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Failure analysis of ultrasonic pitting and carbon voids on magnetic recording disks

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Abstract

In this study, a new electrical tagging pattern system was used in the failure analysis to mark defect sectors, and with Kerr magneto-effect imaging, the defective sectors were effectively located for further failure analysis. The results of the failure analysis of ultrasonic pits and carbon void defects on disks showed that there was 30–40% loss of the recorded magnetic bit signal due to an increase in the gap between a recording head and a hard disk surface with the defects. Furthermore, the experiments conducted to improve disk performance by reducing the ultrasonic pit defects showed that low ultrasonic power for disk cleaning reduced ultrasonic pits significantly. Moreover, removing the biasing voltage on the substrate reduced carbon void defects significantly. The average number of the carbon voids per surface was reduced from 4 to 0.5, and the average size of the carbon voids was reduced from 8 to 3.8 μm.

Keywords: B. Failure analysis; Ultrasonic pits; Carbon void

1. Introduction

The primary function of a hard disk is to store information magnetically for a long period of time. Data are recorded onto the disk by a magnetic field produced from the head, which is flying only about ten nanometers above the disk surface [1–4]. Good dynamic characteristics of the actuation system are required [5,6]. Many techniques have been explored in an attempt to correlate magnetic errors flagged during the drive testing with the physical defects on magnetic disk surfaces [7,8]. Microscopic properties such as grain size, grain coupling and grain crystallographic orientation, determine the noise performance of the films. Optimization of macromagnetics and micromagnetics is required to get the best signal-to-noise ratio performance [2,9].

The substrate material of a hard disk is aluminum because of its light mass, rigidity and low cost. The structure consists of an under-layer (chromium), a magnetic layer (cobalt alloy), a protective layer (carbon) and a lubricant layer [10]. The protective layer acts to enhance the durability of the disk to the wear from heads landing and taking off. This layer also acts as a support for lubricant and a barrier to corrosion. The most common material used is amorphous hydrogenated carbon or “diamond-like carbon”, because of its unique tribological properties such as low friction coefficient, low wear rate and high hardness, which can be controlled by the amount of hydrogen incorporation into the film [11]. Alternate materials, such as yttrium-stabilized zirconia, have been evaluated but none has replaced carbon. In this study, the influence of the substrate bias voltage on the number of carbon void defects is investigated. Because the carbon overcoat acts as a barrier to corrosion, it is essential to reduce the number of carbon void defects.

Cleaning is a process that can happen in many ways and at different places in the overall manufacturing process. In the case of mechanically textured disks, this process can have the additional complexity of needing to remove the abrasives that have been used to roughen the surface. Several aqueous and ultrasonic steps may be needed, as well as carefully controlled surfactant additives. The ultrasonic waves are generated by an array of piezoelectric transducers in an immersion tank and travel parallel to the substrate surface. The ultrasonic energy creates and collapses small bubbles on the surface by cavitation. The collapsing action generates ultrasonic shock waves that dislodge the particles from the

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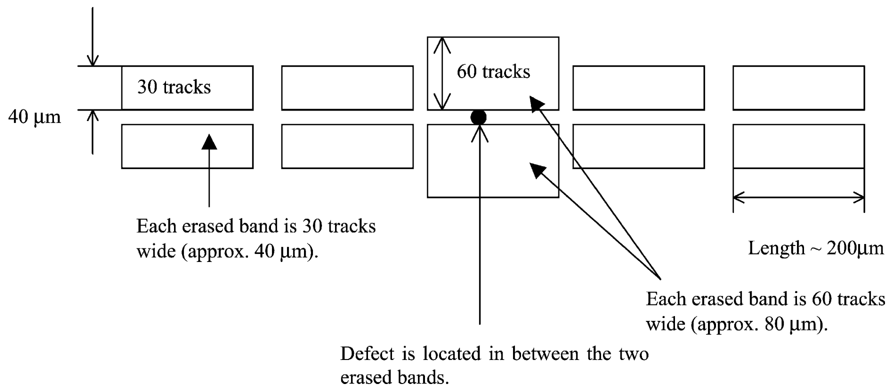

Fig. 1. Schematic diagram of the new electrical tagging pattern used in this study.

surface. Special care must be taken to avoid damage on the substrate surface with excessive ultrasonic energy. Furthermore, the surface being cleaned prior to sputter deposition is primarily made of Ni and therefore can be highly reactive to certain chemicals. The reactions can strongly influence the surface defects (or error bits), as well as mechanical performance of the finished product [10]. In this study, ultrasonic pits on substrate surfaces are investigated.

