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RESEARCH ARTICLE

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Z-Tetraol Reflow versus Trough Width in Heat-Assisted Magnetic Recording.

Abstract:
Lubricant reflow versus trough width for 10 - 13 Å Z-Tetraol films is characterized by numerical simulation using the experimentally determined thickness-dependent diffusion equation. Lubricant reflow is simulated in a single trough of 10 – 13 Å depth as a function of trough width from 50 nm to 50 µm. The results of the numerical simulations indicate that trough recovery by reflow decreases with increasing trough width. The numerical simulations are compared to experimental reflow where such data are available in the literature.

Keywords: Z-Tetraol; perfluoropolyether; heat-assisted magnetic recording; lubricant reflow.

Introduction:
The reflow kinetics of the boundary perfluoropolyether (PFPE) lubricant Z-Tetraol in a trough as might be created under heat-assisted magnetic recording (HAMR) conditions were recently investigated [1, 2]. Fickian diffusion based upon experimental thickness-dependent diffusion coefficient was used to numerically simulate lubricant reflow into laser-depleted troughs as a function of trough number, trough depth, trough width, adjacent trough distances, and duty cycle (reflow time between successive laser exposure). The results of the numerical simulations indicated that trough recovery by reflow increased with increasing duty cycle or decreasing number of adjacent troughs, trough separation distance and laser depletion rate. Reflow rates were computed to slow significantly when closely spaced multiple troughs coalesced to behave like a single, larger trough. These data indicated that conclusions based upon a single laser trough could be misleading when extrapolated to real HAMR conditions [1, 2].

Numerical simulations are validated by replicating experimental data. HAMR laser spots are expected to be approximately 50 nm or less [3]. Thus far most lubricant reflow experiments have been conducted using a single laser trough of significantly larger µm (10^3 nm) to mm (10^6 nm) widths for both experimental and metrological reasons. Here we compare the reflow kinetics of Z-Tetraol in a single trough as a function of trough width from 50 nm to 5 mm. The numerical simulations are compared to experimental data where available to validate the scaling effect.

Materials and Methods:

Lubricant flow was simulated by writing a Fortran computer code based on Fick's second law for diffusion in one dimension using a thickness-dependent diffusion coefficient.

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(D \frac{\partial h}{\partial x} \right) \qquad (1)$$

D is the thickness-dependent diffusion coefficient, h is the lubricant film thickness, x is the distance, and t is the time. The derivatives are approximated by finite differences using the *Forward Time, Centered Space* or FTCS approximation [4]. The time step is defined by the Von Neumann stability criterion, Eq. 2.

$$\Delta t \leq \frac{\Delta x^2}{2D} \qquad (2)$$

The thickness-dependent diffusion coefficient as a function of Z-Tetraol film thickness used in these studies is given in Eq. 3 and its thickness dependence is shown in Fig. 1 [1, 2].

$$D(h) = 1.02 \times 10^{-15} + (2.18 \times 10^{-14})(h) + (3.10 \times 10^{-15})(h^2) \qquad (3)$$

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h is the film thickness in Å and D(h) is in m^2/s. Eq. 3 is derived from a detailed flow study of Z-Tetraol (2200 daltons) as a function of time and of film thickness between 2 and 13 Å [1]. Eq. 3 describes isothermal Z-Tetraol flow at room temperature only. A recent theoretical study for D(h) of sub-monolayer Z-Tetraol films closely reproduces the values of Eq. 3 in the specified film thickness regime [5]. The chemical structure for Z-Tetraol is shown below, where n = 9.9 and m = 10.2.

$$HOCH_2CH(OH)CH_2OCH_2CF_2O\text{--}[CF_2CF_2O]_n\text{--}[CF_2O]_m\text{--}CF_2CH_2OCH_2CH(OH)CH_2OH$$

Z-Tetraol

Results and Discussion:

The experimental and simulated lubricant flow for Z-Tetraol in an initially 5 mm wide trough and an initially 60 µm wide trough are shown in Figs. 2 and 3, respectively. Figs. 2a and b compare the experimental and simulated flow for a 13 Å Z-Tetraol film in an initially 13 Å deep, 5 mm wide trough. The numerical simulation provides an excellent match to the experimental data. Fig. 2c compares the experimental and simulation data directly by plotting the film thickness change in the trough as a function of Z-Tetraol reflow time. Reflow requires approximately 10^6 to 10^8 seconds for substantial healing of the trough.

