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Thin Film Magnetic Head Wafer Inspection Technique using Geometrical Feature-Based Image Comparison

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Abstract

A reliable inspection system for thin film magnetic head (TFH) patterns on a ceramic wafer substrate has been developed. Since the TFH patterns have a great variety of shapes, the inspection criteria becomes much more complex; that is, the fatal defect size and orientation are defined according to pattern shape. To overcome this problem, we have developed a method that can detect fatal defects by examining defect size according to pattern size and pattern direction, which are stored as images. In this paper, the inspection algorithm for TFH patterns is discussed and we also mention the hardware implementation of the inspection system. Experimental results show the validity of our method.

1 Introduction

A thin film magnetic head (TFH) is widely used as an information read/write device to the hard disk drive in personal computers. However, hard disk drives are now cheaper to make and specific model lifetimes have become much shorter. Therefore, the fabrication machine must be able to be applied to various kinds of models and products and must be less costly.

The TFH is fabricated by forming a fine circuit pattern to every TFH chip on a ceramic wafer by lithography. This fabrication process is similar to the semiconductor process and should have a visual inspection step for monitoring the process condition to prevent fabrication of defective products. However, the TFH patterns have a great variety of shapes, and the criteria for inspecting the TFH pattern has become much more complex. Therefore, a visual inspection system is required to vary its sensitivity according to the pattern shape.

Concerning TFH pattern inspection, Wakisaka et al[1] have reported an inspection system which detects defects preventing false alarms caused by the pattern's surface texture. Matsuyama et al[2] have reported an inspection system which detects defects within/on a protection layer using optical defect enhancement and gray scale image processing. However, these systems are expensive and were not designed to cope with the pattern varieties. We have developed a new inspection system to satisfy this requirement.

2 TFH pattern and technical issues

Figure 1 shows an example of a TFH wafer and pattern. Thousands of TFH chips are fabricated on a ceramic wafer in the patterning process. TFH patterns consist of two types of circuit elements, a sub-micrometer-order magnetic sensor head and sub-millimeter-order wiring patterns. Figure 1b shows the TFH pattern, where the wiring pattern is divided into two regions by a center line. These regions are connected to the magnetic sensor. The shape of the wiring patterns is characterized by its variety; it's not uniform like those of semiconductor LSIs. In the visual inspection step, pattern defects and foreign particles should be detected to prevent fatal defects such as "disconnect" or "short" being caused in the upper step rather

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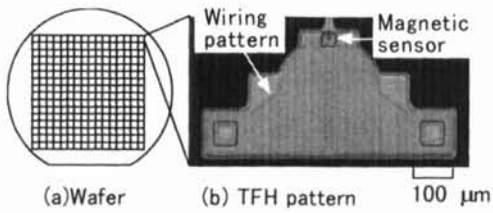

Fig. 1 TFH wafer and pattern

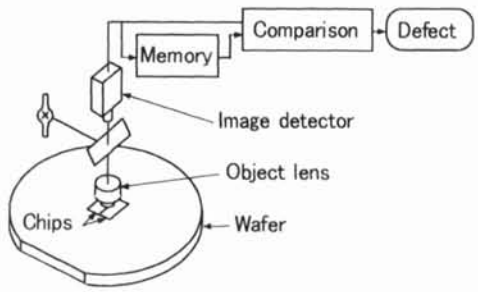

Fig. 2 Inspection principle

than in the electrical test step.

Figure 2 shows the inspection principle. The inspection principle is based on die-to-die image comparison. The optical images of the adjacent TFH chips are detected sequentially by the image detector, and a detected image is compared with the previously detected image that is stored in memory. Only a discrepancy between the two images is regarded as a defect.

The major technical issue concerning the inspection algorithm is to adjust the sensitivity of defect detection according to the objective pattern shape. Since the defect which causes a malfunction in the magnetic sensor circuit region would not cause any damage in the wiring pattern region, this issue we are focusing on is important to achieve a reliable inspection.

3 Geometrical Feature-Based Image Comparison

To match the requirement for TFH pattern inspection, we have developed a reliable inspection technique named "Geometrical Feature-Based Image Comparison". This algorithm is characterized by the following points.

1) It can detect fatal defects by examining the defect size according to pattern size and pattern direction.
2) It can be applied to various kinds of models and products customized by the user.
3) It has real-time processing with a pipelined architecture.

