Near Field Transducer Reliability Improvements Due to Media Stack

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A key challenge in HAMR systems is maintaining NFT reliability, especially as enhanced performance often requires increased laser power, placing additional thermal stress on the NFT. This presents a critical performance-reliability tradeoff. In this study, we investigate fixed NFT design while media parameters changes aimed at breaking this performance-reliability dilemma. Specifically, we explore total resistance at critical interfaces, head to media spacing, recording layer optical properties, heat sink (HS) thickness, heat sink thermal conductivity, soft underlayer (SUL) thickness. Our findings demonstrate how modifications in media layer properties not only impact thermal management but also influence the magnetic field profile essential for effective grain freezing during the recording process. These insights help pave the way for achieving high HAMR performance without compromising long-term device reliability.

***Index Terms*— HAMR, NFT, plasmonic, antenna design, reliability, refractive index, extinction constant, heat sink**

I. Introduction

Heat Assisted Magnetic Recording (HAMR) is a critical technology for enabling continued areal density (AD) growth in hard disk drives (HDDs) [1]. A central component of HAMR is the laser-coupled near field transducer (NFT), which enables localized heating of the recording layer (RL) via surface plasmon excitation from light delivered through a waveguide. Localized heating depends on NFT dimensions and optical-thermal properties of the coupled head/media system [2]-[4]. During operation, the media temperature can reach close to 700K, while writing occurs during the cooling process at temperature just below the grains Curie temperature [3]. A magnetic write head, placed in close proximity to the NFT, produces a sufficiently strong magnetic field at the freezing location to define the grain orientation by the field polarity.

A key challenge in HAMR systems is maintaining NFT reliability, particularly as enhanced performance often requires increased laser power—resulting in additional thermal stress on the NFT. This presents a critical performance–reliability tradeoff. In this study, we investigate various media layer parameters to explore how this dilemma can be mitigated.

A nanobeak NFT design is employed in this study, requiring transverse magnetic (TM) mode to excite the NFT, which in turn excites a localized plasmon and strong optical near-field closer to ABS [5]. The maximum temperature of the NFT near the air bearing surface (ABS) can exceed 100–200K above room temperature, while the peak media temperature can reach approximately 400K above room temperature. This difference arises from light absorption: the NFT absorbs less light than the recording layer. In general NFT temperature increases further as we tune the media parameters to obtain higher areal density, resulting in increased laser power requirement to obtain a constant peak media temperature.

To examine these dependencies, we kept the NFT dimensions fixed while varying the media layer thicknesses, thermal conductivity, interface thermal resistance, and optical properties of the RL. An example case is shown in Figure 1, where the reference model uses standard parameters as presented in Table 1. We scaled the laser power to achieve a peak media temperature of 690 K. Note that the line scan is obtained at the trailing edge of the NFT at the center; the peak media temperature may not necessarily be at this location. Beyond the recording layer, or further away from the ABS, the temperature quickly drops. Maximum NFT temperature near the ABS can be around 525 K.

We also provide two examples of media variations. In Example 1, we demonstrate that optimized media parameters can cause the temperature beyond the RL to drop rapidly, improving both media performance and NFT reliability. In contrast, Example 2 shows that while peak media temperature is similar and media performance is enhanced, the NFT temperature is elevated—causing reliability concerns. These observations motivate a detailed exploration of media parameters to understand their impact on NFT reliability.

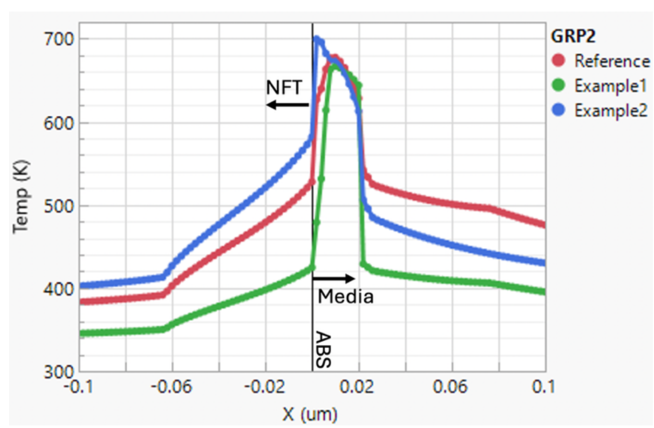

Fig. 1. Temperature as a function of distance perpendicular to ABS at trailing edge of the NFT (downtrack) at the center of the NFT (cross track). Two example line scans are plotted to compare against Reference thermal profile.

The paper is organized as follows: In section II we will provide the details of the model and variables used in the media studies while in section III we will provide some results and discussion on the results before concluding this study in section IV.

II. Model Setup

We used finite-element analysis (FEA) via commercial software [6] to calculate the optical near-field and the thermal field generated by the NFT. NFT details are taken from [5] and applied using current state of the art NFT dimensions. The head surface includes a carbon overcoat and an air gap between the head and the media. The total head-to-media spacing is kept at constant unless varied for spacing studies. The medium consists of a medium overcoat, recording layer (RL), seed layer, heat sink, soft underlayer (SUL), and substrate. Our primary goal was to examine how critical media layer properties affect NFT reliability, so we established a baseline model with standard parameters listed in Table 1.

