Growth, Structure and Neutron Reflectivity of Nanostructured Fe/Ag and Fe/Au Films

V. V. Krishnamurthy, P. Mani, and G. J. Mankey

MINT Center, The University of Alabama, Tuscaloosa, AL 35487-0209

S. G. E te Velthuis and S. Srinath

Materials Science Division, Argonne National Laboratory

Argonne, Illinois 60439

Acknowledgements: DOE/EPSCoR - grant no. DE-FG02-02ER45966 and
NSF MRSEC program - grant no. DMR-9809423 at UA
Introduction

• Nanostructured single crystal surfaces are important for molecular electronics and spintronic devices.

• The growth of metal film on an insulator substrate often proceeds in the Wolmer-Weber growth mode that results in the formation of three dimensional islands, because the surface energy of the film is larger than the surface energy of the substrate.

• Our aim is to grow Ag nanostructures on an a-axis oriented sapphire substrate. Then use the nanostructured Ag film as a template for fabricating nanosized magnetic Fe islands with controlled properties.

• We also aim to grow magnetic Fe nanostructures on flat Au buffer layers deposited on insulating substrates.
### Growth Modes for Epitaxial Thin Films

- The growing film surface can exhibit different behaviors depending on substrate temperature, interfacial strain, and the surface energy of the material deposited.

- These growth modes can be used to grow films of different morphologies.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer by Layer</td>
<td></td>
</tr>
<tr>
<td>Stranski-Kastraunov</td>
<td></td>
</tr>
<tr>
<td>Volmer-Weber</td>
<td></td>
</tr>
<tr>
<td>Diffusion Limited</td>
<td></td>
</tr>
<tr>
<td>Surface Segregation</td>
<td></td>
</tr>
<tr>
<td>Surface Alloy</td>
<td></td>
</tr>
</tbody>
</table>
Experiment

- Film growth by magnetron sputtering.
- Characterization Methods:
  - *in-situ*: RHEED
  - *ex-situ*: Atomic Force Microscopy
    - Magneto-optic Kerr effect
    - Polarized Neutron Reflectivity
Fe(110)/Ag(111) Films - RHEED

- RHEED from the sapphire substrate before deposition.
- The diffraction spots are on a circle. Kikuchi lines are observed.
- RHEED from 50 nm thick nanostructured Ag(111) film showing epitaxial growth.
- RHEED from 10 nm thick nanostructured Fe (110) overlayers show epitaxial growth.
AFM – Ag Islands on Nb Seed Layer

- Flat islands of Ag are observed with narrow size distribution.
- Grains are not flat if growth temperature is decreased.

a-Al$_2$O$_3$/Nb[2 nm]/Ag[50 nm] deposited at 400$^\circ$C
AFM – Ag Islands on Nb Seed Layer

\[ a\text{-Sapphire/Nb}[2 \text{ nm}]/Ag[50 \text{ nm}] \]

400°C
AFM – Fe Islands on Ag/Nb Seed Layer

[Image of AFM scan showing Fe islands on Ag/Nb seed layer.]

a-Sapphire/Nb[2 nm]/Ag[50 nm]/Fe[5 nm]/Au[5 nm] 370°C

THE UNIVERSITY OF ALABAMA

Center for Materials for Information Technology
an NSF Materials Science and Engineering Center
AFM – Fe Islands on Ag/Nb Seed Layer

- Faceting of Fe on the islands.

\[ a-\text{Al}_2\text{O}_3/\text{Nb}[2.4 \text{ nm}]/\text{Ag}[60 \text{ nm}]/\text{Fe}[12 \text{ nm}]/\text{Au}[10\text{nm}] \]
\[ T_g = 370^\circ\text{C} \]
Fe(110)/Ag(111) Films

Ag(111) Film has a nanoisland morphology when grown on sapphire substrate.
Polarized Neutron Reflectivity

- Reflectivity from an Ag/Fe film in an applied (saturation) field of 5 kOe along the x-axis. The reflectivity $R^{++}$ is strongly reduced as compared to the fit, due to the island type nanostructure of Ag.

- Reflectivity oscillations are strongly damped due to a rough Ag/Fe interface.

- Reflectivity from an Ag/Fe film in an applied (coercivity) field of –200 Oe.
When Fe is deposited on Au(111) layer at room temperature, it grows as anisotropic nanoclusters that have size distributions in the range of ~20 to 200 nm.
Fe/Au film exhibits in-plane magnetic anisotropy. The figure on the left side shows the easy axis hysteresis loop. Fe/Ag film has isotropic magnetization. This is shown in figure on the right side.
Polarized neutron reflectivity shows that the reflectivities are spin dependent. This proves that the nanostructured Fe layer is ferromagnetically ordered. The magnetic roughness due to Fe agglomeration gives the difference in reflectivity.
Conclusions

- Epitaxial Fe(110)/Ag(111) and Fe(110)/Au(111) nanostructures have been grown on a-axis oriented Al₂O₃ substrates.
- Growth of flat islands has been demonstrated for Fe(110)/Ag(110).
- The islands are randomly shaped and have average dimensions of 250 to 500 nm. The filling fraction and roughness are found to depend on the growth conditions (temperature, sputtering rate) and film thickness.
- Fe(110) grows as nanoclusters on the Au(111) surface.
- Polarized neutron reflectivity (PNR) has been used to investigate the magnetic and structural properties of the nanostructures.
- Strong mixing of Fe/Ag layers occurs for growth on heated substrates.
- PNR is characteristic of the magnetic roughness of the nanostructured Fe layer.