PRODUCTION OF LIM-DOW MEDIA

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Abstract - Among many types of recording media MO storage has higher possibility to progress with improving random access speed and transfer rate, minimizing drive size, and high capacity at the same time. A lot of engineers have thought one of the approach for such improvement is light intensity modulation direct over write method (LIM-DOW). They thought ,however ,[1] it was hard to mass-produce because LIM-DOW media consists of multiple magnetic multilayer. So we have been using quality engineering (Taguchi method) to improve the efficiency of development. And it was proved that it was possible to do the mass-production of LIM-DOW media.

KEYWORDS : LIM-DOW, MASS-PRODUCTION, QUALITY ENGINEERING, PARAMETER DESIGN, 6-MAGNETIC-LAYERS

1. INTRODUCTION

It is widely known that the recording speed of MO is slower than that of the other types of high capacity media as it requires three process on recording; namely, erasing, writing and verifying. It has been said that this slower recording speed limited the utility value of the MO media. To improve the recording speed of the MO, many researchers have studied LIM-DOW media, which can perform recording without the erasing process [1]. However, tremendous time required for the development of LIM-DOW for mass-production has prevented it from happening. There are some additional reasons why the mass-production of LIM-DOW has not taken place so far. Many researchers have thought its complex magnetic multilayer structure would be an obstacle to scale up the production. The complexity of LIM-DOW, however, does not directly influence the mass-producibility. As a matter of fact, it is the efficiency of its development that is seriously affected by the complexity. Therefore, the development efficiency should be improved, especially for such product as LIM-DOW media that has a highly complex structure and we adopted the quality engineering for that purpose [2]. This paper introduces the example of development of the LIM-DOW media through quality engineering approaches. After a series of optimization and evaluation, a robust generic function for LIM-DOW was obtained, paving the way for the mass-production of the LIM-DOW media.

Some results of the measurement of dynamic properties of the LIM-DOW media made by a mass-producible sputtering machine is also described.

2. QUALITY ENGINEERING

Quality engineering approaches were adopted in developing the mass production process. They use two steps in the design process; one is parameter design and the other is tolerance design. This report will briefly discusses the parameter design alone and will not touch upon the tolerance design.

The outline of the development flow with the parameter design is shown below; [2]

Selection of system

Optimization and evaluation

In selecting the system, for example, a structure of LIM-DOW, a sputtering method and others will be chosen. The control factor [3] of the selected system is then optimized. During the optimization of the selected system, the system needs to be evaluated. If the quality of the selected system is proved to be insufficient, another system should be selected, and the same flow is to be repeated until adequate quality is obtained.

How to measure the quality is a critical issue in this parameter design process. The generic function should be identified as it represents the relationship between an input and output of the selected system. The ideal generic function is defined as $y=\beta M$. M is the signal factor that represents the input, $y$ is the characteristic value that represents the output and $\beta$ is the sensitivity. In fact, some noise such as the one from the production process, environment, etc. cause errors in this function. The objective of the parameter design is to minimize such errors by means of tuning the control factors of the system.

Although, a character represents the error might be required in the process of minimization, the parameter design employs S/N, which quantifies the error. S/N is defined by the ratio of the variance size of sensitivity and the error.

$$\frac{S}{N} = \frac{\beta^2}{\sigma^2}$$

$\sigma^2$ is given by the following equations;

$$\sigma^2 = \frac{S_e}{f}$$

where $f$ is degrees of freedom. $S_e$ is the sum of squares of all
data:
\[ S_T = \sum_i y_i^2 \]  
(4)

\[ S_p = \frac{\sum_i M_i y_i^2}{\sum_i r_i M_i^2} \]  
where \( r_i \) is the number of the repetition at \( M_i \) and \( \beta^2 \) is
\[ \frac{S_p - \sigma^2}{\sum_i r_i M_i^2} \]  
(5)

The robustness of the parameter design needs to be improved against all kinds of noise conditions by means of deliberately imposing noise on the systems.

### 3. DEVELOPMENT BY QUALITY ENGINEERING APPROACHES

We introduce an example of LIM-DOW development by using the quality engineering in the laboratory. A 4-magnetic-layers structure [4] was selected as the system of LIM-DOW as shown in Fig. 1 and the generic function of LIM-DOW was defined as two-step transcription process. The first step is transcription from the light energy to the magnetization of marks on writing layer. The second step is transcription from the magnetized marks on writing layer to memory layer and readout layer. More precisely, the lighting time of LD has adopted as the signal factor \( M \). The characteristic value \( y \) is the length of the magnetized marks on memory and readout layer.

