Progress in Target Metrology at General Atomics

General Atomics

22st Target Fabrication Meeting
Las Vegas, Nevada
March 12-16, 2017

This work supported by U.S. Department of Energy under Contract No. DE-NA0001808
Metrology is central to target delivery and performance

- Tightening specs demands extraordinary verification
  - 100GBar: 10x smaller defects

- What we can’t see hinders target fabrication
  - Double shells: Too opaque to x-ray

- What we can’t see hurts shot performance
  - Oxidation: GDP, Microdots, LiH

0.1um defects
Plugged?
Oxygen writing
Vanishing Dots

Mn
100GBar defect specs 10x tighter than NIF in diameter & 500x in # density, requiring new metrology strategy

- Omega to NIF: Direct-drive platform development
- Allowing 10 particles between 0.1 and 0.5um per shell
  - Particle size 4x < diffraction limit
- Paradigm shift:

  Resolution = \frac{0.61 \times \lambda}{\text{N.A.}}

**Use intensity:** Scattering based techniques, not resolving defects

Precise (4hrs per shell) → High throughput → Fast (5 min per shell)

<table>
<thead>
<tr>
<th>Dark-field Imaging</th>
<th>Laser Scatterometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure Analysis</td>
<td></td>
</tr>
<tr>
<td>Low Vacuum SEM</td>
<td></td>
</tr>
</tbody>
</table>

**Shrink wavelength:** SEM resolves each defect, EDS performs root cause analysis
Use light scattering intensity as defect size indicator, roughly scales as $D^3, \lambda^{-2}$

- Can be modeled
  - Bobbert-Vlieger Model (exact solution)
  - Mie Scatterer
    - Near field image
  - Mie: $D^2, \lambda^0$
  - Rayleigh: $D^6, \lambda^{-4}$

- Can be verified
  - Polystyrene Latex Sphere (PSL)
  - Follow SEMI M53-1103 Standard
PSL-on-glass slide proved 0.1µm defects can be detected by dark-field imaging at 100X Magnification.

All four particles appear similar sized as images are diffraction limited at ~0.4µm.
Four challenges solved for dark-field shell inspection

- Image artifact removal
- Depth-of-focus stitching
- Background flattening
- Defect quantification

Each image covers ~1% shell surface
Located all the real defects after Z-focus stitching, artifact removal, and background subtraction

Also retain radial/depth distribution to inform target fab

Each image covers ~1% shell surface
3D defect rendition to facilitate viewing

Each image covers ~1% shell surface
Best GA polystyrene shell:
Fewer than eight hundred 0.1\,\mu m defects per shell

Each image covers \sim 1\% shell surface

100\,\text{GBar} spec: 10 allowed
Plan to integrate multiple metrology tools onto common 4Pi shell-handling platform

• Dark-field & Laser scatterometer: Omega defects
• Wallmap: Omega GDP & NIF PAMS thickness profile
• Lyncee Tec: NIF GDP defects and Lasik (replace PSDI)

• Benefits
  – Lower cost
    • Share platform
  – Reduce footprint
    • Smaller cleanroom
  – Reduce handling
    • Less contamination
  – Retain coordinates
    • Correlate mapping
Automation of x-ray systems: Absorption edge measures elemental areal density

- Calibration standard not needed

- Applied to a variety of ICF and HED samples
Automated Edge system, under construction, increases versatility and precision of areal density measurement

- **Benefits**
  - Full automation
  - Faster acquisition
  - Batch operation
  - Area mapping
  - Better accuracy
  - Less air exposure
  - Fragile samples

- **Hot topic: cold v. hot opacity**
  - Error bar on cold opacity?
  - Can we constrain it?

Open-tube x-ray source needed to probe <2keV
Five common x-ray databases benchmarked to reveal several % uncertainty in cold matter opacity (below K)

- Spectroscopy needs accurate cold material opacity
  - 7-14Å wavelength translates to 900-1800 eV energy

- Common metal such as Fe are insufficiently known
  - Can automated Edge system tighten error bar?
Fabricated & delivered Cr/W capsule assembly to facilitate LANL double-shell platform development

Leveraged target fab. knowledge to propose new capsule design

Coated
Cr: 12μm
W: 26μm
SEM cross-section of bilayer thkns

Drilled
Laser hole verified by x-ray tomography

Delivered
3D-printed inner-shell assembly holder

Verified
He leak test 00:10:00
New CFTA

Glued
10μm OD Fill tube
GA has overcome high-Z opacity-induced metrology issues to enable target fabrication development

Problem: Too opaque for x-ray to see laser hole
Solution: X-ray tomography (slow), phase contrast imaging (fast)

Problem: Is fill tube plugged by glue?
Solution: Used Xe to optimize XRF detection

Opacity will also plague in-shot diagnosis => interim mid-Z shells for 2017
“UV-Vis”-style optical transmission measurement can model thin metal thickness and test oxidation

- Metal coating <2000Å is translucent
  - Precisely modelled (Rakic 1998) beyond island-coalescence regime
- Micro-focus “Vis-IR” instrument constructed for “micro-dot” shells
  - Tracking oxidation-ind. transparency

Dots fade away over time
Adapting commercial technology: Nexiv VMZ automated measuring microscope

- **4X image res. Improvement** enables penumbral analysis
  - Study NIF x-ray source
- **Measure multiple randomly-oriented pin-hole arrays**
  - Huge time saver
On-demand metrology development at GA meets evolving needs of target fab community

- Recently completed or in the pipeline
  - Xradia Versa x-ray microscope for general metrology
  - XRF system with micro-focus and shell modeling
  - Automated NEXIV microscope for pin-hole arrays
  - Vis-IR optical transmission for microdots
  - Automated x-ray edge system for dopant areal density
  - New 4Pi shell handling station as a shared platform
  - Full surface wall thickness mapping for Omega shells
  - Dark-field defect mapper for LLE 100GBar
  - Lyncee Tec DHM microscope for NIF GDP defects
  - …..