Fig. 3a shows the simulated flow for a 12 Å Z-Tetraol film in an initially 12 Å deep, 60 µm wide trough. Fig. 3b compares the experimental [6] and simulation data by plotting the film thickness change in the trough as a function of Z-Tetraol reflow time. Fig. 3b shows good agreement between experiment and simulation for Z-Tetraol reflows in a laser trough of µm dimensions. Here reflow requires approximately 10^4 to 10^5 seconds for substantial healing of the trough.

Fig. 4 shows the simulated reflow for 10 Å Z-Tetraol in an initially 10 Å deep trough as a function of time and of increasing initial trough width. The trough widths considered are 50, 100, 500, 1000, 5000 and 50,000 nm. With increasing trough width, the time required for trough healing increases significantly from the 1 sec range to approximately 10^5 sec. These data are more readily visualized in the summary plot of Fig. 5.

Conclusions:

The results of the numerical simulations for Z-Tetraol reflow as a function of trough width indicate that trough recovery time by reflow increases significantly with increasing trough width. Single trough lubricant reflow studies based on wide troughs may be misleading in HAMR applications.

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Figures:

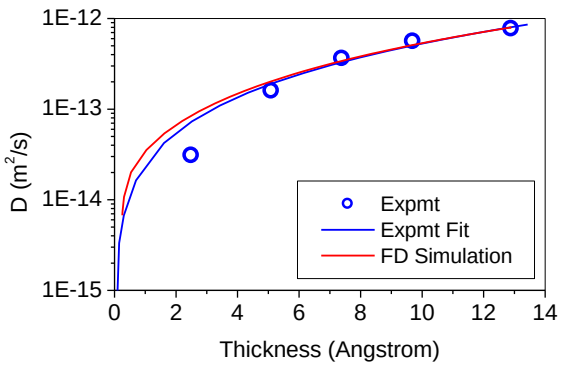

Figure 1. The experimental diffusion constant as a function of film thickness for Z-Tetraol (blue circle). The fit to the experimental data is given by Eq. 3 (blue line). The red line is the D(h) computed and used during the numerical simulations [1].