Figure 3 illustrates the principle of the algorithm. Every step of this algorithm is explained in the following.

(1) Detect defect candidates and calculate geometrical features

The detected image and stored image are compared and unmatched regions are detected as a binary image. In Fig. 3, there are four defect candidates. Each defect candidate is recognized separately through the labeling process and those geometrical features are calculated. Projection sizes of the region are used as geometrical features.

(2) Generate Defect feature images (DFIs)

DFIs are generated according to every feature type. Pixel values in defect candidate regions in DFIs are equal to geometrical features.

(3) Compare DFIs with Defect definition images (DDIs)

DDI is a key component of this algorithm. This image gives the threshold to detect defects. Its pixel values are equal to the inspection criteria, that is, the fatal defect size. Concerning the DDI of the X axis in Fig. 3, pixel values in the vertical pattern region (10) are smaller than those in the horizontal pattern region (30); that is, the projection size of the X axis of a certain region is more fatal in the vertical pattern region than in the horizontal pattern region. DDI is created by the user with a drawing tool using an objective image as a template. DDI is created for every model of products prior to the inspection. In a processing procedure, DFIs are aligned with DDIs using their original objective images. Then DFIs are compared with DDIs according to every feature type. Regions in DFIs whose pixel values are larger than DDIs are regarded as a fatal defect in real time.

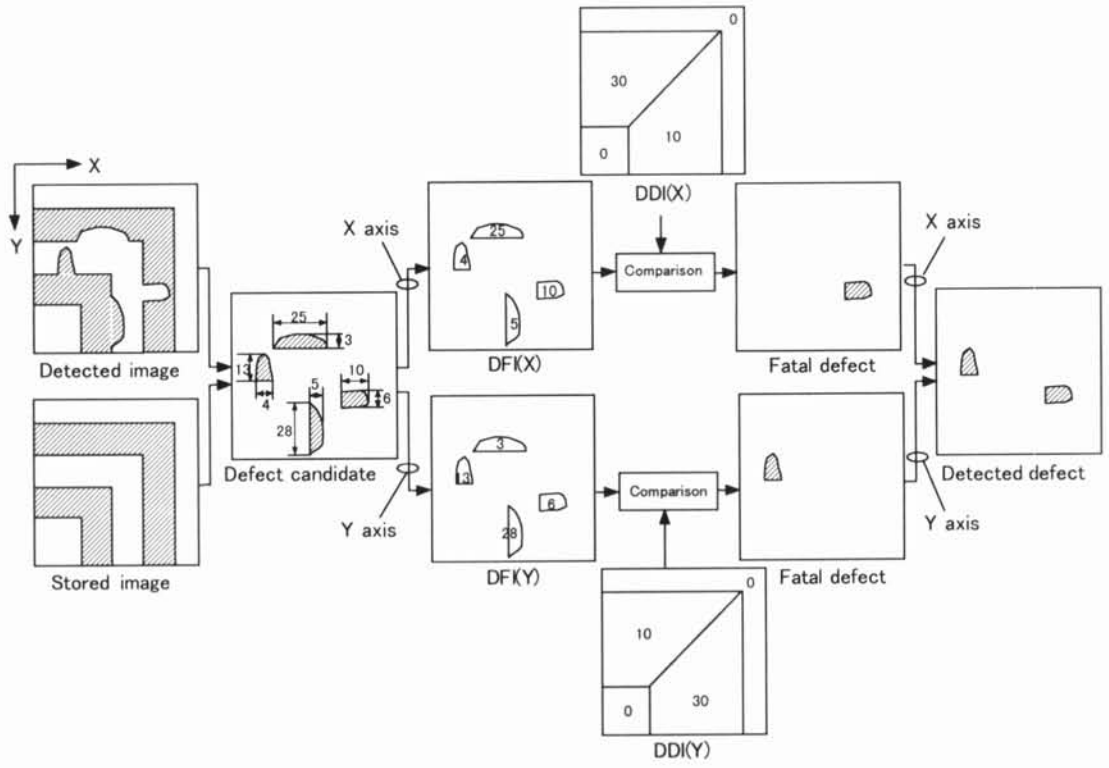

Fig. 3 Principle of Geometrical Feature-Based Image Comparison

(4) Compound of fatal defects of every feature type

Finally, fatal defects of every feature type are compounded as a result.

