

## Ultrafast Lattice Dynamics of Granular L<sub>10</sub> Phase FePt Measured by MeV Electron Diffraction.

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The L<sub>10</sub> phase of FePt exhibits extremely high magnetic anisotropy, making it a material of choice for next generation magnetic storage applications. However, these applications rely on new methods for writing magnetic information, such as Heat Assisted Magnetic Recording [1] or All-Optical Magnetic Recording [2]. Both Heat Assisted Magnetic Recording and All-Optical Magnetic Switching use laser induced thermal dynamics to assist in changing the magnetic state. In this paper we study the Ultrafast response of a granular FePt thin film to rapid thermal heating using a 50 fs optical laser pulse. The response of the FePt grains gives direct insights into the nanoscale heat transport within the grains; the thermal properties of the FePt L<sub>10</sub> phase and the vibration modes of the grains.

FePt grains in a carbon matrix are grown in the L<sub>10</sub> phase by co-sputtering with carbon onto an MgO single crystal substrate. The film segregates into FePt grains separated by carbon, see Fig. 1 (a). The grains formed are approximately cylindrical, with a height of 10 nm and a log-normal distribution of diameters with a modal value of 10 nm. The FePt is in the L<sub>10</sub> structure, with the crystallographic *c* axis normal to the substrate. The substrates are removed by chemical etching and the remaining freestanding FePt film is floated onto a copper microscopy grid.

The experiment is conducted in a collinear pump-probe geometry. The FePt film is pumped with a 50 fs 800 nm laser pulse focused to a spot of 1 mm diameter with an incident fluence of 5 mJ/cm<sup>2</sup>. The lattice response is probed by a relativistic electron bunch with a kinetic energy of 2.2 MeV, subpicosecond duration, and 100 fC charge, produced by an rf photocathode gun at the SLAC ASTA Ultrafast Electron Diffraction facility. The electron diffraction pattern formed on a phosphor screen is imaged by an Andor EMCCD camera for various laser–electron time delays (Fig. 1b).

The FePt film shows well defined Bragg reflections, implying that individual grains grew epitaxially from the MgO substrate and are aligned crystallographically with one another. The diffraction confirms the grains' crystallographic phase and orientation. The intensity and position of various Bragg reflections are monitored as a function of pump probe delay. By tilting the sample surface to 45 degrees

from normal incidence Bragg reflections with components along the crystallographic  $c$ -axis are measured—in particular the [111] and [202] reflections. Together with measurements of the Bragg reflections at normal incidence, these allow the full three dimensional expansion dynamics of the grains to be measured in real time.

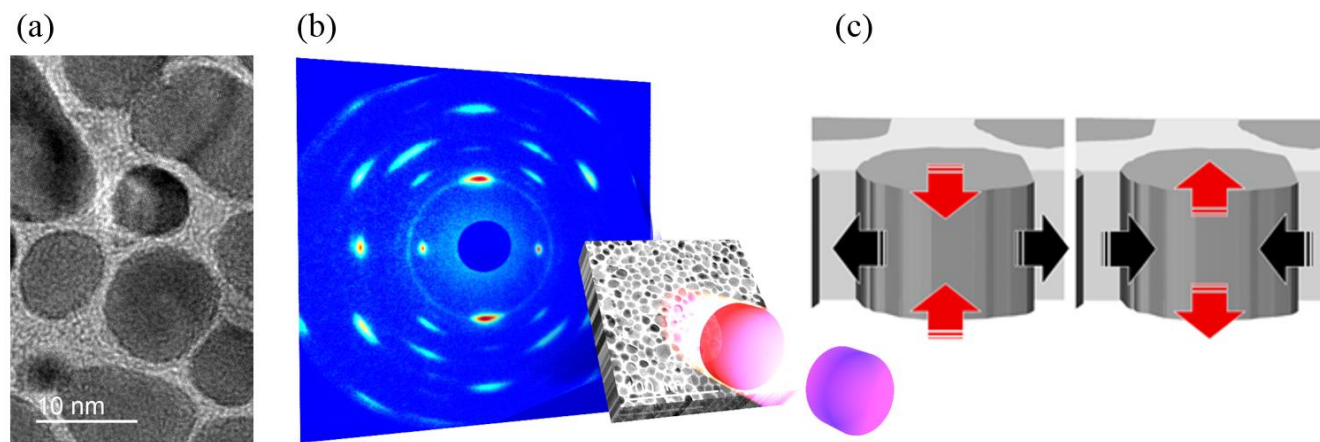
The diffraction measurements reveal that the thermal expansion of granular FePt is anisotropic. A linear thermal expansion is observed for the in-plane  $a$  and  $b$  directions. However, the thermal expansion along the out-of-plane  $c$  axis is near zero. This behavior persists to fluences up to  $17 \text{ mJ/cm}^2$ .

The dynamic response of the FePt grains also exhibits a large degree of anisotropy. The laser pulse causes a rapid volume expansion of the grains, driven by the expansion of the grain in the in-plane (crystallographic  $a$  &  $b$ ) directions. A new equilibrium volume is reached after 3 ps. The rapid in-plane expansion is observed to drive a contraction of the lattice in the out-of-plane direction. This sets up a volume conserving bulk oscillation with a period of 7 ps (Fig 1c, d). These experiments offer new insights into the thermal behavior of nanoscale FePt.

[1] D. Weller *et al.* “ $L1_0$  FePtX-Y media for heat assisted magnetic recording”, *Phys. Status Solidi A* **210**, 1237 (2013).

[2] C-H. Lambert *et al.* “All-optical control of ferromagnetic thin films and nanostructures”, *Science* **345**, 1337 (2014).

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**Figure 1.** (a) TEM image of the FePt grains. (b) Schematic of the electron diffraction experiment with the FePt sample surface tilted with respect to the incoming laser and electron pulses. (c) Illustration of two dynamical motions observed within the FePt grains.