Laser induced nanobump array on magnetic glass disk for low flying height application

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Abstract. Laser processing has found an important application in the hard disk drive (HDD) industry to fabricate bumps for screen testing of the manufactured magnetic disk media prior to HDD assembly. The flying height of the head slider needs to be calibrated by a specifically designed bump array. With areal density of HDD already exceeds 100Gbits/in², the head slider flies at 6 nm flying height and will become even lower. Sub-10nm bump height, as low as 3.5nm, is required to match future slider flying height. In this study, bump arrays with sub-10nm bump height, good height uniformity and precise distribution was fabricated on glass disk substrate using an integrative control system consisting of a pulsed CO₂ laser and a high precision stage. The bump disk requirements were demonstrated successfully and compared with industrial specifications.

1. Introduction

Growth in hard disk drive storage (HDD) capacity is due to the strong demand for more storage space by big enterprises and consumer market, and sustained with the ultra high density storage achieved by the breakthroughs in technology along the way in HDD roadmap [1]. The ultra high density requires reduction of the spacing between read/write (r/w) head and disk media to ensure an acceptable SNR for the r/w operation of the densely packed magnetic bits. The slider with low flying height capability requires a specific flying slider design. The media surface roughness control is also critically important to achieve the low flying height, and at the same time maintain stable flying performance.

A laser processing technique has been applied to fabricate bump disk for use in the screening test of finished disk media in the manufacturing of magnetic recording disk media and for the head slider flying height calibration before they are sent for HDD assembly. With areal density soon to exceed 100Gbits/in², bump disk fabrication faces two challenges. One is the change of material from Al-Mg to glass due to the latter’s superior mechanical properties at high speed r/w operation. The other one is to have smaller bump height to match the slider with sub-10nm flying height.

In this study, bump array with sub-10nm bump height was fabricated on a glass disk substrate using an integrated control laser engineering system. The bump disk functions were demonstrated on the spinstand testers used in HDD manufacturing. A customized bump array design was also fabricated to study the potential of developing a new technique with flying height tester (DFHT).
2. Experimental setup
A schematic diagram of the experimental setup for bump disk fabrication is shown in figure 1. The entire setup was established in a Class 1000 clean room for environmental control. The pulsed CO₂ laser (Coherent Diamond G-100) with wavelength 10.6µm was used which favours glass material absorption. The stage platform has 4-axes to allow flexibility in bump disk design through a greater degree of freedom in movement. The stages offer a resolution of 10nm for linear stages and 10nanodeg for the rotary stage for precise positioning control.

The fabricated bump array was characterized by atomic force microscopy (AFM) for bump height measurement, and the optical surface analyser (OSA), HDD industrial inspection equipment, for large area and high speed bump height uniformity and bump distribution evaluation.

![Figure 1 Schematic diagram of the integrative bump disk fabrication system.](image)

3. Results and discussion
Bump formation mechanisms on glass are due to the relaxation of compressive stress induced on glass during a strengthening process [2-4]. Another mechanism in the terminology of glass technology is a change in the fictive temperature map [5]. Precise control of the laser energy is needed for small bump fabrication to match low flying height of 6 nm and below.

In order to fabricate bumps with sub-10nm height, understanding the effects of various laser parameters on the bump size is critical in tackling the issues of threshold value and the stability of laser output. Experiments were conducted to study the effects of each parameter. Figure 2(a) shows an optical microscopic image of bump array fabricated with single pulses of variable pulse duration and constant power. The bump diameter, which correlates with bump height in a certain aspect ratio, is plotted as a function of pulse duration in figure 2(b). Bump diameter increases with laser pulse width, as the longer duration delivers higher pulse energy. The increase in bump diameter with increasing pulse duration flattened for laser pulse widths larger than 45 µs, which benefits the bump size uniformity control. Figure 2(c) shows the dependence of bump diameter on laser pulse width averaged over four different repetition rates. Changes in laser frequency do not change the relationship between bump size and laser pulse width, and there is no obvious increase in bump size at lower frequency. Only at 100Hz, the bump diameter increases a notable amount. Therefore, higher pulse rates can be selected to increase the fabrication speed. The bump diameter as a function of laser focus offset as shown in figure 2(d), presents a maximum point, whereby the change in bump diameter is small, permitting wide latitude in controlling the accuracy of the focus position.

Sub-10nm bump heights are confirmed by the 3D AFM image and profile analysis shown in figure 3. The smallest bump height was 2.2 nm. To obtain higher density storage, the disk surface has to be smooth to allow the magnetic head fly closely over the surface. A burnishing process is used to control the surface smoothness and a gliding test is used to monitor the contact voltage of the asperity debris with the gliding slider. A bump height targeting 3-4 nm will support an areal density of 1 Tb/in².
Besides bump height, the bump height uniformity and precise distribution are the other important factors for glide height test. Figure 4 shows the OSA image (left) of the whole bump disk surface, and the zoom-in image (right) where one sees a uniform bump height. The corresponding AFM profile shows bump heights of 6 ±1nm, and bump pitch of 28×28μm which is comparable to the existing industrial standard for glide height testing. The bump disk was designed and fabricated as shown in figure 5 (left), with bump height of 8 nm, to perform flying height test with phase metrics dynamic flying height tester (DFHT) which is based on white light interferometry. An AE sensor was placed near the slider suspension to detect any slider-disk contact. The optical recording shown in figure 5
(right), presents the light density changes as the slider flies across the glass disk with/without the bump array before the mechanical contact which is monitored by an AE sensor. The distinct peak signals correlate well with the bump array as expected. The flying height can be determined from the amplitude and width of the recorded light density, based on the simulation model of [6]. However, the challenge remains to determine ultra-low slider flying height accurately as short range forces such as contact force, intermolecular forces, and slider-lube interaction play out during the slider-bump interaction process. The ultra-low bump height is required to study the short range interaction and to improve the accuracy of the simulation model.

Figure 4. OSA (left) and AFM images (right) of bump array with 6 ±1 nm uniformity.

Figure 5. OSA image (left) and DFHT signals (right) for the bumpdisks with specially designed pattern

4. Conclusions
The integrated bump disk fabrication system assembled here has the control and precision to fabricate bump disk for glide height testing of future high areal density HDD that has sub-10nm head disk spacing and uses a glass disk substrate. Bump array with 6 ± 1 nm height was fabricated for functional testing by the glide height test and flying height test. A lowest bump height of 2.2 nm was achieved. The laser method meets existing industrial specifications for sub-10 nm bump disks, and has been applied to the study of short range force interaction of slider-bump.

References
[1] INSIC roadmap: http://www.hitachigst.com/hdd/technolo/overview/chart06.html
[2] Teng E, Goh W and Eltoukhy A IEEE Trans. On Magn. 1996 32 3759
[3] Baumgart P, Krajnovich D J, Nguyen T A and Tam A C IEEE Trans. On Magn. 1995 31 2946
[4] Bennett T D 1998 J. Appl. Phys. 84 2897
[5] Shiu T R, Grigoropoulos C P, Cahill and Greif R 1999 J. Appl. Phys. 86 1311
[6] Suzuki S, Frusescu D, Shiraki D M, Patel J P, and Hua T H US. Patent No. 6164118