Cr-Be Pushered Single Shell (PSS) Capsule Development

H. Xu,[1] H. Huang[1], M. Ratledge,[1] C. Kong,[1] K. Sequoia[1], N.G. Rice,[1] J. Bae,[1]
Y. Wang,[2] S. Maclaren,[2] S. Baxamusa[2], M. Stadermann[2], R. Tipton[2], D. Ho[2], and C. Young[2]
1General Atomics, P.O. Box 85608, San Diego, California 92186-5608
2Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94550

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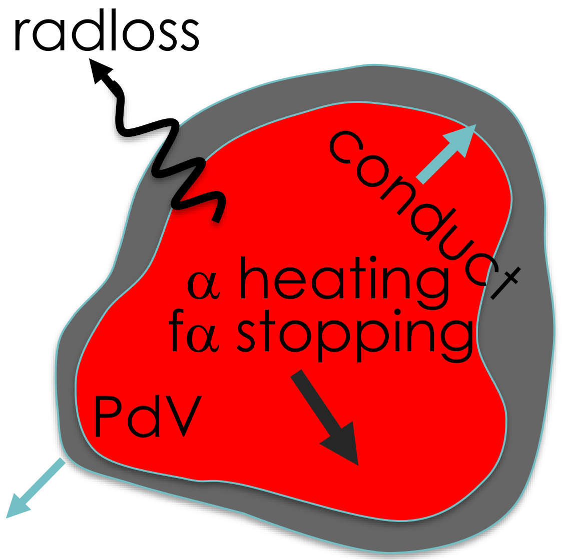
The Pushered Single Shell (PSS) project aims to study trade-offs to fusion performance from a metal-gas implosion

- **Top objective is code validation for burn physics in the presence of:**
  - Reduced radiation losses (radiation “trapping”)
  - Enhanced confinement time (tamping)
  - High-Z mix into the fusion fuel



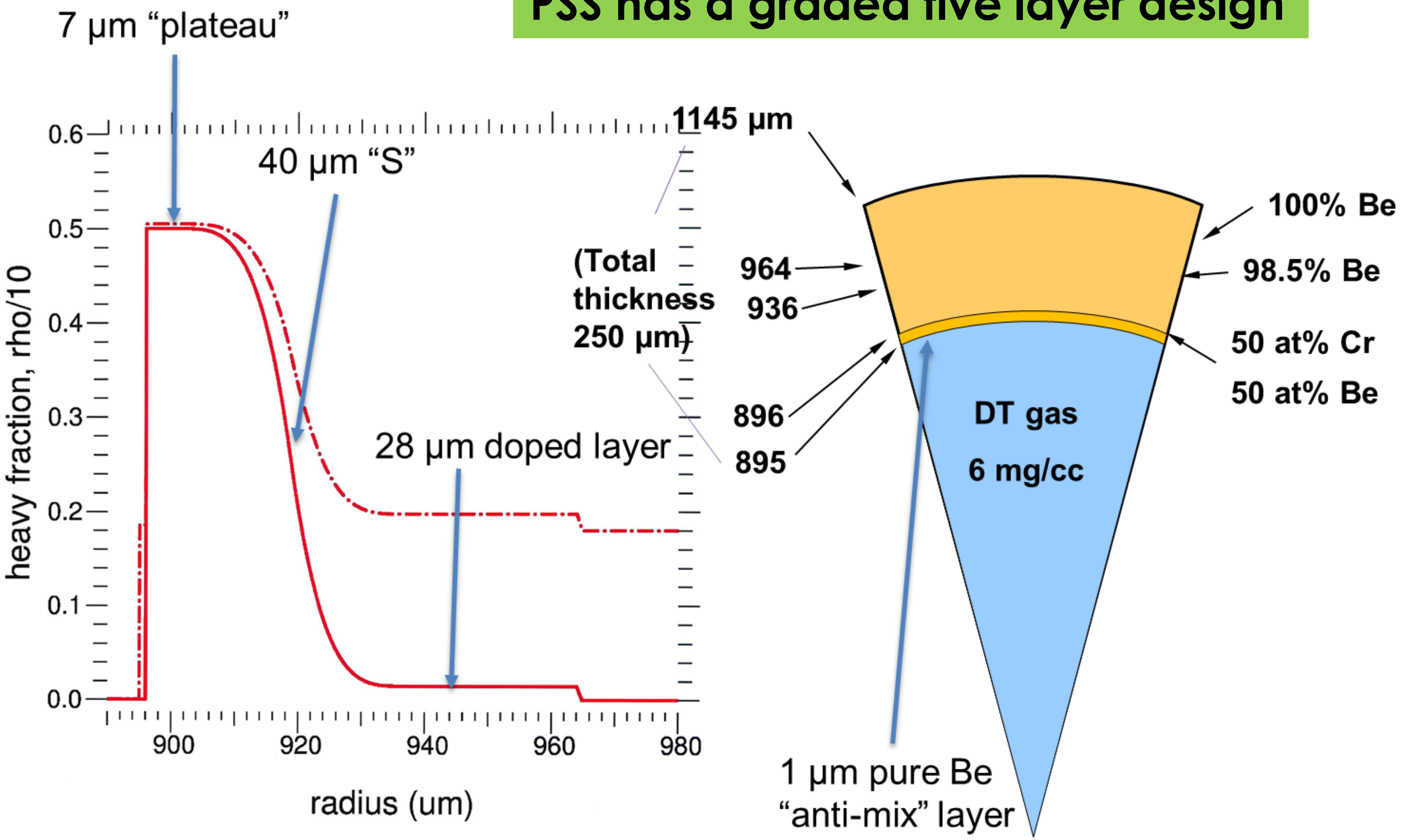
- **Near term objectives include:**
  - A symmetric implosion at or near the design velocity
  - Test graded ablator at mitigating ablation front instability
- **Current PSS design takes advantage of:**
  - Be ICF platform success with symmetric implosions in low-fill 672 hohlraums
  - Capsule coating technology that blend mid- and high-Z metals with Be in a prescribed radial profile