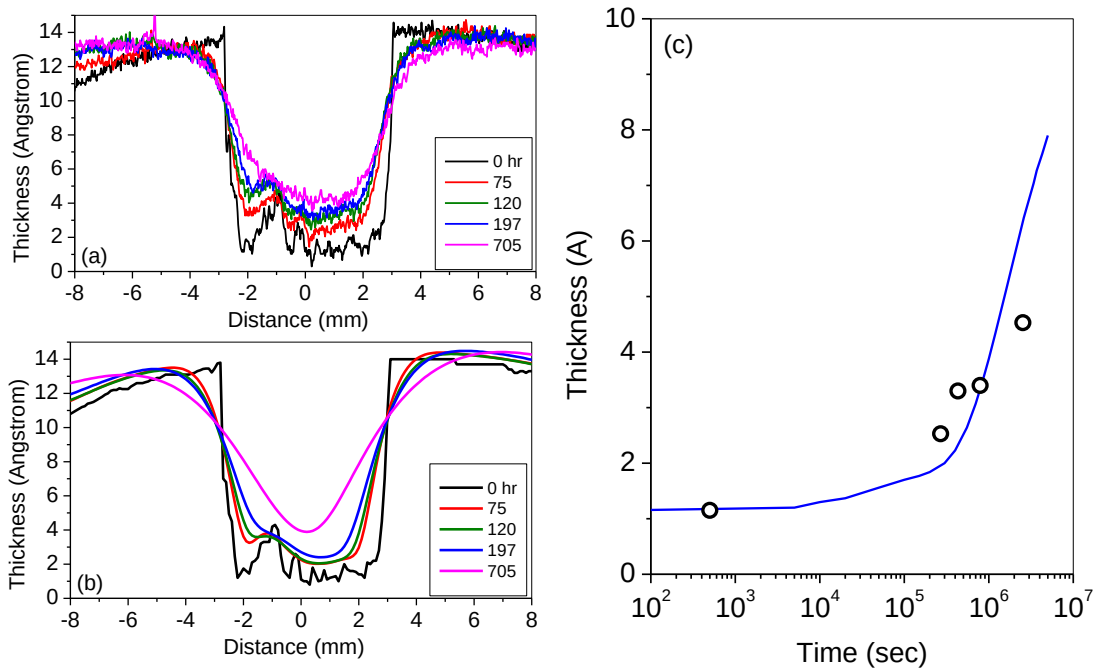

Figure 2. (a) Experimental 13 Å Z-Tetraol 2000 reflow in an initially 13 Å deep and 5 mm wide trough as a function of time. (b) Numerical simulation for the 13 Å Z-Tetraol 2000 reflow as a function of time using D(h). (c) Summary plot comparing experimental (black circle) and numerical simulation (blue line) of thickness change in trough.

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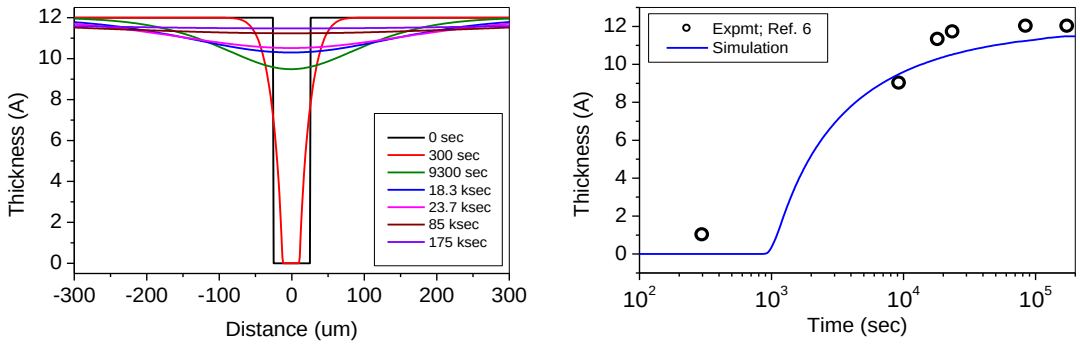

Figure 3. (Left) Numerical simulation for 12 Å Z-Tetraol 2000 reflow in an initially 12 Å deep and 60 µm wide trough as a function of time using D(h). (Right) Summary plot comparing experimental (black circle) and numerical simulation (blue line) of thickness change in trough due to reflow.