With our reliable inspection algorithm, only fatal defects can be pointed out and the review operation time after inspection is very much reduced.

4 Inspection system

We applied the developed technique to the TFH inspection system. Figure 4 shows an overview of the developed inspection system. This system consists of three main components: a wafer positioning tool, an optical microscope with a highly accurate auto-focus, and an image processing computer.

To detect the objective pattern with appropriate resolution, two objective lenses of the microscope are selected according to the inspection area. In the wiring pattern inspection, the pixel size is set to 3.0 μm and it changes to 0.2 μm in the magnetic sensor head inspection.

In the magnetic sensor inspection process, the large searching area in the matching process for the image comparison is expensive computationally. With a highly accurate and expensive wafer positioning tool, the searching area can be reduced but the inspection system is too expensive. Reducing this computational cost is the key issue. The pyramid algorithm is known to accelerate correlation. However, an aliasing error occurs in the image shrinking steps in a certain condition. Therefore, we adopted a correlation method whose convolution step is replaced with multiplication of their FFT images as follows.

$$F\{g(x,y)\bigstar h^*(x,y)\} = G(f_x,f_y)H^*(f_x,f_y) \quad (1)$$

where $g(x,y)$: detected image
$h(x,y)$: stored image
$*$: conjunction

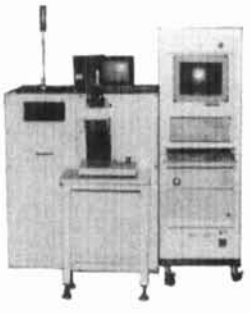

Fig. 4 Overview of inspection system

$\bigstar$: correlation
$F\{\ \}$: FFT operation
$G(f_x, f_y)$: FFT result of $g(x, y)$
$H(f_x, f_y)$: FFT result of $h(x, y)$

In addition, the calculation of FFT is accelerated by hardware that employs a vector processing unit. With our system (CPU:68040 + 40-MHz RISC processing unit), correlation with 256-pixel square images is achieved in 260 msec. As a result, our system can inspect at a high magnification without a highly accurate and expensive wafer positioning tool.

5 Evaluation of the system

Figure 5 shows an example of a defect detection result. Figure 5a shows the detected image. There are three abnormal parts in this image. There is only one fatal defect, however, which is located in the space between wiring patterns. Figure 5b shows the DDI. In this case, the inspection criteria for both the X and Y axis are the same. Figure 5c shows the defect candidates and Figure 5d shows the detected defect. With our method, only the fatal defect can be detected based on DDI.

The performance of the system was evaluated using a TFH wafer in a production line. In the case of the magnetic sensor inspection, 274 chips were inspected: 24 defective chips with fatal defects and 250 satisfactory chips. The detectable minimum size of the defect is 0.5 μm. The system achieved a defect detection rate of

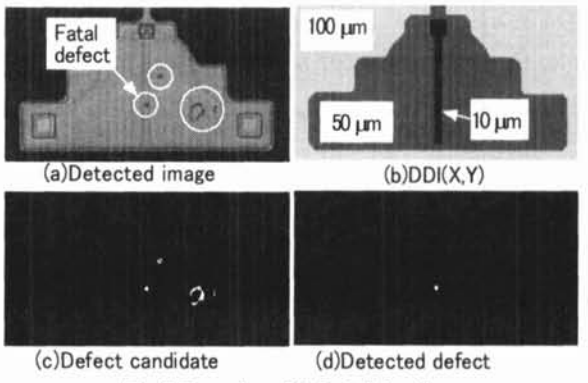

Fig. 5 Examples of defect detection

100% and a low rate of false alarms (0.8%). The inspection time was 1.0 sec/chip.

6 Conclusion

We developed a reliable inspection system for TFH patterns on wafers. To overcome the problem of adapting to complicated inspection criteria, a reliable inspection algorithm named "Geometrical Feature Based Image Comparison" was developed. This algorithm can detect fatal defects by examining defect size according to pattern shape. The performance of the inspection system was evaluated and it achieved a 100% defect detection rate, a low false alarm rate, and an inspection time of 1.0 sec/chip.

References

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[2] Y. Matsuyama, H. Iwata, H. Kubota, "Automatic visual inspection system for TFH (Thin Film magnetic Head) wafer using optical enhancement and image processing techniques", SPIE, Vol. 1771, pp. 20-29, July 1992.