It has become of paramount importance to be able to perform failure analysis of these defects quickly and accurately without contaminating or confounding the defects. Non-destructive defect detection of defects with the help of magnetic makers using the Kerr effect imaging is used in the experiments to locate the defects with almost pinpoint accuracy (±5 μm). This eliminates a lot of guesswork in locating the defects for failure analysis. Although there is great progress in media design and fabrication to reduce the overall surface defects, the experimental techniques used in this study are expected to provide a new realm of understanding for further improvement.

2. Method and equipment

Issues mentioned above are addressed with a new electrical tagging pattern system developed by Seagate. The defect is marked using magnetic tagging software, which applies a non-return-to zero scheme to directly translate the channel bits to magnetic transitions during the writing of the magnetic pattern around the defect. This involves the erasure of a band of formatted tracks 360° around the hard disk surface. The erased bands will show a different optical contrast from the formatted tracks due to the Kerr effect. This enables one to quickly find the defects on the disk. In addition, it also eliminates inaccuracy of the old technique. A schematic diagram of the erased band of formatted tracks is shown in Fig. 1.

An atomic force microscope (AFM) was used to measure surface microscopic morphology of defects that can cause magnetic signal degradation. A scanning electron microscope (SEM) provided a multitude of applications for failure analysis of hard disk drives. An oscilloscope (disk drive analyzer) was used to perform electrical failure analysis at the drive level to correlate magnetic errors flagged during drive testing with actual physical defects. A glide tester was used to conduct glide test for zero defects. A surface profiler allowed for three-dimensional (3D) characterization of defects.

An optical surface analyzer (OSA) combining a high-speed ellipsometer, a reflectometer, a scatterometer, and a Kerr effect microscope, was used to measure surface characteristics of disks. The Kerr channel of the OSA detected the magnetic pattern and defects could be scribed for subsequent failure analysis. An optical microscope was also used for quick assessment of defective parts.

3. Analysis of ultrasonic pits

Fig. 2 shows amplitude changes of the recorded magnetic bit signal with respect to four locations with ultrasonic pits. The circles show locations of defects. The results show that there was 30–40% loss of the recorded magnetic bit signal due to an increase in the gap between a recording head and a hard disk surface with the defects.

Fig. 3 presents an OSA magnetic Kerr-channel image of one defect location, which is marked magnetically. The im-

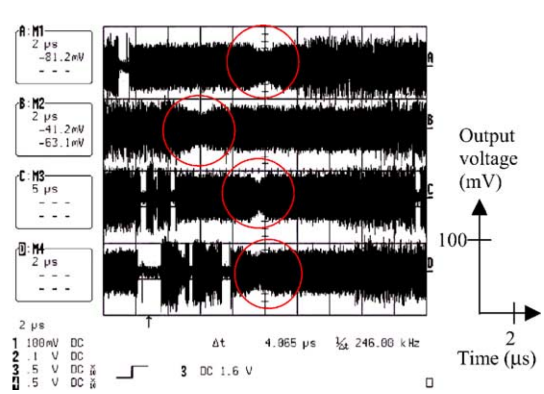

Fig. 2. Electrical oscilloscope signal showing amplitude changes at defect locations.

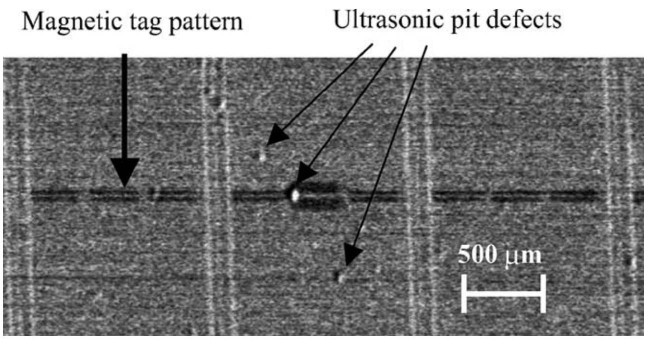

Fig. 3. An OSA Kerr-channel image showing ultrasonic pits magnetically tagged.

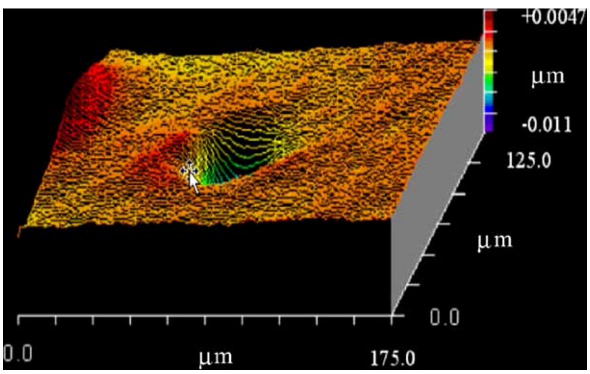

Fig. 4. A 3D image showing a shallow ultrasonic pit.

age is a section of the whole disk scan. The vertical lines are the servo wedge patterns on the disk surface. The magnetic tagging patterns are the dark horizontal lines and a defect is the bright spot located within the tagged pattern. The OSA Kerr-channel [12] enables multiple defects to be quickly located in tens of seconds compared to the undesirable ferro-fluid technique that is time consuming and may contaminate defects. The defects are then simultaneously tagged using a diamond scriber in the OSA for further analysis.

