Changes in Fill Tube Curvature During Target Assembly

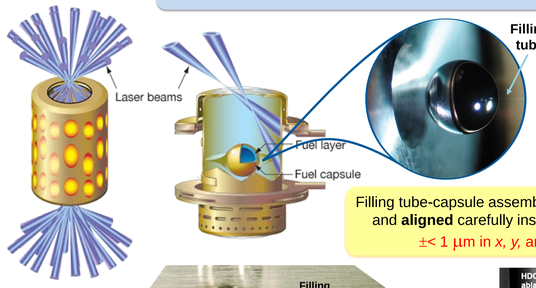
Xavier Lepró*, Daniel Malone, Chantel Aracne-Ruddle, Alexander Schwartz, Marcus Monticelli

Target Science and Technology group, Lawrence Livermore National Laboratory
7000 East Avenue, Livermore CA 94550, USA

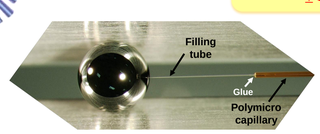
xnlepro@llnl.gov

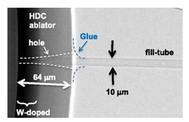
IGNITION since 2022

Fill Tubes in Target Assembly

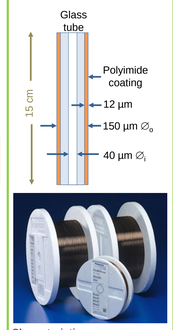


Filling tube-capsule assembly must be **vacuum-tight** and **aligned** carefully inside the hohlraum within
±< 1 μm in *x*, *y*, and *z* coordinates



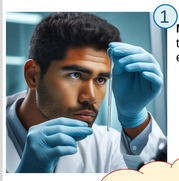


Polymicro (PM) capillary structure

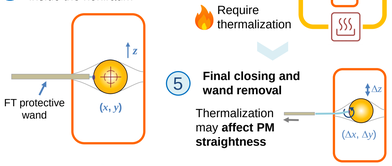


Characteristics
- High temperature polyimide coating
- Synthetic fused silica
- 100% proof tested for strength
- Operation up to 400°C

Current Mainstream Process



1. **Manually sort** the polymicro tubes by straightness by an experienced **"trained eye"**
2. **Insert & glue the tube** to the fuel capsule
3. **Align capsule** in x,y, z inside the hohlraum
4. **Downstream assembly operations**
   Require thermalization
5. **Final closing and wand removal**
   Thermalization may **affect PM straightness**

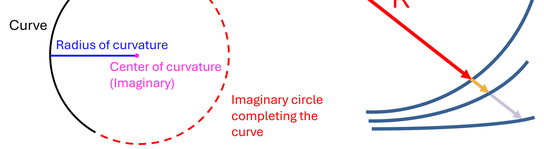


Undesirable capsule displacement leads to:
- **Leaks**
- **Clogs**
- **Out-of-spec**
- **Failed target**

What is too bent? How can we quantify it?

How can we measure curvature?

Radius of Curvature



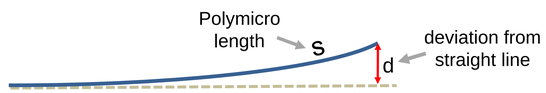
The higher the radius of curvature the less curved is the line.

Remember, for a **perfect straight-line, R→ ∞**

Curvature is defined as $\kappa \equiv \frac{1}{R}$, $R = \left|\frac{ds}{d\varphi}\right|$

Relationship between R and the deviation from a straight line

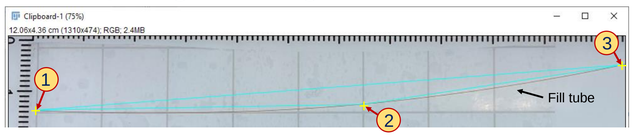
$$R = \frac{s^2}{8d}$$



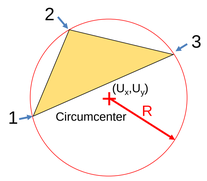
Quantifying curvature

Use computer software to analyze optical pictures
Image J 2.0 - Fiji

Computing the triangle's circumcircle



Circumcircle



1. **Select 3 points** (triangle vertices) along the length of the PM
2. A script calculates the properties of the circumference that passes through the 3 vertices of the triangle

