Devising Process of Release of Micro-Origami Patterns of Zinc Sacrificial Layer by Sublimation

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Abstract

Micro-origami techniques require the deposition of thin film patterns on top of a sacrificial layer. In the process of forming micro-origami structures, the sacrificial layer must be removed selectively without affecting the film patterns. In addition, in heteroepitaxial structures the lattice constants of the substrate, sacrificial layer, and film patterns must all match within several percent, which is a challenge. Zinc is a good candidate for a sacrificial layer due to two reasons: The first is because it can be sublimated in a vacuum at relatively low temperatures, between 140 ˚C and 200 ˚C, when compared to most other metals, which melt rather than sublimate. The second is that zinc has similar lattice constants to elements/compounds such as Ti, Ru, Co, graphite, and SiC and the same hexagonal unit cell structure as Al_2O_3, Ti, and Ru. **The goal of this project was to grow epitaxial Zn films.** Various parameters were changed to see how they would affect Zn film growth. From FESEM images gathered, it appears as though zinc likes to cluster together and form in a polycrystalline fashion, rather than as an epitaxial film as desired.

Introduction

- For this project, aluminum oxide (sapphire) was used as the substrate.
- Zn does not grow epitaxially on Al_2O_3.
  - This is partially due to disparity between the lattice constants of Zn and Al_2O_3.Below is a table of relevant elements/ compounds with their structure and lattice constants.

Element/ Compound	Unit Cell Structure	Lattice Constants
Al_2O_3	HCP	a = 4.785 Å, c = 12.99 Å
Ru	HCP	a = 2.7 Å, c = 1.584 Å
Ti	HCP	a = 2.95 Å
Zn	HCP	a = 2.66 Å

Table 1. *Relevant elements/ compounds with their corresponding unit cell structure and lattice constants, given in angstroms. The letter a corresponds to the x-axis lattice dimension. The letter c corresponds to the z-axis lattice dimension.*

- Therefore, seed layers of Ru or Ti were deposited on Al_2O_3 to promote epitaxial growth of Zn films. Below is a visual illustration of the substrate and thin films.

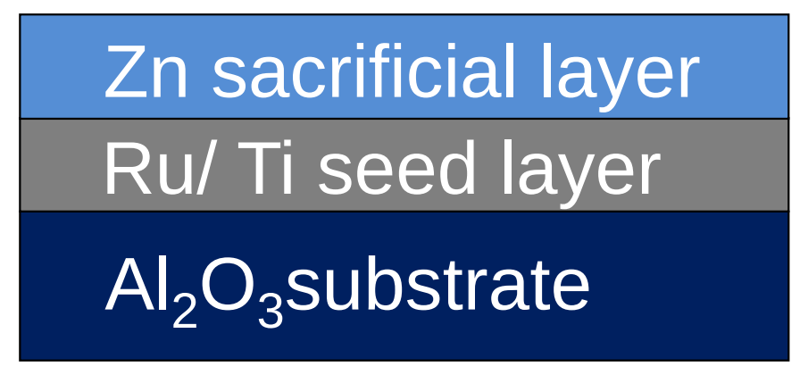
Zn sacrificial layer
Ru/ Ti seed layer
Al_2O_3substrate

Figure 1. *Visual illustration of the substrate and thin films used in this project.*

- The crystallinity of Al_2O_3, Ru, Ti, and Zn was characterized using Reflective High Energy Electron Diffraction (RHEED).
- A Field Emission Scanning Electron Microscope (FESEM) was used to get an image of the Zn film surface before and after sublimation.
- If epitaxial growth of Zn is proven possible, other elements can be deposited on top of the Zn sacrificial layer.
- With the help of photolithography, rolling thin films can be released upon Zn sublimation. The potential applications of rolling thin films are widespread.
- Applications include: micro- and nano- electromechanical systems, magnetoresistive random access memories (MRAM) , magnetic sensors, stress sensors, biosensors, metamaterials, and tunable microwave devices.

Methods

1. Clean an Al_2O_3 wafer via sonication with acetone for 5 minutes, distilled water for 5 minutes, and isopropyl alcohol (IPA) for 5 minutes.
2. Dry the wafer off with N_2 gas.
3. Load the wafer and check the crystallinity of the Al_2O_3 wafer with RHEED.
4. Deposit the seed layer: either Ru or Ti.
   - If Ru, use sputtering deposition at 600 ˚C, with a 10 nm thickness.
   - If Ti, use electron beam deposition at 400 ˚C, with a 50 nm thickness.
5. Check the crystallinity of the Ru/ Ti seed layer with RHEED.
6. Deposit Zn with electron beam deposition under the desired conditions:
   - Zn deposition rate
   - Zn deposition temperature
   - seed layer (Ru/ Ti)
   - Zn layer thickness (thought to have little effect on epitaxial growth)
7. Check the crystallinity of the Zn sacrificial layer with RHEED.
8. Take the wafer out and cut it in half with a diamond cutter.
9. Put half of the wafer back into the chamber and sublimate the Zn sacrificial layer at 200 ˚C for 15 minutes.
10. Check the crystallinity of the sublimated wafer with RHEED.
11. Coat both halves of the wafer with 5 nm of Pt using sputtering. This increases the conductivity of the sample so that it shows up better under the FESEM.
12. Look at both halves of the wafer under the FESEM.
13. Repeat the process under different conditions.