Fig. 4 presents a 3D image showing morphology of an ultrasonic pit. The ultrasonic pit was measured to be approximately 11.3 nm in depth. The ultrasonic pits were

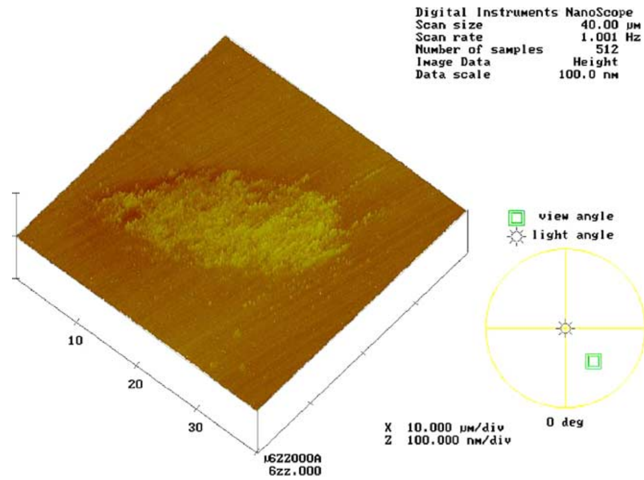

Fig. 6. AFM image of a carbon void.

shallow pits, typically measured to be 7.5–12.5 nm in depth.

Previously, the ultrasonic power supply voltage was set to be 200 V and the power was allowed to float. Now the power is set to be 100 W and the voltage is allowed to float to reduce the defects. The position of the disks in the tanks during the ultrasonic cleaning process is critical. The disks that are situated nearer to the source of the ultrasonic waves or exposed to greater ultrasonic energy will exhibit a cluster type of ultrasonic pits on the surfaces of the disks. On the other hand, the disks that are exposed to lower ultrasonic energy will exhibit a single type of ultrasonic pits. Fig. 5 shows the ultrasonic pitting levels before and after the power settings were changed. The result clearly shows significant reduction in the level for both single and cluster types of ultrasonic pits.

4. Analysis of carbon void

The electrical oscilloscope signal revealed amplitude changes of the recorded magnetic bit signal due to carbon void defects. Fig. 6 shows an AFM image of a carbon void defect. Cross-section analysis of the carbon void defect re-

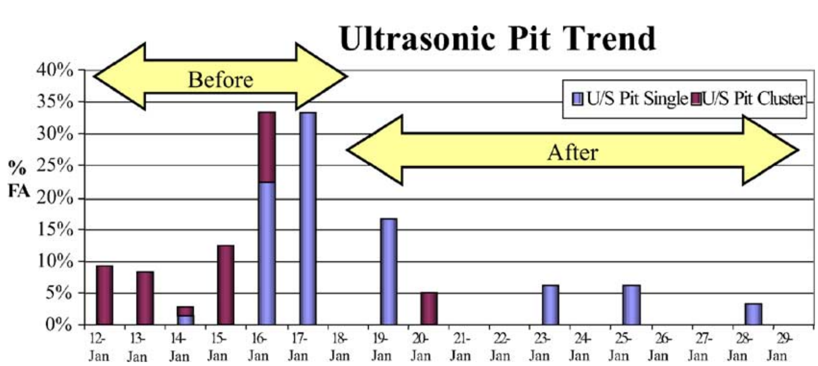

Fig. 5. Ultrasonic pitting levels before and after ultrasonic power settings were changed.

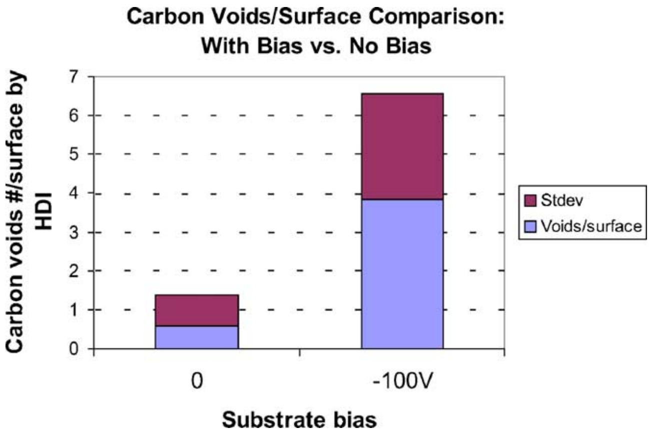

Fig. 7. Comparison of the numbers of carbon voids per surface.

