Epitaxial Lift-Off of Barium Hexaferrite Membranes

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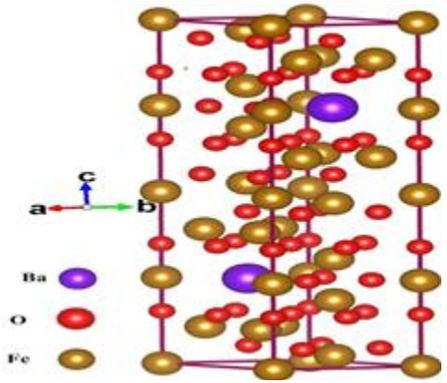
ARADIM AN NSF MATERIALS INNOVATION PLATFORM

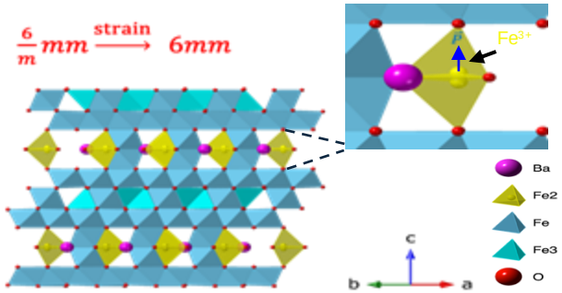
Introduction: Expanding $BaFe_{12}O_{19}$

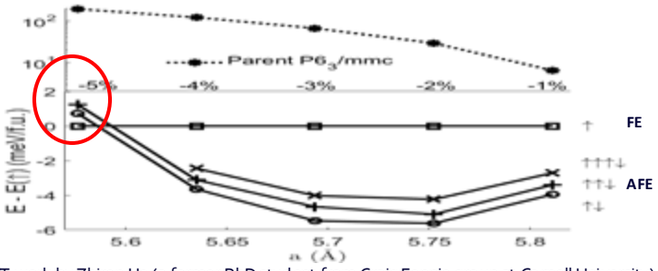


$BaFe_{12}O_{19}$ Crystal Structure

- Barium hexaferrite ($BaFe_{12}O_{19}$, BaM) is a ferrimagnetic material with high Curie temperature and chemical stability, commonly used in refrigerator magnets.
- This research explores $BaFe_{12}O_{19}$ beyond these traditional use by developing freestanding membranes via Molecular Beam Epitaxy (MBE). These innovations could advance electronics.

Strain-Induced Ferroelectricity

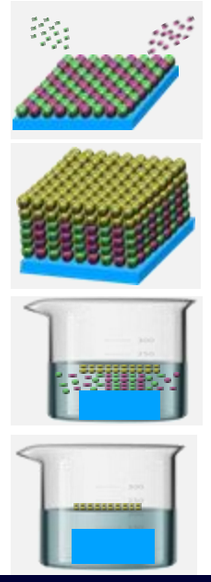




DFT work by Zhiren He (a former PhD student from Craig Fennie group at Cornell University)

- Barium hexaferrite may exhibit ferroelectricity under strain. Density Functional Theory (DFT) calculations indicate that compressive strain distorts the crystal lattice.
- This distortion disrupts the centrosymmetric point group, shifting BaM enabling electric polar order. Increased strain could lead to ferrielectric behavior.

Lift-Off Process



Deposition of Sacrificial Oxide Layer

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Deposition of Barium Hexaferrite Layer

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Etching Process

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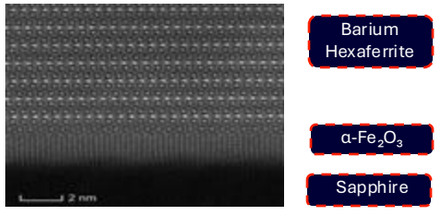
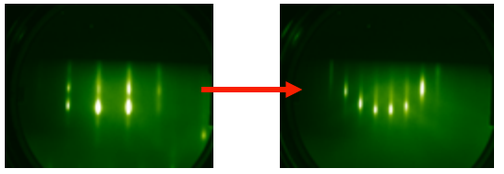
Free-Standing Barium Hexaferrite?