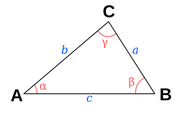
The diameter of the circumcircle is found from the length of the triangle's sides:

$$\text{diameter} = \frac{abc}{2 \cdot \text{area}} = \frac{|AB||BC||CA|}{2 \cdot |\triangle ABC|}$$

$$= \frac{abc}{2\sqrt{s(s-a)(s-b)(s-c)}}$$

$$= \frac{2abc}{\sqrt{(a+b+c)(-a+b+c)(a-b+c)(a+b-c)}}$$

where s is the semiperimeter of the triangle, $s = \frac{1}{2}(a+b+c)$

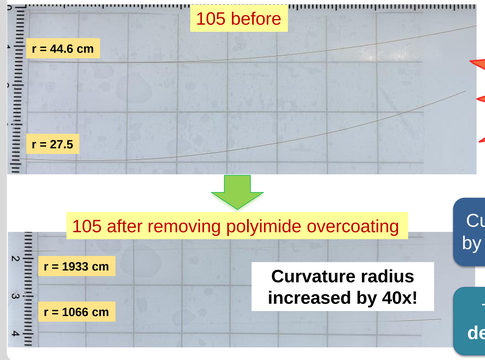


output

a: 60,157
b: 751.5,143.5
c: 1306.5,59.5
Area of circumcircle: 27516897.9 pix²
Radius: 4797.1 pix
Menger Curvature: 1/R = 0.0002085 pix⁻¹
Circumcentre: 312.3589,4633.4502

Curvature Radius
r = 44.15 cm
(in real space)

Polyimide removal decreases fill tube curvature



Curvature radius increased by 40x!

Now, we can measure how much!

Hypothesis

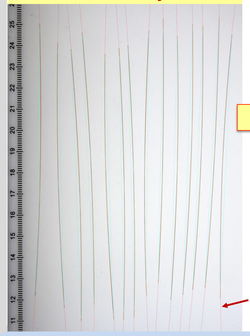
Curvature is mostly driven by the polymer overcoating

To decrease curvature, **decrease polymer stress**

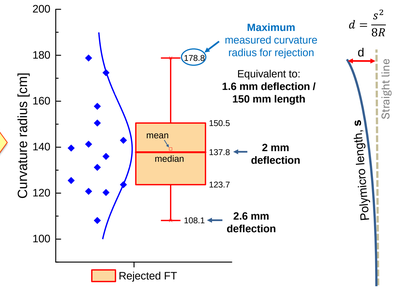
Validating the measurement: FOM

Previously known value for Curvature Specs: < 2 mm departure / 150 mm length

Actual PMs rejected

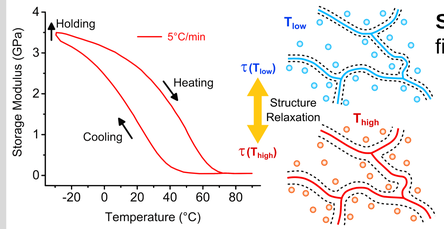


Precut PolyMicro (PM) Filling Tubes
REJECTED BY CLEANROOM



Established limit for rejection: R < 180 cm

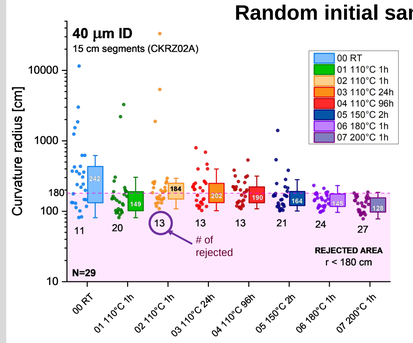
Thermal annealing to relax polymer stress



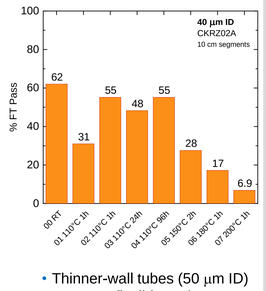
Stress on polymer thin-films can be **relaxed by thermal annealing**

