Optical-Thermal-Mechanical analysis for Heat Assisted Magnetic Recording(HAMR)

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INTRODUCTION

- ✓ Heat-assisted magnetic recording (HAMR) is expected to be the next generation technology for HDDs, pushing the areal density up to 10 Tb/in2.
- ✓ The EM field absorption in NFT will cause its own temperature increase called the self-heating effect.
- ✓ The back-heating effect is also stronger if FH is reduced to 1-2nm with thermal fly-height control (TFC) technology.
- ✓ The flying characteristics of the HAMR is studied considering the nanoscale heat transfer with air conduction and phonon conduction .

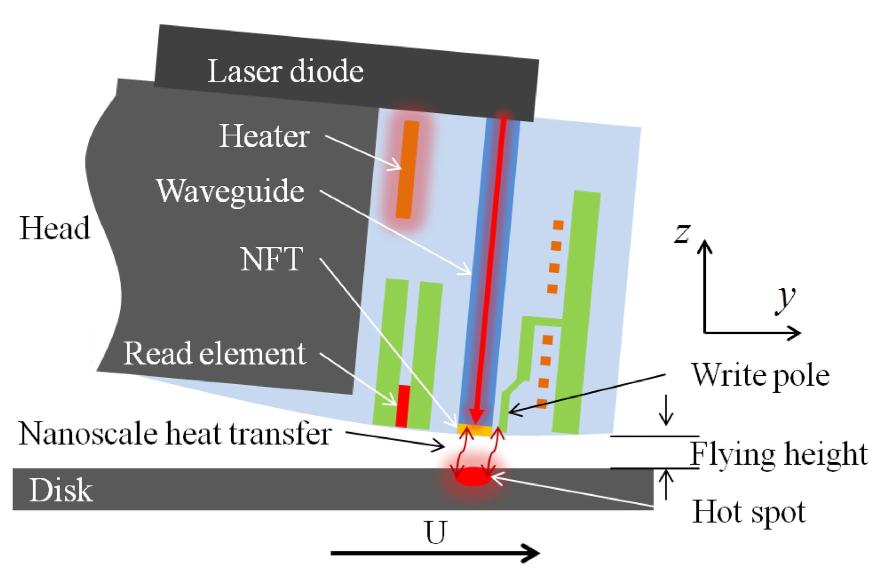

FIG. 1 The schematic of the HAMR system

HAMR SYSTEM AND THEORY

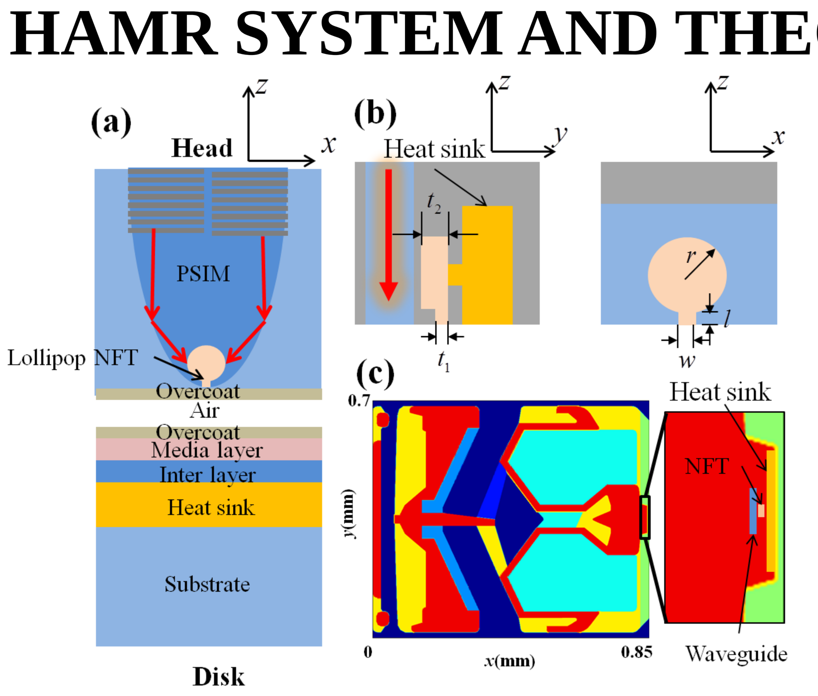

FIG. 2 Simulation geometry

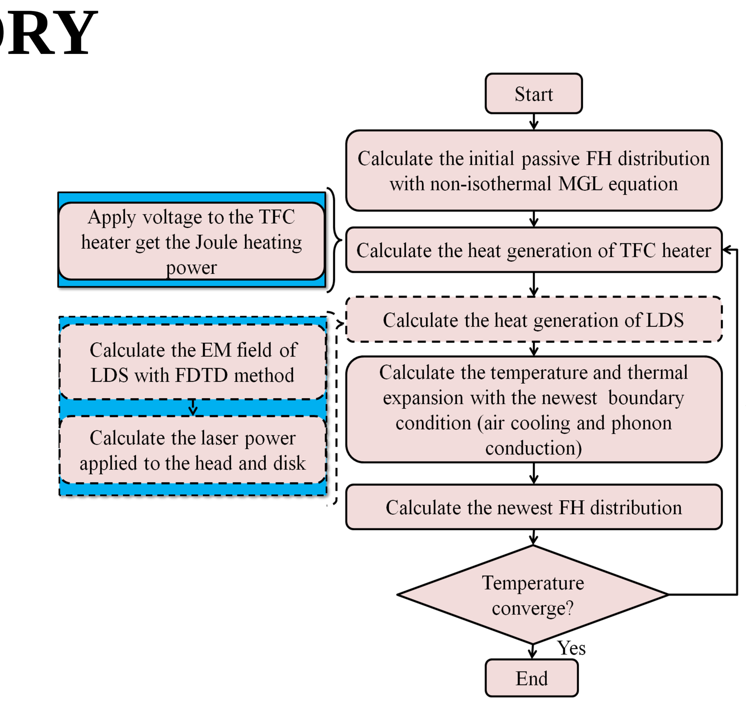

FIG. 3 Flowchart of the comprehensive simulation

- **Laser-EM Field:**

$$\nabla\cdot\mathbf{D} = \rho_V,\quad \nabla\cdot\mathbf{B} = 0,\quad \nabla\times\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t},\quad \nabla\times\mathbf{H} = -\frac{\partial\mathbf{D}}{\partial t}+\mathbf{J},$$

