Recent Advances in the Metrology of Magnetostriction of Ultrathin Films

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Motivation

- Magnetostriction is, simply put, the change in dimensions of a magnetic body due to an applied magnetic field.
- It is an important parameter for head design because it represents an additional magnetic anisotropy contribution.
- It is usually a small effect, and difficult to measure.
- Magnetostriction, λ, is usually on the order of 10^{-6} (for materials of interest such as FeCo, NiFe).
- Metrology commonly used:
  - Optical cantilever method (from Lafouda Solutions) [1,2]
    - High sensitivity but many disadvantages, for example:
    - Low maximum field of 100 Oe.
    - Destructive (coupon technique).
    - Slow.
    - Limited choice of substrates (silicon).
- Need new technique for fast, full wafer size measurement capability under much higher fields with comparable sensitivity.
- This paper presents an advanced loop tracer method that fulfills these requirements.

Description of new instrument (MESA 200)

- BH loop tracer: uses inductive pickup coils to measure magnetic flux.
- Applied field is typically 10 Hz sine wave.
- Maximum magnetic field of 1000 Oe.
- Accommodates circular samples of 150 and 200mm diameter.
- Utilizes inverse magnetostriction effect: Measures change in anisotropy field, Hk, due to applied mechanical strain.
- Pneumatically driven knives to apply **well controlled** strain.
- Automated sample rotation of 0.1 deg resolution.
- Full in-plane magnetic characterization in one measurement: (Flux, coercivity, Hk, dispersion [3] , exchange, skew, inverse magnetostriction).
- Non-destructive.
- Fast (3 minutes for entire parameter suite).
- Can handle any type of common substrate stiffness.
- Non-optical method: not sensitive to surface irregularities.

Inverse Magnetostriction

- Apply mechanical strain of order of 10^{-4}.
- Wafer is bent through two double knives with edges parallel to magnetic hard axis, see Fig 1.
- Accurately controlled pneumatic system drives one set of knives against a static set.
- Accurate alignment of hard axis is crucial and achieved through automated sample rotation algorithm (loop flattening under transverse field).
- Measure change in Hk between mechanically unstressed and stressed sample: ΔHk , see Fig. 2.
- ΔHk is indirect measure of magnetostriction. In simple terms:

$$\lambda \boxtimes \Delta Hk \cdot Ms/(E\cdot\varepsilon).$$

Ms: saturation magnetization, E: Young's modulus, ε: film strain.

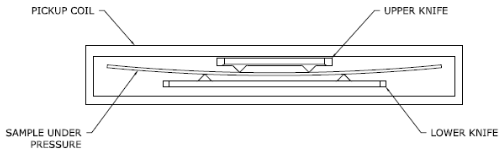


Fig. 1: Schematic geometry of sample and knives.

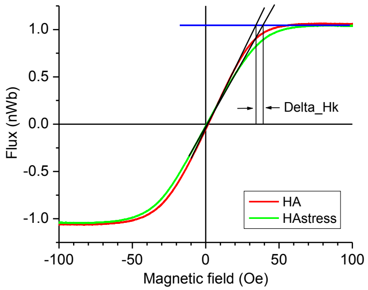
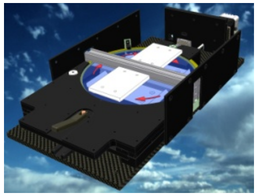


Fig.2: Extraction of ΔHk.

Further Background

- The inverse magnetostriction method had been used on loop tracers before but had always been deficient in repeatability and sensitivity [4].
- The 'golden' tool to compare with is the Lafouda magnetostriction tester with best known sensitivity.



Experiment I

- To test and verify the capability of the MESA various sets of samples were first measured on the MESA and then cross-measured on a Lafouda tester.
- One sample set was reader stack samples of proprietary thickness and composition on silicon wafer substrates of 150mm.
- Exchange coupling: 5 to 20 Oe. Free layer thickness: 30 Å and 110 Å.
- All samples were first measured on the MESA under the same applied stress (center displacement of about 2mm), then cut to size (10x40mm^2) and measured on a Lafouda tester.
- The applied maximum field was 100 Oe in all measurements.
- Fig. 3 shows an excellent correlation between the two methods, with λ covering a wide range of $3\cdot10^{-5}$.

Experiment II

- Another sample set consisted of NiFe films of compositions from about 19 to 22% atomic Fe.
- The thickness of the films was 100nm. Substrate was silicon.
- Repeatability tests of ΔHk of these NiFe films on silicon and AlTiC substrates yielded a repeatability sigma of below 0.05 Oe, which translates into a λ sigma equivalent of $4\cdot10^{-7}$.
- Fig. 4 shows again a very good correlation between λ and ΔHk.

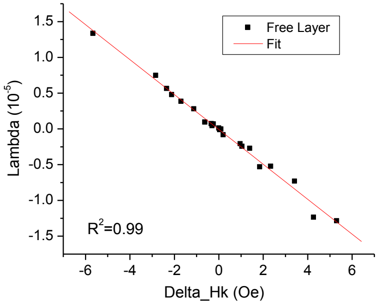


Fig.3: Correlation between λ and ΔHk for reader stack film set.

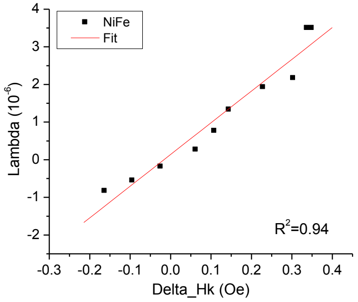


Fig.4: Correlation between λ and ΔHk for NiFe film set.

Summary and Outlook

- A highly advanced loop tracer with automated wafer/sample rotation and automatically driven magnetostriction knives was developed .
- Magnetostriction measurement capability was demonstrated for extremely thin (30Å) to thick magnetic films .
- The new loop tracer is fast, fully automated, non-destructive , provides 1000 Oe maximum field, and handles also very stiff substrates.
- Sensitivity is comparable to an optical cantilever method.
- Need to find general expression for this setup to deduce λ from ΔHk.
- Need to work on measurement capability for non-ideal samples ('high hard axis remanence'.

References:
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