Growth and texturing of rare earth nitride thin films

Q2.3 MRS

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Growth and texturing of REN thin films

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Rare earth nitrides

- Across the RE series you get very…
  - similar chemical properties (5d and 6s electrons)
  - different magnetic properties (unfilled 4f shell)
- All have simple cubic rock salt (NaCl) structure
- React with water in atmosphere
  - Need to passivate with capping layer
Growth and texturing of REN thin films

Rare earth nitrides

• Interesting questions
  – Electronic structure calculations are challenging
    • localized 4f electrons are tough to deal with
    • Many different predictions
    • Metallic, half-metallic and semi-conducting states predicted
  – Magnetic ordering
    • SmN magnetism
      – Small magnetic moment, magnetic ordering
      – see Claire Meyer Q10.6

• Very clear need for experimental results
Growth and texturing of REN thin films

Growth methods

• MBE
• RE(NH$_2$)$_2$ -> REN
• Reactive Ion-Beam sputtering
  – Leuenberger et al, PRB 72, 014427 (2005)
• Thermal evaporation (VUW)
  – Granville et al, PRB 73, 235335 (2006)
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Thermal evaporation

- UHV
- Partial pressure of $N_2$ gas
  - $P_{N_2} \sim 10^{-4}\text{mbar}$
- This works!
- GaN or MgF$_2$ capping layer
Characterization

- SmN, GdN, DyN, ErN, LuN
- Good 1:1 stoichiometry ± 2% (RBS)
- Low O content, uniform films (SIMS)
- Semiconducting (transport)
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Characterization - XRD

- Typical REN
- Randomly oriented nanocrystals (~10nm)

![XRD spectrum image]
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Characterization - XRD

GdN (!)  SmN
Characterization

- Clear magnetic transitions (GdN: 70K)
- Coercive field ~ 250 Oe

Granville et al, “Semiconducting ground state of GdN thin films”
Characterization

• Semiconducting behaviour
  – smaller gap in ferromagnetic ground state

Granville et al, “Semiconducting ground state of GdN thin films”
Pulsed Laser Deposition (PLD)

• Laser ablation of RE metal source
• Similar to thermal evaporation techniques except that evaporation rate is time dependent (depends on pulse frequency)
• Main advantages
  – Can grow at elevated temperature
  – Novel capping materials possible
  – RHEED for *in situ* characterization
PLD - GdN

- Have grown thin films of GdN
- At elevated temperatures: ~700°C
- Substrates: Si, Sapphire, YSZ
- Capping layer: YSZ
Characterization - RHEED

• RHEED taken along 2 different directions
  – Match RHEED of substrates (in-plane epitaxy)
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Characterization - XRD

(200) (400)

YSZ (substrate)

GdN
Characterization - Magnetic

• Magnetization saturates at very small field strengths
• Coercive field ~ 20 Oe
  – Order of magnitude smaller than thermal samples
Many parameters to explore

- Rare earths
- Substrates
  - Si
  - YSZ (lattice matched, but oxygen is a worry)
  - Sapphire
- Growth temperature
- Growth pressure
- Activated $N_2$
- Capping layers
Summary

• Both theory and measurements of nanocrystalline films indicate interesting properties
• Further advances require quality epitaxial films before they can be answered
• This has been achieved as a proof of concept
• Much more work to do
Thank You

Claire Meyer (Q10.6)
Magnetic properties of REN thin films
Appendix
Growth and texturing of REN thin films

Extra Info - N$_2$ Pressure

\[ \sigma (S \text{ cm}^{-1}) \]

\[ P_{N2} (10^{-5} \text{ mbar}) \]
Growth and texturing of REN thin films

Extra Info - PLD XRD
Extra Info – Substrates

- Sapphire: 41.8
- Si: 28.6
- YSZ: 34.8, 73.8
Extra Info – RBS
Extra Info – $N_2$ content

GdN11: variable $N_2$ pressure

Conductance [Ω$^{-1}$]

Pressure [10$^{-6}$ mbar]

Time [s]

semiconducting  metallic
Extra Info – SIMS profile

- $N_2$ GdN (GaN cap)