Sample Number	Substrate	Seed Layer	Zn Layer Thickness	Zn Deposition Temperature	Zn Deposition Rate
1	Al_2O_3	Ru	50 nm	20 °C	0.2 Å/sec
2	Al_2O_3	Ru	100 nm	50 °C	0.2 Å/sec
3	Al_2O_3	Ru	50 nm	100 °C	0.4 Å/sec
4	Al_2O_3	Ru	50 nm	20 °C	0.5 Å/sec
5	Al_2O_3	Ti	50 nm	20 °C	0.2 Å/sec
6	Al_2O_3	Ru	50 nm	20 °C	>1.0 Å/sec

Table 2. *All samples and the conditions that were used.*

***Note: the desired deposition rate for Sample 6 was 1.0 Å/sec, but the rate spiked when the filament current was increased too high. Thus, the deposition rate for Sample 6 is unknown.*

Figure 2. *Both the sputtering and electron beam deposition systems in Thin Film lab.*

RHEED Images

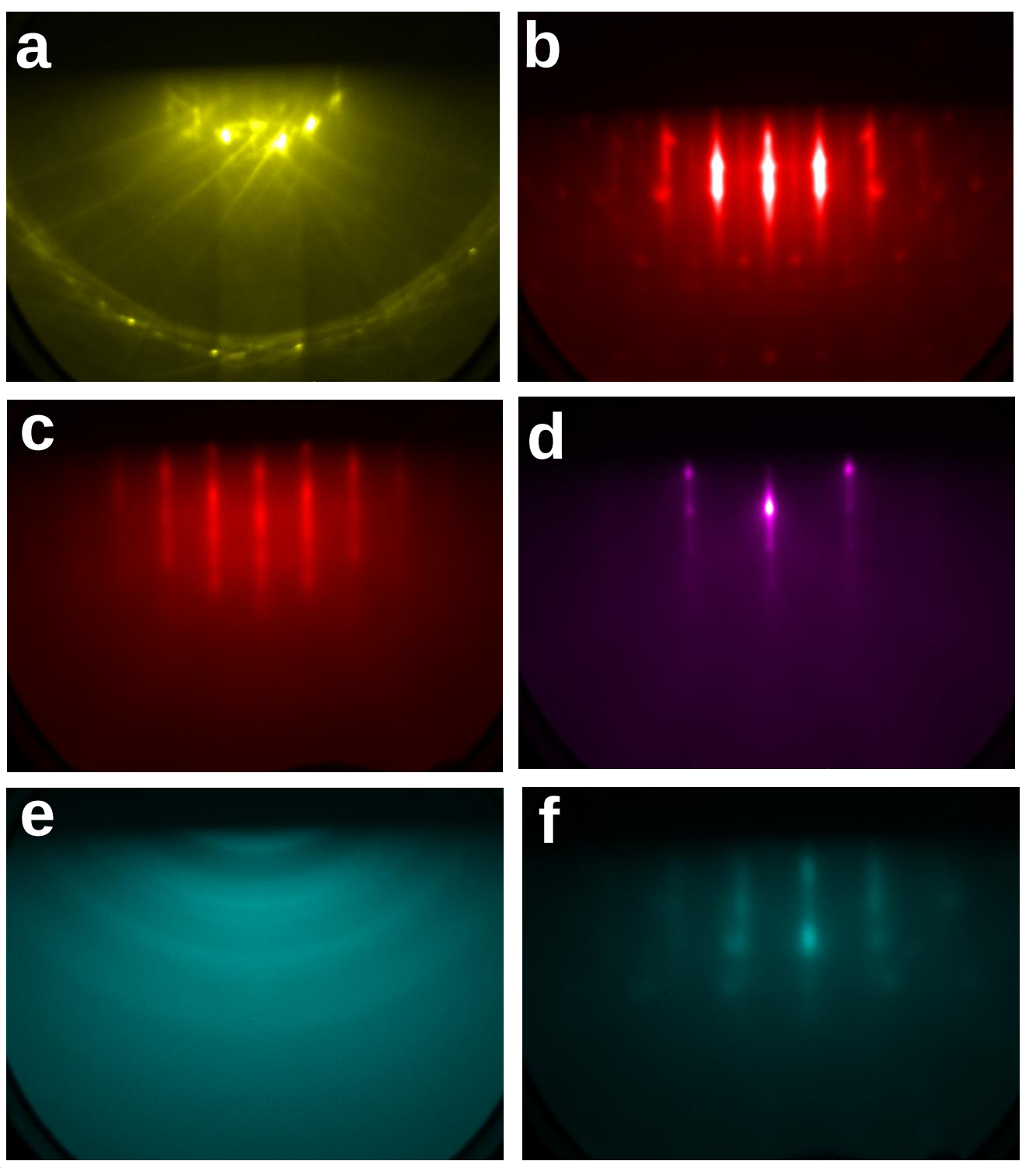

Figure 3. Example *RHEED images:*
a: Al_2O_3 (Sample 3)
b: Ru (Sample 1)
c: Ti (Sample 5)
d: Zn before sublimation (Sample 6)
e & f: Zn after sublimation (Samples 4 & 5)

