Introduction and Background

Beryllium has been of interest as an ablator material for inertial confinement fusion (ICF) targets and has been in development for over 30 years. The main issues with beryllium shells are meeting the roundness specification, reducing inner surface roughness, reducing non-uniform argon incorporation, and increasing yield.

Roundness

Roundness impacts implosion uniformity. It is influenced by mandrel roundness, coating stress, deposition conditions, and polishing.

Inner/outer surface roughness

Capsule roundness also impacts implosion uniformity. It is influenced by mandrel roughness, coating stress, deposition conditions, and polishing.

Impurities

Impurities present in the coating increase opacity to x-rays. Argon incorporation due to substrate biasing is azimuthally non-uniform and detrimental to implosion symmetry.

Process Overview and System Hardware

Beryllium capsule production overview

- Produce mandrels 2 weeks GDP coating - Pyrolysis
- Coat beryllium 4 weeks Sputter deposition
- Pre-inspection < 1 week Determines which parts proceed to polishing
- Polish 3-5 days Mechanical polish to meet exterior roundness spec
- Inspection 1 day Verify exterior surface finish spec is met

Total production time = ~13 weeks

Coating system setup

- The rotating and vibrating pan allows for uniform coating of the mandrel. The pan is negatively biased allowing for a leak tight and dense film.
- Modes 7-12
- Modes 13-25

Capsule Roundness

- The roundness of the mandrel affects the final roundness of the capsule. The roundness of the beryllium capsule is never better than the GDP mandrel. An improvement in the mandrel roundness improves the final capsule roundness.

- Power spectra of the mandrel at different stages: 20 cm Mandrel 40 cm Mandrel 60 cm Mandrel

- Modes appear after 5 µm of beryllium coating and persist after removal of the coating, permanently altering the mandrel shape. It is important to manage coating stress early in the coating process to minimize the change in roundness and subsequent propagation throughout the coating of the change in shape.

- As-deposited outer surface SEM image

Inner and Outer Surface Roughness

- As-deposited outer surface Wyko image

Impurities

- Post-pyrolysis inner surface SEM image

- Oxygen and argon impurities both increase the x-ray opaquity of beryllium capsules. Most oxygen contamination comes from the mandrel pyrolysis process. Argon gets implanted in the coating from ion bombardment of the biased film and is azimuthally non-uniform.

- Cross-section SEM image of beryllium capsule

- As-deposited outer surface Wyko image

- Mid-tumble polishing outer surface Wyko image

- Post-tumble polished outer surface Wyko image

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- We are looking into several ways of reducing the oxygen content of the capsules:
  - Attempt moderate temperature mandrel removal with ozone
  - Coat PAMS or PVP and remove them by low temperature solvent dissolution

- We are currently investigating the effect of high power impulse magnetron sputtering (HIPMS) and pulsed substrate biasing on argon incorporation in the film

- Many of the aforementioned improvements would also enhance the yield of HIF quality capsules