Fabrication and characterization of epitaxial FeGa thin films

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Magnetostrictive FeGa

- Recently, it has been discovered that quenched bulk FeGa (19 atomic percent Ga) has <100> magnetostriction of ~ 350 ppm.
- FeGa has a low anistropy and high magnetization, can be easily saturated (~2K/M)[Clark IEEE Mag 36, 3238 (2000)].
- The low saturating field and high magnetostiction make FeGa an attractive MEMS material for magnetostrictive actuation.

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Epitaxial Fabrication

- As the high magnetostriction in localized in the $<100>$ directions, it is necessary to fabricate epitaxial structures.

- Epitaxial recipe
  1. HF etch Si (100), remove oxide, create Si-H bonds
  2. Grow (200) Cu
  3. Deposit (110) FeGa

- Due to BCC on FCC epitaxy, up to 4 variants are formed; $\{110\} // \{200\}$ and $<-111> // <110>$

Samples grown 10, 20, 40, 80, 120, 160 nm FeGa
Structure-Transmission Electron Microscopy

- In-plane TEM images of 160 nm Thick FeGa show all four variants present in SAD.
- TEM images enhancing grain contrast show that the grains are very uniform in size distribution.
- Grains are also arranged at the 90 and 109 degree angles predicted by the epitaxial relationships.

SAD, Image 160 nm epitaxial FeGa
Structure-X-ray Diffraction Pole Figure

- Phi scans measured at 60 degrees to the (110) pole, show the other (110) planes. If a single variant was present, 4 (110) planes would diffract.
- Due to the presence of 4 variants and their rotation at 90 degrees and 19.12 degrees, the variants show as 4 doublet peaks and 8 unique peaks.

160 nm (110) FeGa/90 nm (200) Cu/H-terminated (100) Si
Angular measurements - Remanence

- Angular remanence measurements on thin FeGa films show behavior consistent with a single (110) orientation.
- The angles between the easy directions are consistent with the angles between [100] and [110] directions.

Angular remanence 40 nm (110) FeGa
Angular Measurements - FMR

- Ferromagnetic resonance can be used to determine anisotropy of textured films
- Shown is angular X-band measurement of 40 nm (110) FeGa. Due to saturation problems do not show full dip between [100] and [110].
- Measurements performed at Centro Atomico Bariloche (Argentina)

X band FeGa 40nm (g=2.09, (ω/γ)=3334Oe) Hcubic=22 Oe
Heasy axis=-8 Oe Meff=1020 Oe
Angular Measurements - Torque

- Torque measurements were performed using home-built torque magnetometer [Flanders Rev. Sci. Instrum. 70, 2732 (1999)].
- Shown is torque (black) and fit (red) for 40 nm FeGa sample (9.6 mm²) at 660 Oe.
- Fit includes $K_1$, $K_u$ as well angles $K_1$ 0.125 at 24.1 deg ($\sim 3.3 \times 10^5$ ergs/cm³)
  $K_u$ -0.0781 at 34.7 deg ($\sim 2.0 \times 10^5$ ergs/cm³)
Conclusions

• It is possible to fabricate (110) oriented the FeGa films on epitaxial Cu (200) films.
• Thicker films measured by TEM and XRD show that all four variants are present.
• Angular measurements made by VSM, FMR, and Torque on thinner films show either 1 or 2 variant structures.
• Currently working on producing (100) FeGa on (100) MgO to simplify analysis.