FESEM Images

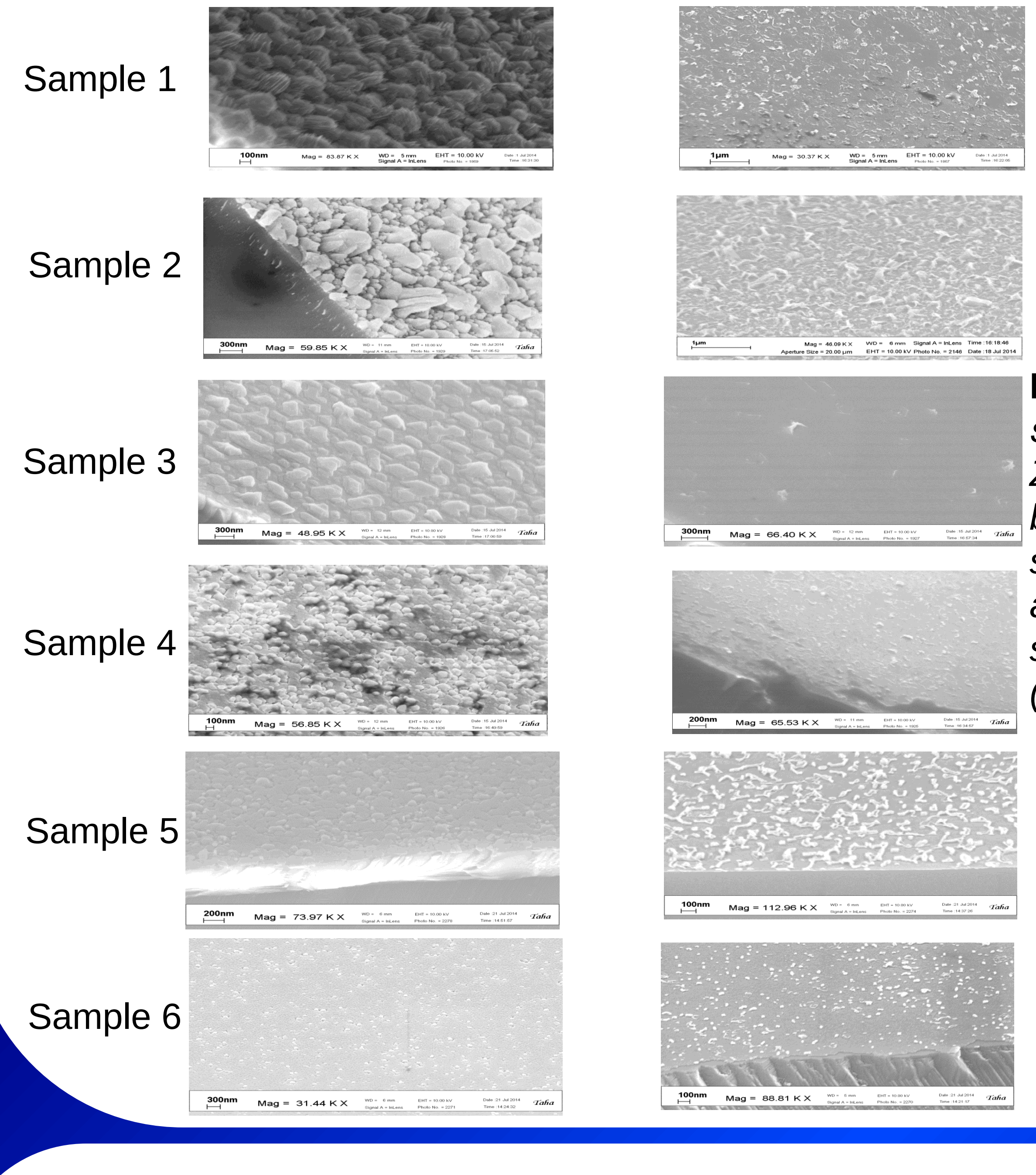

Figure 4. *Each sample's FESEM Zn image, both before sublimation (left) and after sublimation (right).*

Conclusion

- Effect of Zn deposition rate (comparing samples 1, 4, & 6):
  - low rate = bigger grains, film with larger roughness
  - high rate = smaller grains, smoother film
- Effect of seed layer (comparing samples 1 & 5):
  - Ti is better than Ru
- Effect of deposition temperature (comparing samples 3 & 4):
  - low temperature = smaller grains, better film
  - high temperature = bigger grains, increased film roughness
- Sublimation success:
  - Most Zn sublimated, but some ZnO left

Therefore, to get the best Zn film, it appears that a titanium seed layer, at low temperature, with a high rate should be used.

References

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