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EXPERIMENTAL STUDY OF NANOSCALE HEAD-DISK HEAT TRANSFER IN HEAT-ASSISTED MAGNETIC RECORDING

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ABSTRACT

To study the nanoscale heat transfer and laser-related protrusions in heat-assisted magnetic recording (HAMR), we performed static touchdown experiments between HAMR waveguide heads and non-rotating media such as a silicon wafer and a recording disk with an AlMg substrate. During the static touchdown, the laser element is energized with DC current and the embedded contact sensor (ECS) is used to monitor the head temperature. The experimental results show that the thermal fly-height control (TFC) touchdown power decreases with increasing laser current. Meanwhile, the head temperature increases due to the laser heating. From this the ECS resistance rise induced by the laser is extracted. The results show that the silicon wafer dissipates heat effectively under the laser exposure, while the AlMg-substrate disk undergoes a higher temperature rise, which in turn heats the head.

INTRODUCTION

Heat-assisted magnetic recording (HAMR), one of the promising technologies to boost the areal density of hard disk drives, is approaching commercialization. In the HAMR head-disk interface (HDI), a focused laser is employed over the read/write area to heat the media and facilitate data writing. The introduction of the laser leads to potentially serious thermal transport and reliability issues such as laser-related protrusions and smear. Previously, heat transfer, protrusions and smear in HAMR have been extensively investigated [1–3]. An embedded contact sensor (ECS) was used to study the heat transfer across the head-disk interface. The laser-related protrusions were measured using the readback signal of recorded data and a touchdown technique [4,5]. Also, an analysis on the smear was carried out [6].

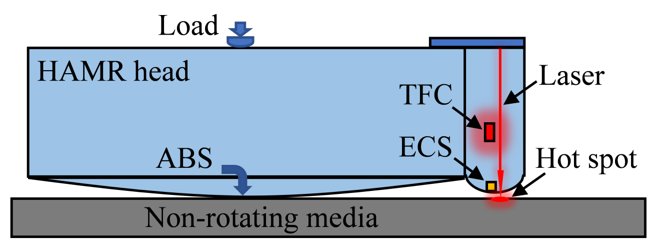

FIGURE 1. A schematic diagram of the experimental setup (not to scale).

In this study, we performed static touchdown experiments using HAMR waveguide heads to study the nanoscale heat transfer and the laser-related protrusions. The static experiments were conducted over non-rotating media so that air-bearing cooling is excluded. The experimental results show the ECS resistance rise as a function of TFC power and laser current in the two cases of a silicon wafer and a recording disk with an AlMg substrate. Further analysis indicates that the silicon dissipates heat effectively, while the disk undergoes a high temperature rise and in turn heats the head.

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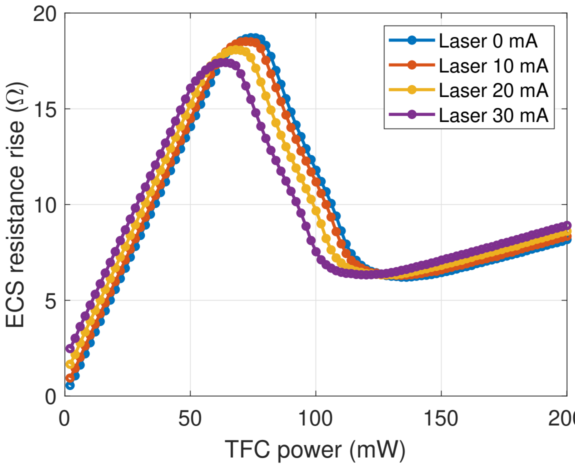

FIGURE 2. The ECS resistance rise versus the TFC power during static touchdown on a silicon wafer for various laser currents.

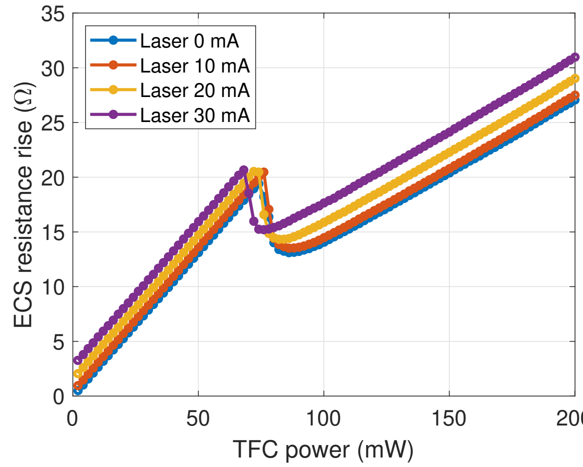

FIGURE 3. The ECS resistance rise versus the TFC power during static touchdown on an AlMg-substrate disk for various laser currents.

EXPERIMENTAL SETUP

In the experiments, a component-level test stage was set up as shown in Figure 1. HAMR heads that contain the waveguide element (∼ 250 nm, without a near-field transducer) were used. The head was loaded such that its air-bearing surface (ABS) reached static contact with the non-rotating media. The tilt of the ABS crown was adjusted to control the initial head-media spacing. Then the thermal fly-height control (TFC) was energized to achieve head-media touchdowns until contact. During the touchdown process, the laser was biased with DC currents and the ECS was used to monitor the head temperature.