- **Laser Power Absorption:**

$$\dot{q}_{EM} = \frac{1}{2}\mathrm{Re}(\sigma)\,|\mathbf{E}|^2 = \frac{1}{2}\varepsilon_0\omega\,\mathrm{Im}(\varepsilon_r)\,|\mathbf{E}|^2,$$

- **Thermal Field:**

$$\rho c\mathbf{u}\cdot\nabla T - \nabla\cdot(k\nabla T) = \dot{q}_V,$$

- **Boundary Condition-Nanoscale heat transfer**

1) Air conduction:(model(1))

$$q_{air} = -q_{conduction} + q_{viscous} = -k_{air}\frac{T_s - T_d}{FH + 2b\lambda} + q_{viscous},$$

2) Phonon conduction :(model(2))

$$q_{rad}(T_s,T_d) = N\int_0^{\omega_D}\int_0^{\theta_A}\Big\{(1-|R(\omega,\theta)|^2)\times\Big[P(\omega,\theta;T_s\frac{q}{q_s}) - P(\omega,\theta;T_d\frac{q}{q_d})\Big] - 2|R_s(\omega,\theta)|\sqrt{1-|R(\omega,\theta)|^2}\times P_{sd}(\omega,\theta;T_s,T_d,q)\cos\chi\Big\}d\Omega$$

- **Boundary Condition-friction heating:(model(3))**

$$q_{d\text{-}fri} = -\mathbf{n}_d r\eta u F_{contact},\qquad q_{s\text{-}fri} = -\mathbf{n}_s(1-r)\eta u F_{contact},$$

- **Rarefied Gas Lubrication:**

$$\nabla\cdot\Big(ph\big(\frac{\mathbf{u}}{2T} - \bar{Q}_p\frac{h^2}{12\mu T}\nabla p + \bar{Q}_T\frac{ph^2}{12\mu T^2}\nabla T_w\big)\Big) = 0,$$