Key challenges with Hgh-Z PSS metal shells

1. **Stability: Keeping the shell intact**
   - Graded density suppresses instability growth
2. **Fabrication**
   - Composition gradient leads to severe stress
   - Microstructure changes with position
3. **Inability to diagnose interior symmetry and process**
   - Be->Cr as dynamic surrogate for implosion tuning

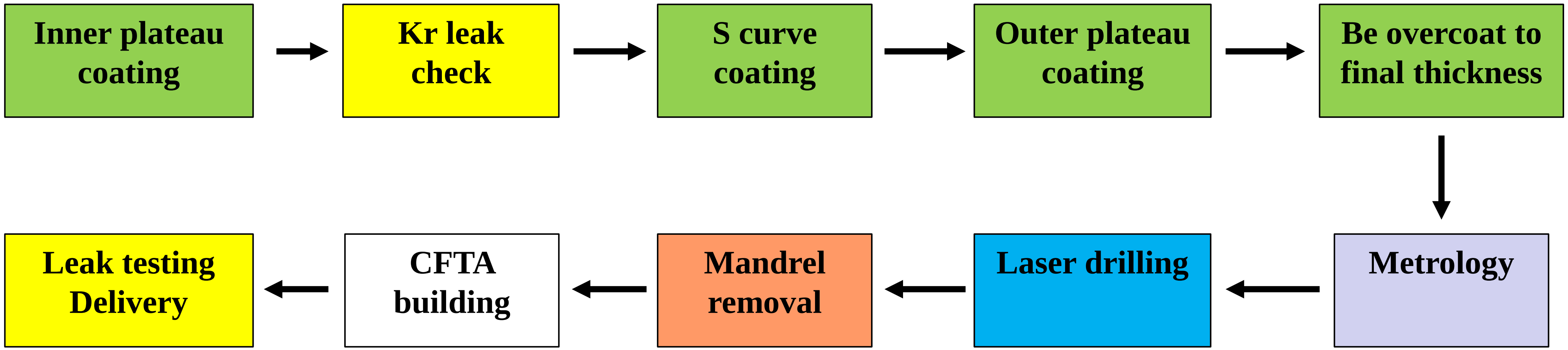
Be/Cr is a hydro dynamic surrogate for Be/Mo and Be/W, can be seen through by current x-ray diagnostics

PSS has a graded five layer design



- **Be Ablator**
  - 130 um
- **1.5/98.5 Cr/Be Tamper**
  - outer plateau
  - 28 um
- **Graded Cr/Be Pusher**
  - S-curve
  - 40 um
- **50/50 Cr/Be Liner**
  - inner plateau
  - 2 um
- **Be Anti-Mix**
  - 1 um

Careful execution of month-long multiple-step production cycle required to meet stringent requirements