Table 1 shows the signal factor and the noise factors. We used the L9 and L4 orthogonal arrays (L9 and L4) to calculate the S/N. The signal factor and the noise factor that relate to the recording process was put on L9, and the noise factor that relates to the production process was put on L4. The noise factors were assigned to evaluate the robustness of generic function. Table 2 shows the example of the measurement results of the length of the magnetized marks on memory and readout layer with disk tester. Signals of TIA (Time Interval Analyzer) were measured according to each condition of L9 \( \times \) L4. The min. and the max. refers to the minimum and the maximum mark length of the distribution of all the mark lengths. S/N was calculated as follows:[5]

\[ S_T = 71^2 + 94^2 + \cdots + 155^2 = 153625 \]
\[ r = 70^2 + 130^2 + 190^2 = 57900 \]
\[ S_p = 71^2 X 70 + 3259 X 130 + 4479 X 190^2 / (24 X r) \]
\[ = 1466125.52 \]
\[ S_e = S_T - S_p \]
\[ V_e = S_e \]
\[ S/N = 10 \log ((S_s V_e) / (24 X r)) / V_e = -29.71 \text{ (db)} \]

When higher S/N was obtained, the generic function of LIM-DOW was more robust against the fluctuation of noise factors in table 1.

#### Table 1 The signal factor and the noise factors.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal Factor</td>
<td>M</td>
<td>LD irradiation time (nsec)</td>
<td>70</td>
</tr>
<tr>
<td>Noise Factors</td>
<td>Orthogonal array L9</td>
<td>N</td>
<td>Write durability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>O</td>
<td>Magnetic field (Oe)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P</td>
<td>LD power (mW)</td>
</tr>
<tr>
<td>Orthogonal array L4</td>
<td>Q</td>
<td>M.Layer Tb%</td>
<td>+1.5%</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>W.Layer Dy%</td>
<td>+1.0%</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>MO thickness</td>
<td>+5.0%</td>
</tr>
</tbody>
</table>

#### Table 2 The result of the measurement by using of L9 and L4.

<table>
<thead>
<tr>
<th>No.</th>
<th>M</th>
<th>N</th>
<th>C</th>
<th>P</th>
<th>min</th>
<th>max</th>
<th>min</th>
<th>max</th>
<th>min</th>
<th>max</th>
<th>min</th>
<th>max</th>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>71 nsec</td>
<td>94</td>
<td>45</td>
<td>100</td>
<td>83</td>
<td>102</td>
<td>0</td>
<td>0</td>
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<td>2</td>
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<td>3</td>
<td>3</td>
<td>119</td>
<td>137</td>
<td>101</td>
<td>121</td>
<td>159</td>
<td>89</td>
<td>105</td>
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<tr>
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<td>3</td>
<td>161</td>
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<td>3</td>
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<tr>
<td>9</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>172</td>
<td>187</td>
<td>154</td>
<td>171</td>
<td>171</td>
<td>202</td>
<td>137</td>
<td>155</td>
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</tbody>
</table>
L18 orthogonal array (L18) was used to optimize the control factors shown in Table 3, where the factors A, B, C, D are related to the sputtering process, that are the pressure of Ar and so on. And the factors E, F, G, H have relations with the structure of LIM-DOW, that are the contents of material, the thickness of the magnetic layers and so on. The control factors were assigned to L18 to obtain a robust function by selecting the each control factors level. According to the condition of each line in L18 orthogonal array, the LIM-DOW samples were made and S/N of each lines were calculated as in table3. Then the best recording power of each sample which had also the minimum jitters were measured.

The S/N of each control factors levels (conditions) are calculated by using the S/N in table3 as follows;

\[
S/N(A1) = (-44.60-35.12-32.11-\cdots-29.71)/9
\]
\[
S/N(A2) = (-35.35-30.95-36.34-\cdots-38.29)/9
\]
\[
S/N(B1) = (-44.60-35.12-32.11-35.35-30.95-36.34)/6
\]
\[
S/N(H3) = (-32.11-45.01-45.82-36.34-32.80-33.58)/6
\]

![Graph showing the factorial effect of S/N and recording power](image)

**Figure 2** The factorial effect of the S/N and the recording power at which the samples perform the jitters minimum.
Table 4 The result of the confirmation experiment.