RESULTS AND DISCUSSION

- **Clearance effect on the coupled power**

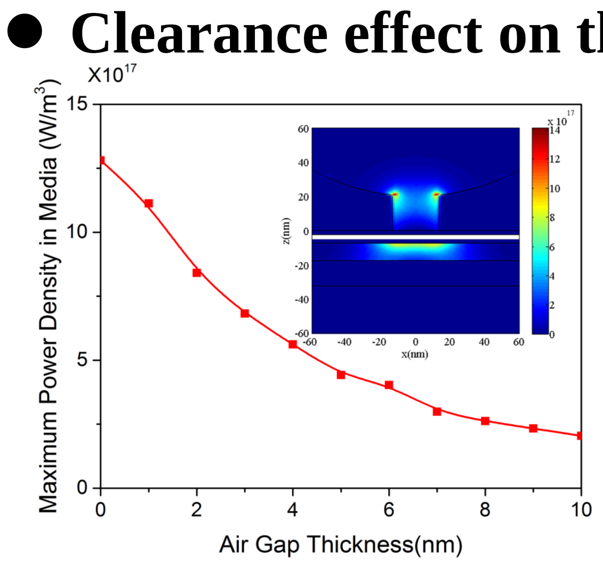

FIG. 4 Clearance effect on the absorption of the media.

- ✓ As the gap size increases from 0 to 10nm, the power density in the media decreases from the maximum to its 20%.
- ✓ The absorption of the NFT is comparable to that of the media, which may cause a strong self-heating resulting in the additional thermal expansion in the NFT.

- **Disk temperature effect**

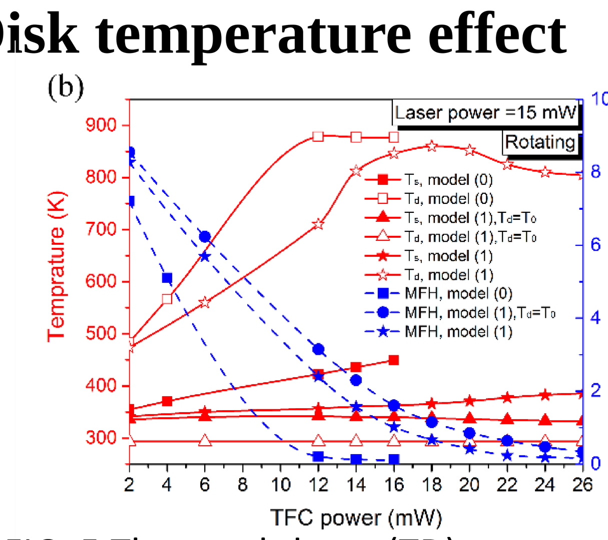

FIG. 5 The touchdown (TD) process with three different HDI settings

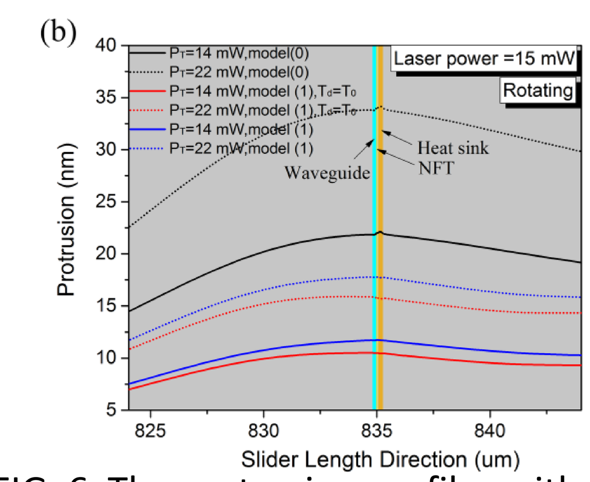

FIG. 6 The protrusion profiles with three different HDI settings

- ✓ Assumption of disk temperature remaining at room temperature predict a postponed Touch-down process.
- ✓ The protrusion difference on the head is the main reason of different MFH curves .