Fill tube curvature should change after thermalization

Random initial sampling



Pass rate

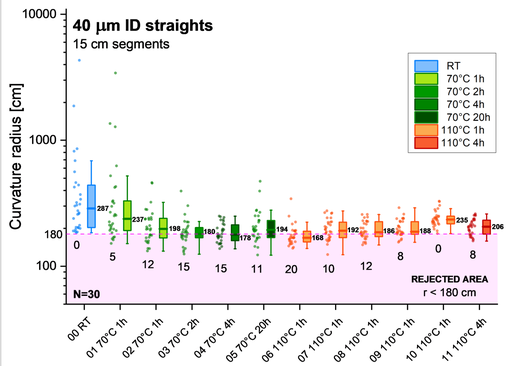


- In all cases, all fill tubes became more curved (*ie.* **decrease curvature radius, r) after annealing treatments.**
- Thinner-wall tubes (50 μm ID) are more flexible and prone to curve more than 40 μm ID.

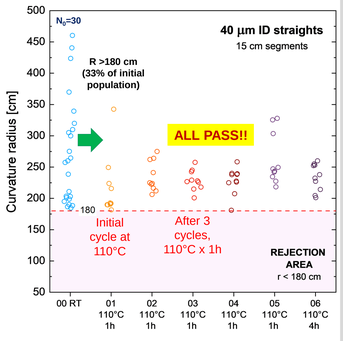
Thermal history of pre-sorted straight tubes

100% of individual PMs with R >180 cm (PASS)
AFTER initial heating at 110°C 1h, remained PASS (R >180 cm)
after 2 subsequent 110°C heating cycles (as required for production)

Population changes

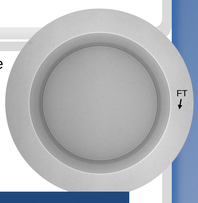


Tracking individual behaviors



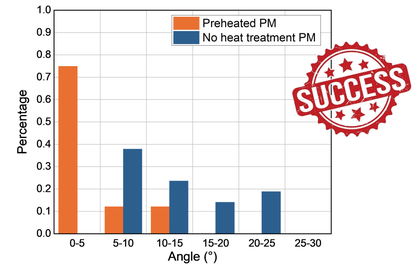
Implementing pre-heating in assembly increases target yield!

Sagometer: X-ray image of capsule alignment



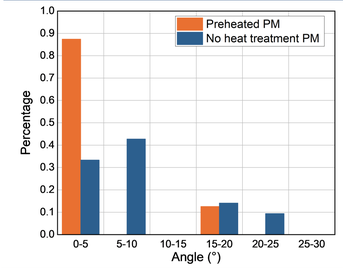
Sorting filling tubes after 2h annealing at 110°C reduced capsule misaligning downstream during assembly

Rotation of capsule from nominal at wanding



Smaller angle means significant reduction of heroics, effort and risk to CFTA at wanding

Rotation of capsule from nominal at close

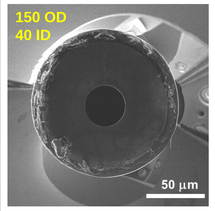


Smaller angle means less chance of fill tube breaking and leaks at cryo

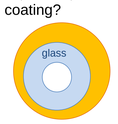
*Courtesy of Marcus Monticelli

What's next?

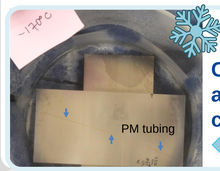
Understanding curling origin…



- Is there a radial asymmetry on the coating?



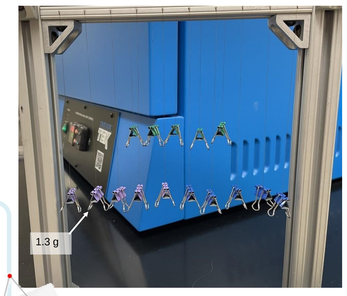
- Residual stress from PM manufacturing?

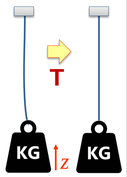


Curling behavior at cryogenic conditions?

Coming SOON

& … is possible to reverse it?





Thermal and load-induced stress relief

Contact the presenter!

LLNL-POST-867026

Target Fabrication at the National Ignition Facility • Lawrence Livermore National Laboratory • Operated by the US Department of Energy
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Lawrence Livermore National Laboratory

National Nuclear Security Administration