α-Fe_2O_3 Sacrificial Layer

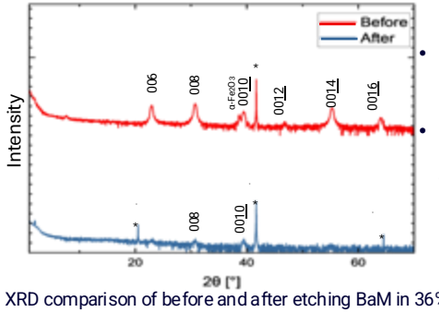




Acid concentration	Etching rate (nm/min)
HCl 15%	~0 for 1 hour etching
HCl 18%	0.4 nm/min
HCl 24%	1.8 nm/min

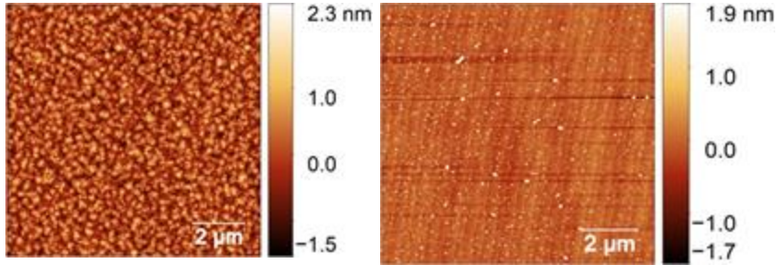
Slow etching rate even with 24% HCl

Iron oxide (α-Fe_2O_3) unexpectedly formed during $BaFe_{12}O_{19}$ growth. It acted as a sacrificial layer, enabling the $BaFe_{12}O_{19}$ membrane to detach from the substrate through HCl etching, resulting in a freestanding membrane.



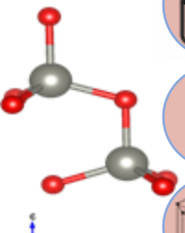
XRD comparison of before and after etching BaM in 36% HCl

- Etching tests on BaM grown on α-Fe_2O_3 showed issues with the lift-off process.
- XRD analysis revealed that both the sacrificial layer and the $BaFe_{12}O_{19}$ were removed, indicating the etching was too aggressive.



The before and after images confirmed that the $BaFe_{12}O_{19}$ film did not remain intact post-etching

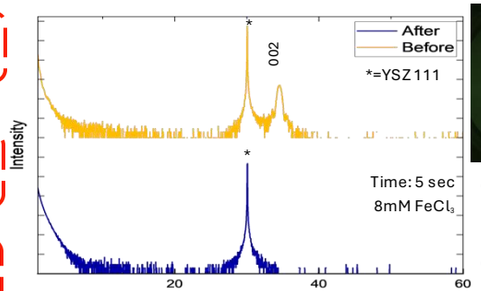
ZnO Sacrificial Layer



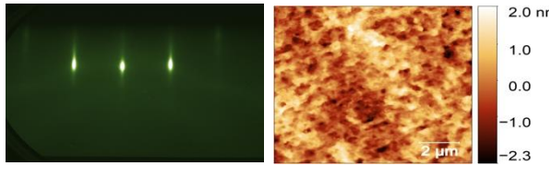
Easily dissolvable in very mild etchants

Comparable growth temperatures (700 °C)

Hexagonal (4% lattice mismatch with BaM)



XRD comparison of before and after etching ZnO in $FeCl_3$



- Zinc Oxide (ZnO) has proven to be an effective sacrificial layer for the epitaxial lift-off of BaM due to its compatibility.
- This layer, easily dissolved in mild etchants like 8 mM $FeCl_3$, allowed for etching in only 5 seconds.
- The successful lift-off demonstrates ZnO's potential.

Conclusion

- In this study, we identified ZnO as a promising sacrificial layer for lifting off BaM membranes.
- The successful ZnO etching shows its potential to help create freestanding BaM membranes, allowing exploration of ferrielectric properties through strain engineering.

Future Experiments

- Future experiments will involve growing Barium Hexaferrite (BaM) on Zinc Oxide (ZnO) as the sacrificial layer.
- The focus will be on optimizing the epitaxial lift-off process to create freestanding BaM membranes.
- We will test various etching conditions and $FeCl_3$ concentrations to refine the lift-off technique.
- Additionally, we will explore how these freestanding membranes can induce ferrielectric properties through strain engineering.