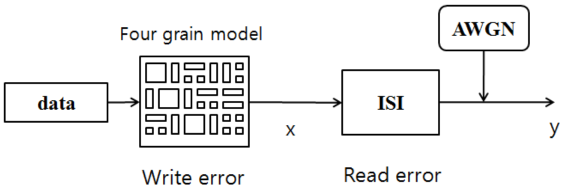

Fig. 2. TDMR channel modeling block diagram

stored on 2 grains). In conventional method, for example, we transfer 10 user bits to 40 channel bits, and then write these channel bits on 20 grains medium. We know nothing about the boundaries of the grain. After readback, we can get the soft information about the 40 channel bit, and, finally, transfer them back to 10 user bit[3].

In addition, we use a high code rate LDPC code for the data encoding instead of 1/4 modulation code to make 20 billion grains recording 10 billion user bits. The LDPC code used in our channel includes 1/2, 1/3, 1/4 and 2/3 code rate LDPC code, and changing the proportion of user bits per channel bit in this TDMR channel by changing the code rate of the LDPC encoder.

In our study, the parity check matrix H is created by two submatrixes. One is created randomly and the size of the submatrix is parity length by message length. Another submatrix is dual diagonal form, and the size of this submatrix is parity length by parity length. The matrix size is 414×552, and it is divided into 9×12 block matrix. The size of each block is 46×46. Each number in the matrix means the number of cyclic right shift of 46×46 identity matrix.

For the signal processing, in addition to the LDPC code we have used partial response (PR) equalizer, and soft output Viterbi algorithm (SOVA) are also used in our channel to decrease the bit error rate.

The write process knows nothing about the location of the grains. Because of the random distributed recording grain, and the grains with random size and shape in TDMR, the bit error rate will be very high[1,3]. To decrease this media error and ISI error, a high code rate 2-D channel coding needs to be used[1]. In conventional method, even the high code rate error correcting code is used for the TDMR channel, the bit error rate is still very high. This has already become a big barrier for TDMR to be applied in real-world. Considering the character of the grains lying on the medium, we write the same data on two different places of the medium, the media error will occur in different parts of these two places. Combining this two channel output will reduce the nonlinearity media error. This may look like a multichannel transmission used in the TDMR channel.

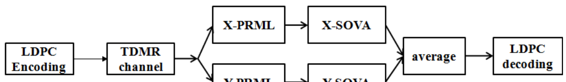

Fig. 3. Block diagrams of the proposed signal processing system for conventional writing method

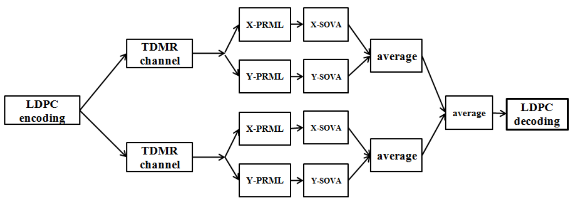

Fig. 4. Block diagrams of the proposed signal processing system

Ⅳ. SIMULATION RESULT

We assumed that the data is read per-page. Each page has a size of 1024×1024, and we choose the PR target (1 6 1) for both along- and across-track. We chose a 2/3 code rate LDPC code for the parallel writing method and a 1/3 code rate LDPC code for conventional method to make these two methods get the same user bits per grain. The channel density is varied by changing the size of the bit cell. For example, here we get four different probabilities (16/24 3/24 3/24 2/24) for p_1, p_2, p_3 and p_4, respectively, and we can get the average grain size equals to the area of 1.5 channel bits from these four probabilities; this will achieve 2 user bits per grain. In the same way (17/24 3/24 3/24 1/24) to achieve average capacity equals 2.18 user bits per grain, (53/72 9/72 9/72 1/72) to achieve average capacity equals 2.32 user bits per grain and (59/72 6/72 6/72 1/72) to achieve average capacity equals 2.48 user bit per grain.