- **Touchdown process with Rotating Disks**

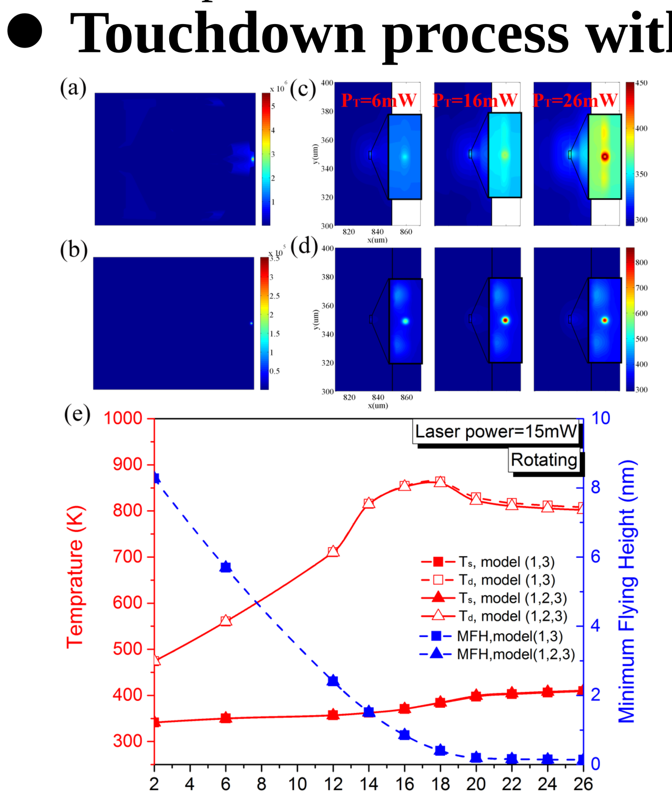

FIG.7 The TD processes of HAMR case with different HDI settings

- ✓ The heat flows back from the disk to the head at the NFT location whereas at other locations the heat flows from the head to the disk.
- ✓ The disk temperature has a drop when the clearance smaller than 1 nm because of the back heating from the disk to the head.
- ✓ There is no thermal tail for the hot spot on the media because the heating and cooling time of the hot spot is in nanosecond.
- ✓ The phonon conduction will increase the back heating at the NFT location which cause more temperature drop on the media.

- **Laser heating effect**

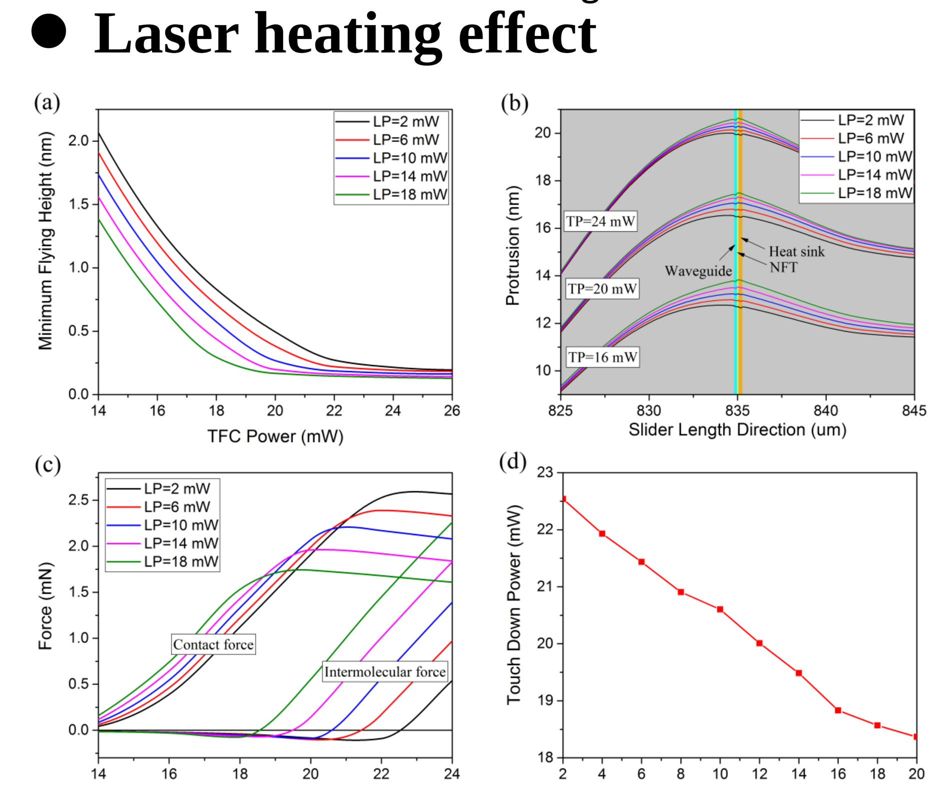

FIG.8 Laser heating effect

- ✓ The TD curve will shift to left with the laser power increase.
- ✓ The self heating of the NFT and the back heating from the hot media will cause the additional protrusion.
- ✓ The touch-down power almost linearly decreases with the PL increase.

CONCLUSION

We establish a comprehensive optical-thermal-mechanical model for the HAMR system. The gap thickness effect on the absorption of the media is considered. It was found that the disk temperature setting is important for the simulation of the HAMR. The phonon conduction has a slight effect when the gap is smaller than ~1 nm in HAMR application. And the TDP linearly decreases with the laser power.

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