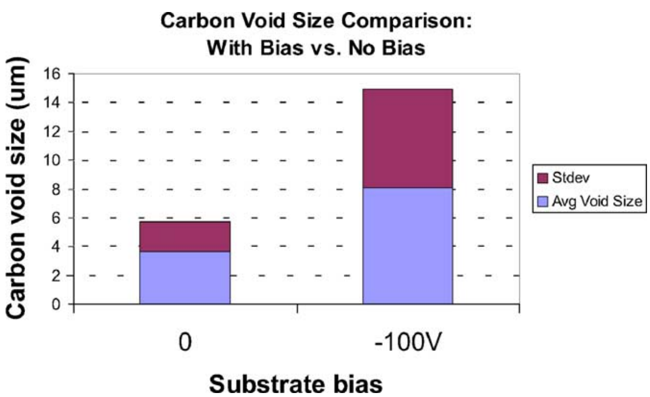

Fig. 8. Comparison of the sizes of carbon voids.

vealed that it was 14 μm × 30 μm in size, 5.8 nm in depth and 10.63–11.6 nm in height. The 5.8 nm depth of the carbon void is approximately equal to the carbon overcoat thickness of the disk.

Figs. 7 and 8 compare the numbers and the sizes of the carbon voids respectively when bias settings of 0 and −100 V were used. The results in Fig. 7 show that the number of carbon voids per surface was reduced from 4 to 0.5 when the bias voltage was reduced from –100 to 0 V. In addition, the average size of the carbon voids was also reduced from 8 to 3.8 μm, as shown in Fig. 8. Improvement in the standard deviation of the carbon void defects was also observed for the two cases. The substrate bias voltage can influence the numbers and sizes of carbon void defects on disk surfaces. Removing the bias voltage from the substrate helps to reduce the number and size of carbon voids significantly.

5. Summary

In this study, a new electrical tagging pattern system was used effectively to mark disk defects for failure analysis. The exact failure modes could be determined and the necessary improvement can be implemented to reduce the defects. The failure analysis of ultrasonic pits and carbon voids shows that the 30–40% loss of the recorded magnetic bit signal is due to an increase in the gap between a recording head and a hard disk surface with the defects. Reduction of ultrasonic pits on the disk surfaces could be achieved by reducing the ultrasonic power setting for the tank from 250 to 100 W. Reduction of carbon void defects can be achieved by removing the bias voltage on the substrate. The average number of carbon voids per surface was reduced from 4 to 0.5. In addition, the average size of carbon voids was reduced from 8 to 3.8 μm.

References

[1] J. Hajdu, F. Yarkowky, M. Suplicki, The electroless nickel process for memory disks, in: Proceedings of the Symposium on Magnetic Materials, Processes and Devices, California, 1990, pp. 685–686.
[2] K.E. Johnson, in: T. Arnoldussen, L. Nunnelly (Eds.), Fabrication of Low Noise Thin Film Media, Noise in Digital Magnetic Recording, vol. 12, World Scientific, Singapore, 1992, pp. 139–141.
[3] Z.W. Zhong, Z. Zheng, Flying height deviations in glide height tests, Sens. Actuators A: Phys. 105 (3) (2003) 255–260.
[4] Z.W. Zhong, Z. Zheng, Head–disk interfacial behavior in glide tests for manufacturing hard disks, Mater. Manuf. Process. 18 (1) (2003) 123–134.
[5] J. Sun, Z.W. Zhong, Finite element analysis of a new PZT actuator for hard disk drives, Sens. Actuators A: Phys. 100 (2002) 257–263.
[6] Z.W. Zhong, J. Sun, Modal analysis of a suspension integrated with a novel piezoelectric microactuator, in: Proceedings of the 10th International Congress on Sound and Vibration, 2003, pp. 4435–4440.
[7] K. Derbyshire, E. Korczynski, Giant magnetoresistance for tomorrow's hard drives, Solid State Technol. 2 (1995) 57–59.
[8] E. Grochowsky, D. Thompson, Areal density growth in magnetic recording, IBM Access—Sel. Top. Storage Technol. IX (3) (1995) 63–66.
[9] H. Bertram, Fundamental magnetization process in thin film recording media, in: H. Ehrenreich, D. Turnbull (Eds.), Solid State Physics—Advances in Research and Application, vol. 46, 1992, pp. 271–273.
[10] D. Glocker, S. Shah, Handbook of Thin Film Process Technology, Institute of Physics Publishing, New York, 1995.
[11] H. Tsai, D. Bogy, Characterization of diamond-like carbon films and their application as overcoats on thin film media recording, J. Vac. Sci. Technol. A5 (1987) 3287–3290.
[12] S.W. Meeks, A combined ellipsometer, reflectometer, scatterometer, and the Kerr effect microscope for thin film characterization, Proc. SPIE 3966 (2000) 385–392.