

Epitaxial Lift-Off of Barium Hexaferrite Membranes

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Abstract:

Freestanding barium hexaferrite ($\text{BaFe}_{12}\text{O}_{19}$ or BaM) membranes are valuable for various technological applications, and their fabrication via Molecular-Beam Epitaxy (MBE) involves overcoming significant challenges, particularly in the epitaxial lift-off process. Initially, $\alpha\text{-Fe}_2\text{O}_3$ was chosen as the sacrificial layer for membrane detachment due to its compatibility with the BaM crystal structure. However, $\alpha\text{-Fe}_2\text{O}_3$ proved problematic due to its slow etching rate, which led to inefficient lift-off even with strong acids, jeopardizing membrane quality. To address this, the study explored alternative materials and found that ZnO, with a similar crystal structure and a much faster dissolution rate, significantly enhanced the efficiency of the lift-off process. This transition to ZnO not only improved process efficiency but also underscored the critical role of material selection in optimizing epitaxial lift-off techniques. This work advances the fabrication methods for freestanding BaM membranes and highlights the practical application of material science principles in overcoming fabrication challenges.

Introduction

In this study, we investigate the epitaxial lift-off process for Barium Hexaferrite ($\text{BaFe}_{12}\text{O}_{19}$ or BaM) membranes, to achieve thin films using Molecular Beam Epitaxy (MBE). BaM is a ferrimagnetic material well-known for its high Curie temperature, robust chemical stability, and widespread use in refrigerator magnets. The focus of this research is on utilizing sacrificial layers; Iron Oxide ($\alpha\text{-Fe}_2\text{O}_3$) and Zinc Oxide (ZnO) to explore the potential of freestanding barium hexaferrite membranes.

Recent Density Functional Theory (DFT) calculations suggest that BaM could exhibit multiferroic properties under compressive strain. By altering the crystal symmetry through controlled straining, the iron atoms within BaM shift, inducing polarization and potentially leading to ferroelectricity. As the strain increases, so does the polarization, indicating that BaM could become multiferroic through this process. The motivation for exploring freestanding BaM membranes arise from the potential to control these properties through strain. This is significant because combining ferroelectricity with BaM's natural magnetic properties could make it valuable

for advanced electronic devices requiring both electric and magnetic control.

Experimental

The approach for creating freestanding $\text{BaFe}_{12}\text{O}_{19}$ membranes focused on evaluating sacrificial layers which is then conducted through a lift-off process involves depositing the sacrificial layer, growing the $\text{BaFe}_{12}\text{O}_{19}$ layer, and then etching the sacrificial layer to release the $\text{BaFe}_{12}\text{O}_{19}$ membrane.

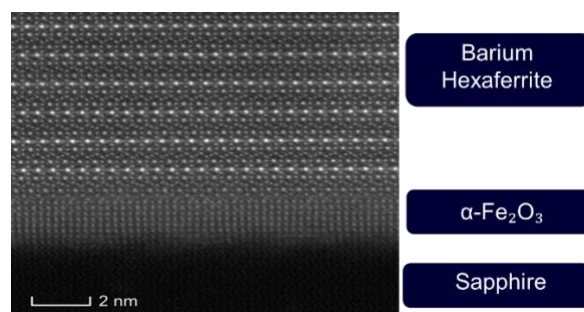


Fig1: TEM image showing the microstructure of the unintentional $\alpha\text{-Fe}_2\text{O}_3$ layer underneath $\text{BaFe}_{12}\text{O}_{19}$

During initial experiments for BaM film growth, $\alpha\text{-Fe}_2\text{O}_3$ naturally formed during the growth of $\text{BaFe}_{12}\text{O}_{19}$, which was identified through Transmission Electron Microscopy (TEM), and was considered as a sacrificial layer due to its compatibility with Barium Hexaferrite. This

encouraged further evaluation into its intentional use for creating freestanding BaM membranes and facilitating a lift-off process. Intentional growth of α -Fe₂O₃ as a sacrificial layer was pursued and Reflection High-Energy Electron Diffraction (RHEED) images confirmed the successful growth of BaFe₁₂O₁₉.

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

Table 1: Acid concentrations used in the etching process for removing α -Fe₂O₃ and BaFe₁₂O₁₉ layers.

Various concentrations of hydrochloric acid (HCl) were tested to dissolve the α -Fe₂O₃ layer. However, the etching rates were slow, with even the strongest concentration (24% HCl) achieving only 1.8 nm/min. Additionally, it was found that the BaM itself was also susceptible to etching under these conditions, leading to the unintended removal of the material along with the sacrificial layer.

Given the limitations of α -Fe₂O₃, ZnO was investigated as an alternative sacrificial layer. ZnO was selected due to its hexagonal crystal structure, and 4% lattice mismatch with BaM. Etching trials with ZnO were significantly more successful; ZnO dissolved rapidly in very mild etchants like 8 mM FeCl₃ within 5 seconds, making the lift-off process more efficient. The etching process with ZnO allowed for a more reliable lift-off, preserving the integrity of the freestanding BaFe₁₂O₁₉ membrane.

Results

The study attempted the epitaxial growth and lift-off of freestanding BaFe₁₂O₁₉ membranes using α -Fe₂O₃ as a sacrificial layer. However, the process encountered significant challenges: the fast-etching rates of α -Fe₂O₃ led to the unintended dissolution of BaFe₁₂O₁₉ along with the sacrificial layer, making the lift-off unsuccessful. Initial investigations have shown ZnO to be a promising sacrificial layer. ZnO demonstrated controlled etching behavior, suggesting it could be a more suitable option for future lift-off processes involving BaFe₁₂O₁₉.

Future Work

Future work would focus on further optimizing the lift-off process to improve membrane quality. Additionally, more in-depth studies on the multiferroic properties of BaFe₁₂O₁₉ and its possible integration into advanced electronic devices.

Conclusion

This study explored the use of α -Fe₂O₃ as a sacrificial layer for the lift-off of freestanding BaFe₁₂O₁₉ membranes. However, the fast etching of α -Fe₂O₃ resulted in the dissolution of BaFe₁₂O₁₉, rendering the lift-off unsuccessful. Preliminary findings with ZnO suggest it could serve as a more reliable sacrificial layer, offering controlled etching and the potential for better membrane quality. Future work will focus on leveraging ZnO to achieve successful lift-off and further explore the multiferroic behavior of BaFe₁₂O₁₉ for device applications.

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