Recent Developments in Glass Capsule Fabrication and Processing

M.E. Schoff, C.M. Shuldberg, M.L. Hoppe, A.L. Greenwood

General Atomics, P.O. Box 85608, San Diego, California 92186-5608

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

This work performed under the auspices of the U.S. Department of Energy
by General Atomics under Contract DE-NA0001808
Drop Tower (DT) Glass Capsules – Original Uniform, Spherical Pressure Vessels

Diagram of Drop Tower

- Used as exploding pusher platform
  - Proton/neutron source, nuclear reactions

- Requirements:
  - Gas retentive
  - Uniform thin wall (<0.5 µm Δwall)
  - Spherical (up to 1 mm OD)
• Proton backlighter: $^3$He fills for monoenergetic 15 MeV proton source
• Physics: H and He isotopes for fusion reaction studies
• Diagnostic Development: DT fills for neutron source
To Support Goals of ICF Community, Need High Confidence in Target Quality and Low Effort per Capsule

- Provide reliable exploding pusher platforms
  - Repeatable and consistent
  - Know pressure at shot time
  - Support variety of fill and fielding schemes
  - Limited 3He availability

- To meet demand, increase quantity with same level of effort
DT Glass Process

On-going

Fabricate, Wash, Sieve, Sort
(In Advance of Order)

Cull from Selected Batch &
Optical Inspection

Measure Dimensions

For each order

Add Permeation Barrier?

Measure He Half-Life (HL)

Fill at GA?

Package & Ship

Low yield process

Fragility and low contrast
main challenge for
automating culling &
optical inspection
Fabrication Effort was Decreased to Focus Effort on Metrology and Delivery

- Consume existing inventory
- New drops to backfill inventory, no new development
  - Focus on common sizes and compositions
Pressure at Shot Time Determined by Fill Pressure, Outgassing Time and Permeation Half-life (HL)

Outgassing time limited to facility cycle time
- HL tradeoff: outgassing vs fill time
- Fill and outgassing temp provides some flexibility
- Desire to minimize uncertainty in pressure at shot time

\[ P = P_0 \times 2^{-(t/HL)} \]

HL determined by:
- composition
- fill gas
- OD and wall
- temperature
Permeation Barrier Can be Added to Increase Capsule Permeation HL

- 0.1 µm thick sputtered Al coating reduces effective permeation area

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Resulting HL Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Coat one side</td>
<td>4-5X</td>
</tr>
<tr>
<td>B</td>
<td>Coat two sides, rotating between coatings</td>
<td>5X to infinite</td>
</tr>
<tr>
<td>C</td>
<td>Coat two sides, then chemical etch</td>
<td>1X to infinite</td>
</tr>
<tr>
<td>D</td>
<td>Coat two sides with mask of known area</td>
<td>~20-100X</td>
</tr>
</tbody>
</table>
- ~20 nm thick $\text{Al}_2\text{O}_3$ coated by Atomic Layer Deposition (ALD)
- Uncoated area only at contact spot with gelpak
- ~2% of surface area, increasing HL ~50X
- Tailor HLs by varying contact spot/mask
Multiple Points of Capsule Outgassing Measured to Determine HL

\[ P = P_0 \times 2^{-\left(\frac{t}{HL}\right)} \]

\[ \frac{dP}{dt} \propto 2^{-\left(\frac{t}{HL}\right)} \]

**Internal Pressure Over Time**

Collect and measure outgassing on Mass Spec

**Multipoint Method**

- HL calculated from exponential fit to multiple outgassing rate measurements
- Able to only resolve a limited range of HLs
- Time consuming for 3 measurements
Calibrated Single Point HL Measurement Increases Accuracy and Reduces Measurement Time ~30%

- HL calculated by directly solving non-linear equation
  - Calibrated fill pressure and out-gassing rate
- More accurate and over larger range of HLs
- Only single point needed, reducing measurement time

\[
P = P_0 \times 2^{-\left(\frac{t}{HL}\right)}
\]

\[
\frac{dP}{dt} = -\frac{P_0}{HL} \times 2^{-\left(\frac{t}{HL}\right)}
\]

\[
P = P_0 \	imes 2^{-\left(\frac{t}{HL}\right)}
\]

\[
\Delta P \\
\Delta t \\
t
\]

Internal Pressure Over Time

Collect and measure outgassing on Mass Spec
Automation of Single Point HL Method Doubles Throughput and Saves ~8% of Total Glass Capsule Effort

- Measurement time cut >50%
- Software controlled operation
- Reduces operator fatigue by limiting involvement to loading/unloading capsules
- Welded construction reduces leaks, wear-and-tear

2 banks of 10 shells can be measured in one run
Attaching a Fill Tube Eliminates Permeation and HL Concerns

- **Benefits:**
  - Fill on demand
  - More fill gases and mixtures
  - Only need to leak test

- **Drawbacks:**
  - Difficult to laser drill glass
  - Assembly and shipping costs
  - Lower fill pressure

Jagged laser drilled holes

Shell failure
Additional Methods Under Investigation to Meet Increasing Demand

- Automation
  - Capsule culling and inspection
  - Dimensional measurements by interferometry
- Increase control of permeation barrier to remove need for individual HL measurements
- Request greater dimensional tolerances to increase yield
- Recycle capsules delivered but not shot
- Use higher yield, but longer process Hoppe glass