RESULTS AND DISCUSSION

Figure 2 and Figure 3 show plots of the ECS resistance rise versus the TFC power during static touchdown on the silicon wafer and the AlMg-substrate disk, respectively. Both curves consist of three stages. In the first stage, also known as free heating stage, the ECS resistance rises linearly with TFC power because the actual spacing is over several nanometers such that phonon conduction cooling does not take effect. Then the near-field phonon conduction dominates and the ECS resistance drops remarkably. Finally, the head protrusion comes into contact with the media, resulting in a smaller linear slope due to the contact cooling.

As the laser current increases, the figures show that the two turning TFC powers of the local maximum/minimum ECS resistance both decrease. The reason for this shift is that the laser-related protrusions lower the head-media spacing. Thus, smaller TFC powers are needed for the two critical points. Additionally, considering that the typical laser threshold I_{th} is between 10 mA and 15 mA, there is no laser shining on the media for the case

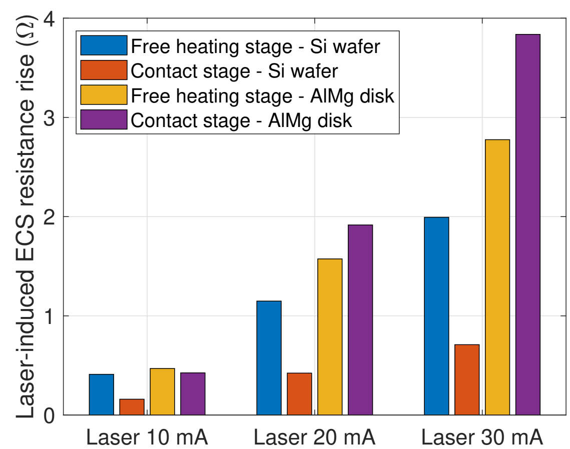

FIGURE 4. The laser-induced ECS resistance rise in the free heating stages and contact stages for the silicon wafer and the AlMg-substrate disk.

of 10 mA laser current. Therefore, the shift for the case of 10 mA indicates that the laser-induced protrusion forms on the head surface.

The ECS resistance rise is caused by both the TFC heating and the laser heating. Figure 2 and Figure 3 show that this rise grows linearly with the TFC power in the free heating stage and the contact stage. Thus, the laser heating effect can be obtained by subtracting the laser-off curve from the laser-on curves. The laser-induced ECS resistance rises for these laser-on curves are shown in Figure 4. In the case of the silicon wafer, the laser heating effect in the contact stage (contact laser heating effect) is always smaller than that in the free heating stage (free laser heating effect). This is due to the contact cooling, since silicon is a good thermal conductor and dissipates heat effectively. On the other hand, the AlMg-substrate disk displays an opposite result. In the cases of 20 mA and 30 mA laser currents, the contact laser heating effect becomes larger than the free laser heating effect, which indicates that the disk is heated by the laser and in turn heats the head (back-heating) through contact. Furthermore, in the case of 10 mA laser current (below I_{th}) without laser output, the contact laser heating effect is only a little smaller than the free laser heating effect because of less contact cooling of the disk and the absence of back-heating.

Additionally, in the real HAMR case with the rotating disk, the air-bearing cooling decreases the head temperature as compared to the non-rotating case. The TFC power shift of the critical points as shown in Figure 2 and Figure 3 is dependent on the ABS design because the introduction of the laser-induced protrusion is likely to change the ABS pressure distribution and the spacing condition.

CONCLUSIONS

The static touchdown experiments were conducted between the HAMR waveguide heads and the two non-rotating media. The experimental results show the ECS resistance rise and the spacing change due to the laser heating. Further analysis on the laser-induced ECS resistance rise demonstrates that the silicon wafer can dissipate the laser-induced heat very fast due to its high thermal conductivity, and hence has less back-heating effect on the head, while the AlMg-substrate disk undergoes a higher temperature rise, which in turn heats the head. In the future, simulations will be performed to fully interpret the results and the underlying physics.

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REFERENCES

[1] Yuan Ma, Amin Ghafari, Bair V Budaev, and David B Bogy. Measurement and simulation of nanoscale gap heat transfer using a read/write head with a contact sensor. *IEEE Transactions on Magnetics*, 53(2):1–5, 2016.

[2] Haoyu Wu and David Bogy. Use of an embedded contact sensor to study nanoscale heat transfer in heat assisted magnetic recording. *Applied Physics Letters*, 110(3):033104, 2017.

[3] Qilong Cheng, Siddhesh Sakhalkar, Amin Ghafari, Yuan Ma, and David Bogy. Dependence of nanoscale heat transfer across a closing gap on the substrate material and ambient humidity. *Applied Physics Letters*, 116(21):213102, 2020.

[4] Shaomin Xiong, Robert Smith, Jian Xu, Shuji Nishida, Masaru Furukawa, Kenji Tasaka, Kenji Kuroki, Yeoungchin Yoon, Na Wang, Sripathi Canchi, et al. Setting write spacing in heat assisted magnetic recording. *IEEE Transactions on Magnetics*, 54(8):1–7, 2018.

[5] Qilong Cheng, Haoyu Wang, Siddhesh V Sakhalkar, and David B Bogy. Measurement of angstrom-level laser induced protrusion using touchdown in heat-assisted magnetic recording. *Applied Physics Letters*, 117(15):153105, 2020.

[6] James D Kiely, Paul M Jones, Yang Yang, John L Brand, Manuel Anaya-Dufresne, Patrick C Fletcher, Florin Zavaliche, Yvete Toivola, John C Duda, and Michael T Johnson. Write-induced head contamination in heat-assisted magnetic recording. *IEEE Transactions on Magnetics*, 53(2):1–7, 2016.