<table>
<thead>
<tr>
<th></th>
<th>Best condition</th>
<th>Worst condition</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated value of S/N (dB)</td>
<td>-30.31</td>
<td>-44.11</td>
<td>13.80</td>
</tr>
<tr>
<td>Experimental value of S/N (dB)</td>
<td>-25.97</td>
<td>-41.67</td>
<td>15.25</td>
</tr>
</tbody>
</table>

Figure 2 shows the factorial effect of S/N (effect of control factor) and the recording power at which the output signal performs the best jitters. From this figure the best S/N and the worst S/N conditions can be estimated as follows;

- Best: A2B2C3D3E2F3GIH2
- Worst: A1B2C1D2E2F2G2H2

From this factorial effect figure the several technical issues can be identified.

The reproducibility can be evaluated and confirmed by an experiment. Table 4 shows the result of the confirmation test, where the estimated value is calculated by using factorial effect in Fig. 2 and experiment results are obtained by measuring samples that are newly made according to the best and the worst conditions. When the difference between the estimated gain and the experimental one is small, the reproducibility of each control factorial effect in L18 is judged as good. On the other hand, when the difference is large, another system needs to be selected. In this table, the difference between estimated value and the experimental value is quite small. So, we judged the gain of these control factor in this system must reproduce in the mass-production as same as in the laboratory.

It is possible to estimate the tunable range of sensitivity without the reduction of S/N. For example, the control factor H is tunable in wider range. But S/N at H1 or H3 is lower than the one at H2. When tuning the sensitivity by the factor H, therefore, the reduction of S/N should be taken into consideration. If the tunable range is wide enough, it is possible to design some media with different sensitivities at the same time.

Quality engineering approaches allow the evaluation of mass-producibility of LIM-DOW just in the laboratory, where only the experiments of a smaller scale than mass-production can be performed. A new sputtering machine was then designed reflecting the result of quality engineering approaches for LIM-DOW. This sputtering machine has the ability to produce 6-MO-layers LIM-DOW media.

4. PERFORMANCE OF LIM-DOW

LIM-DOW media shown in Fig. 3 with the sputtering machine mentioned in Section 3 were fabricated. The media have six magnetic layers sandwiched between SiN layers. An AI layer was placed on the top of these layers. The magnetic layers consist of read-out, memory, intermediate, writing, switching and initializing layers.

The jitter needs to be monitored when the writing power deviates from the optimum value. Figure 4 shows the result of the relationship between jitters and writing power of this LIM-DOW disk with overwriting random pattern. The horizontal axis is writing power and the vertical axis represents jitters of the random pattern. In this figure, the curve of the margin with erasing process of the same disk is also shown. There is no difference between these margins of the two-types writing.

Figure 3 The cross-section of LIM-DOW media that has 6-magnetic-layers. This media is added to switching and Initializing layer on 4-magnetic-layers LIM-DOW.

Figure 4 The power margin of LIM-DOW of writing after erasing(●) and overwriting(○). The overwriting or erasing is after writing the 1.1 times of nominal power. The writing data is random pattern. The inner velocity is 9.4 m/s, and the wave length is 680 nm.
Figure 5 shows the performance before (●) and after (○) the cyclic writing durability test. The circles around 3.0 mW indicate the erasing process of 2T tone marks by DC power, where 1T is 38.0 ns. As shown in the Fig. 5, writing process begins at the power of 5.0 mW, where 1 MHz and 50% duty marks are plotted (process 1). From 5.0 mW to 15.0 mW, C/N of 7 MHz 16% duty marks before/after the cycles are plotted (process 3). The linear velocity is 9.4 m/s, and λ=780 nm.

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5. CONCLUSION

We have used quality engineering for the development of LIM-DOW media. Quality engineering achieved two important things. Firstly, it allows the evaluation of the reproducibility of mass-production.

Secondly, it enables the estimation of the tunable range of the sensitivity without the reduction of S/N. These two points were first estimated in the laboratory and then the possibility to mass-produce LIM-DOW media from the parameter design point of view was confirmed.

6. REFERENCES

[2] G.Taguchi, “Taguchi methods, research and development” American Supplier Institute, 1992, (Translation from Japanese)