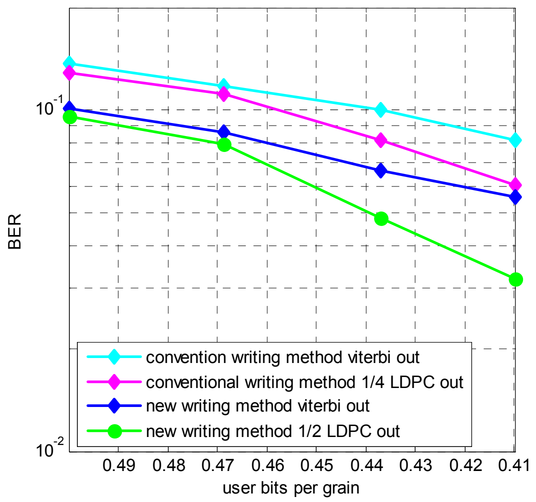

Fig. 5. BER performance of channel capacity

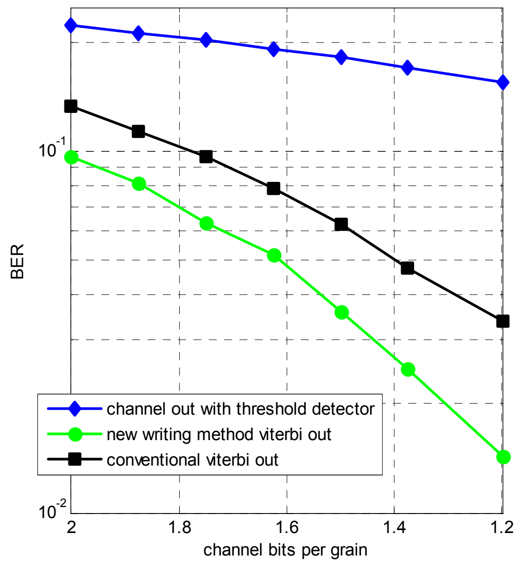

Fig. 6. BER performance of channel bit density

In Fig. 5, we have chosen 1/4 and 1/2 as the LDPC code rate for the conventional writing method and the proposed method, respectively. Both achieve 10 Tb/in^2 when the channel bit per grain rate is 2. Fig. 6 shows that Viterbi detector output of the proposed writing method has a better BER performance than the conventional method. In Fig. 7, we set the T_{50} equal to 1.2*T*, which can make the detector a larger margin as the ITI becomes more significant at all densities.

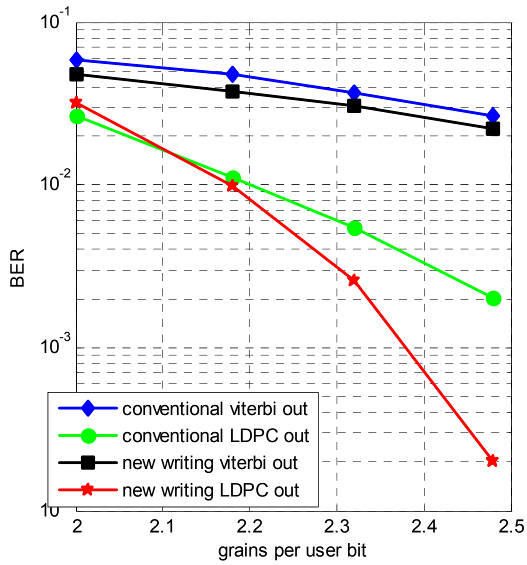

Fig. 7. The relationship between BER and the capacity of two writing method with T_{50}=1.2T.

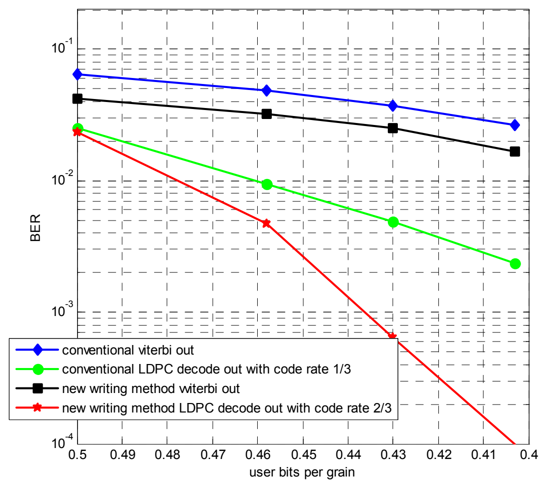

Fig. 8. The relationship between BER and the capacity of two writing method with (1 3 1) PR target.

We have tried several different kinds of PR targets for the TDMR channel. From Fig. 8 and 9, the channel LDPC decoder output BER achieves a better performance at (1 6 1) PR target than (1 3 1) PR target. These two methods achieve the same capacity, but the proposed writing method can achieve a better bit error rate than the conventional method. Also, it achieves 10^{-6} at about 2.48 grains per user bit, which can achieve about 8 Tb/in^2.

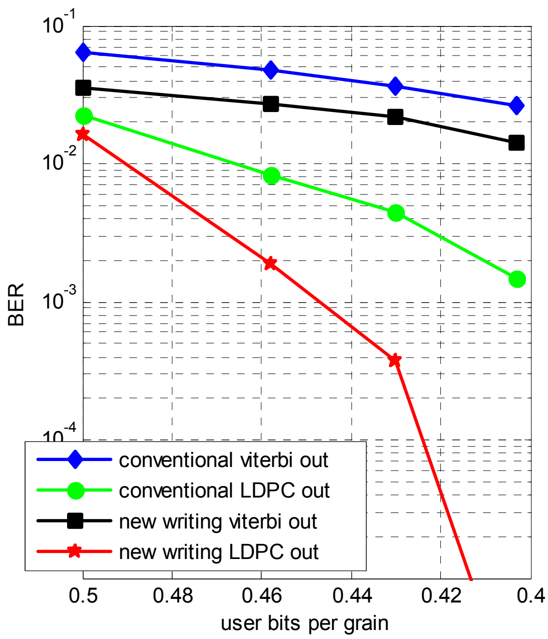

Fig. 9. The relationship between BER and the capacity of two writing method with (1 6 1) PR target

V. CONCLUSION

In this paper, we have described a four-grain model for TDMR channel modeling. Then considering the characteristics of the bit recorded in the TDMR medium and the tiling character of magnetic grain in the TDMR medium, we built a new writing method for TDMR. We compared this writing method with the conventional TDMR method. From the simulation, the proposed method can effectively decrease the nonlinear media error. Thus, while these two methods achieve the same capacity, the proposed writing method has a better performance than the conventional recording method.

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