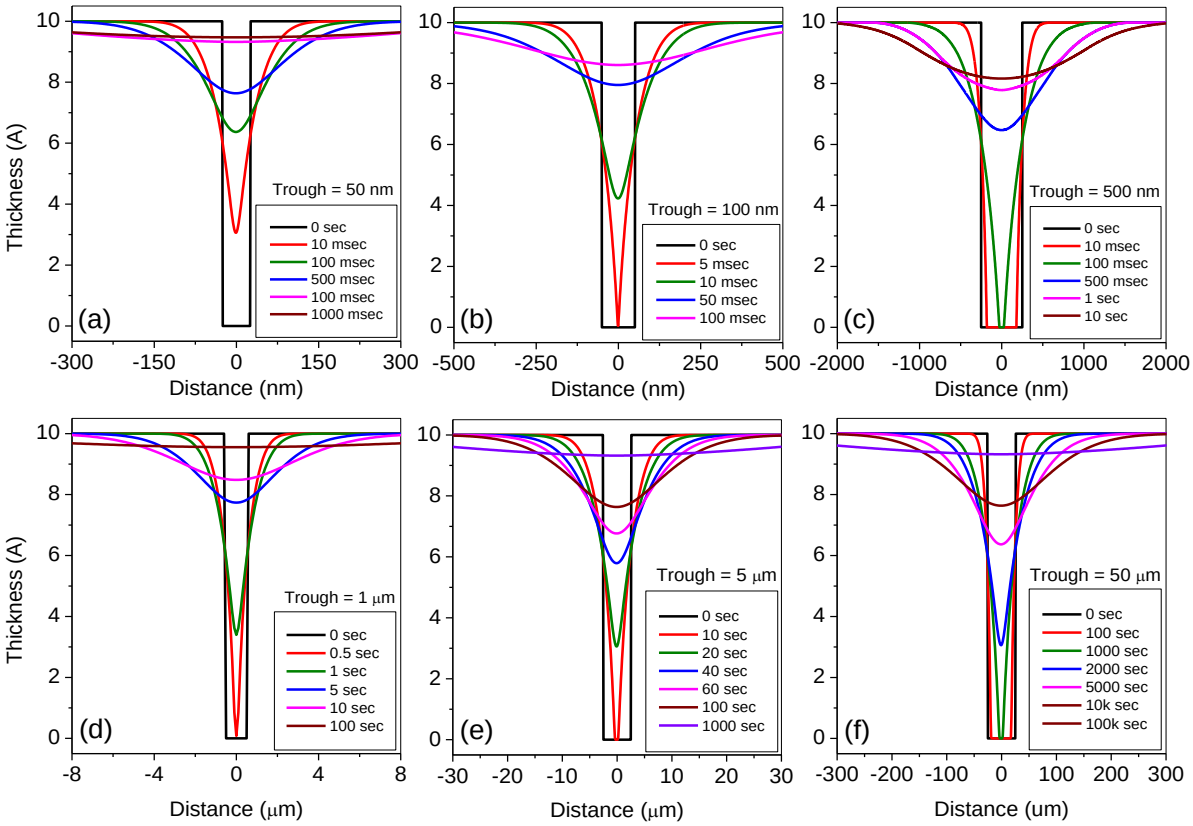

Figure 4. Numerical simulations for 10 Å Z-Tetraol 2000 reflow in an initially 10 Å trough as a function of time and trough width using D(h). Trough width is equal to: (a) 50 nm; (b) 100 nm; (c) 500 nm; (d) 1 µm; (e) 5 µm; (f) 50 µm.

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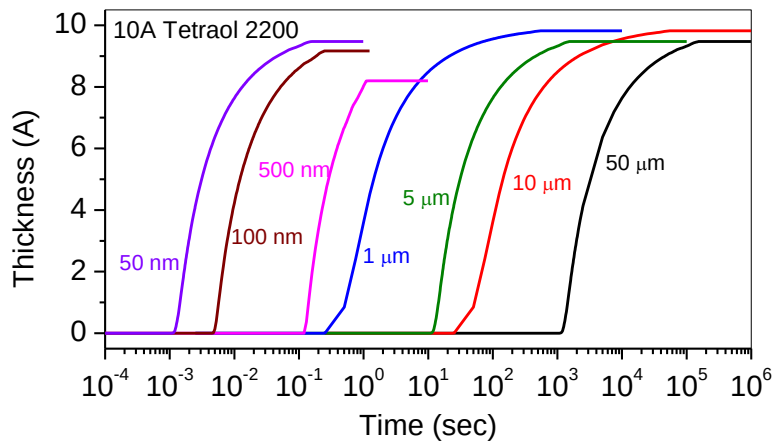

Figure 5. Numerical simulations for 10 Å Z-Tetraol 2000 reflow in an initially 10 Å trough as a function of time and trough width using D(h). The y-axis is the Z-Tetraol thickness in the trough center. The x-axis represents the trough recovery time.

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