TABLE I
MEDIA LAYER VARIATIONS

Item	Variation
Spacing (nm)	2 - 7
RL (nm)	5 – 20
RL n	0.5 - 5
UL resistivity (m^2K/GW)	0.5 – 20
Seedt (nm)	1 – 20
HSt (nm)	10 – 150
HSk (W/mK)	10 – 100
SULt (nm)	50 – 300

III. RESULTS AND DISCUSSION

To compare NFT performance and reliability with various media parameters, we determined the required laser power to reach a fixed peak media temperature of 690 K. This enables us to relate laser power to NFT temperature, as shown in Figure 2 (a). Since writing occurs at a temperature below the curie temperature, we used the 630 K temperature contour to compare magnetic write width (MWW) in Figure 2(b), thermal downtrack gradient (DTTG) at the 630K contour line in Figure 2(c), and cross-track gradient (CTTG) at the 630K contour line in Figure 2(d). Recording layer variations in the legend correspond to those in Table 1.

We find that NFT temperature increases with laser power. However, some parameters both reduce MWW, improve DTTG and CTTG, and simultaneously decrease NFT temperature. These key parameters include spacing, underlayer resistance (ULR), and RL optical refractive index.

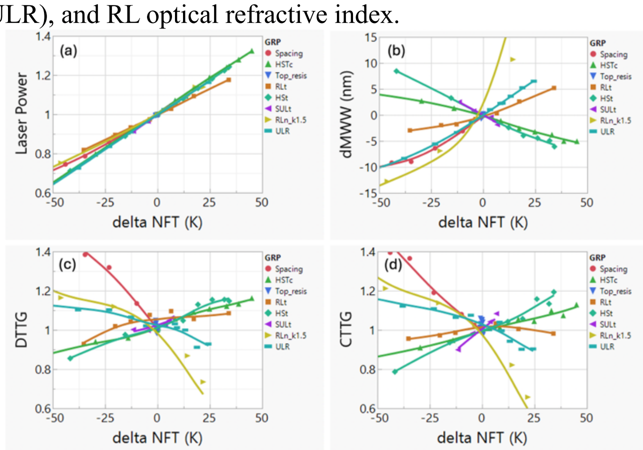

Fig. 2. Delta NFT temperature is plotted against laser power (a), delta MWW (b), normalized DTTG (c) and normalized CTTG (d). Within each graph an individual line shows the impact of varying one parameter across the range provided in table 1.

The higher interface resistance between the RL and the seed traps heat within the RL, lowering the laser power requirements and improving thermal gradients at fixed peak temperatures. Reducing spacing brings the RL closer to the NFT, which improves the system optical coupling and improves performance. A lower optical refractive index of the RL also improves the system optical coupling, providing higher absorption in the RL. Therefore, reducing the RL's refractive index significantly enhances NFT reliability and performance by reducing laser power.

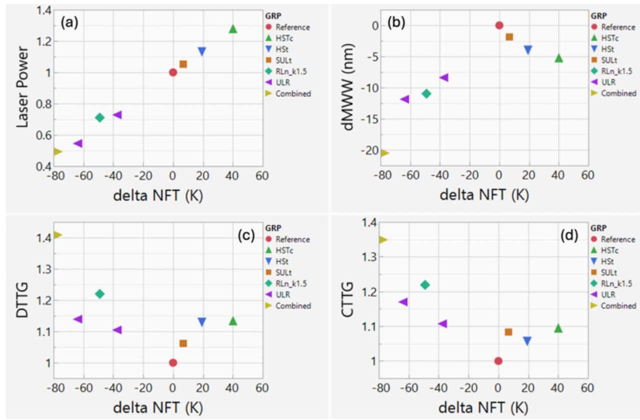

Fig. 3. Delta NFT temperature is plotted for few key cases and combined media case to show Laser Power (a), MWW reduction (b) and DTTG (c), CTTG (d) improvements.

Conversely, other parameters - such as heat sink (HS) thickness or SUL thickness or HS thermal conductivity - improve performance (smaller MWW and higher thermal gradients) at the expense of higher laser power and increased NFT temperature.

To evaluate the cumulative effects, we combined the beneficial media parameters in one configuration. Figure 3 shows that this combined media can reduce MWW by 20 nm and improve thermal gradients by 35–40%, while also lowering NFT temperature by 80 K.

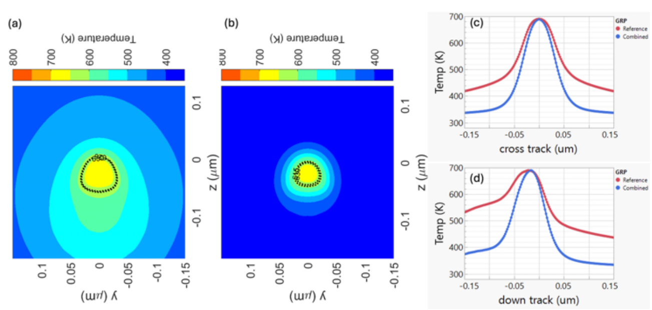

Fig. 4. Thermal maps are plotted at the center of the recording layer for Reference and Combined media cases (a), (b) respectively. Line scan along downtrack (c) and cross track (d) vs temperature for two cases is provided.

Figure 4 compares thermal maps of the Reference and the combined media, captured at the center of the recording layer. Downtrack and crosstrack line scans in Figures 4(c) and 4(d) show a clear reduction in background temperature, narrower MWW, and much improved thermal gradients in the optimized media.

IV. Conclusion

This study demonstrates that careful tuning of media layer parameters—especially recording layer optical properties and interface thermal resistance—can significantly improve both media performance and NFT reliability. These findings provide a path to break the performance–reliability dilemma in HAMR systems.

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