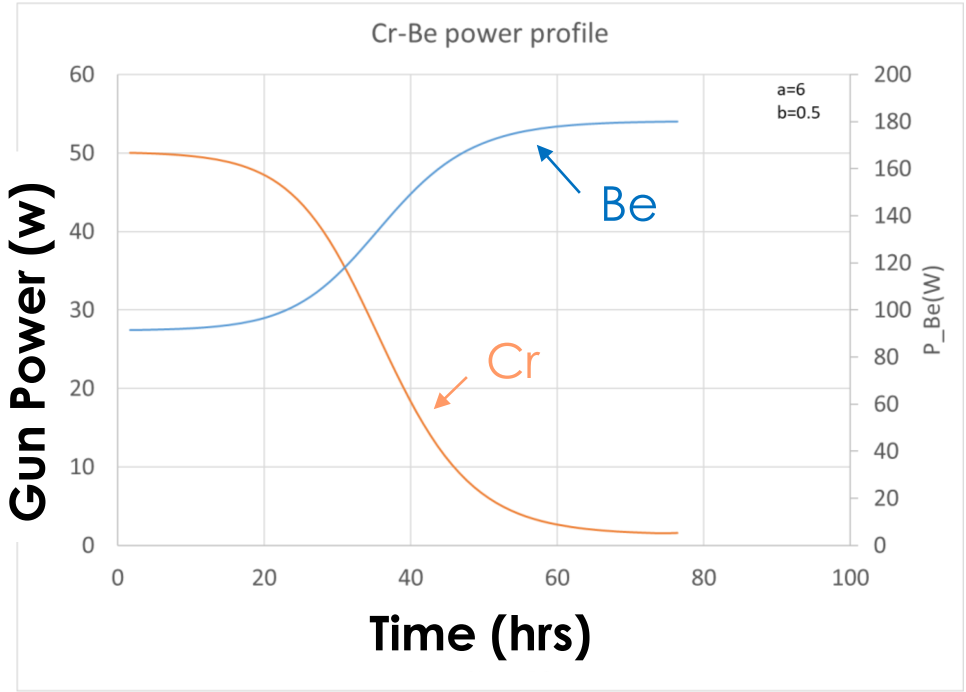


Requirements:

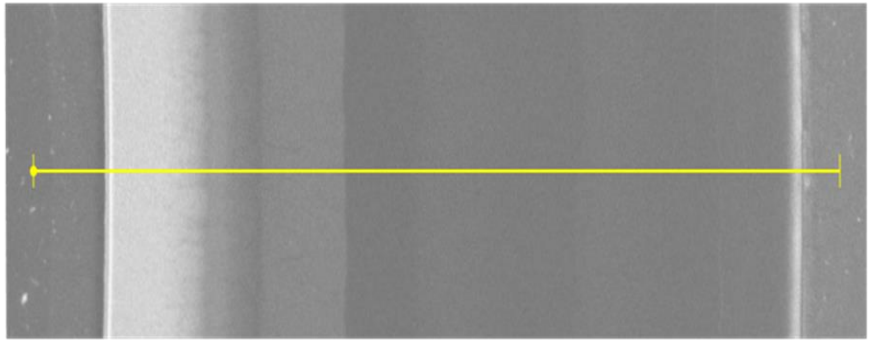
1. ICF convergence => Spherical mandrel
2. Hydrodynamics => Precise composition profiles
3. Hold fuel gas => Leak tight
4. Spherical implosion => Uniform microstructure
5. Mandrel removal => Burn out in oxygen
6. Cyro fielding => CFTA

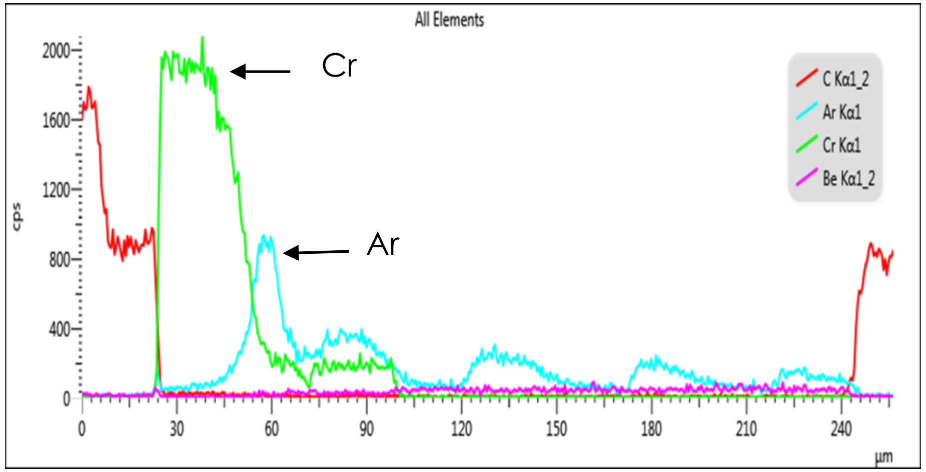
Tailored gun power profile, verified after fab by EDS line profile, is used to achieve required comix composition profile

Gun power simulation → Co-deposition → SEM/EDS validation



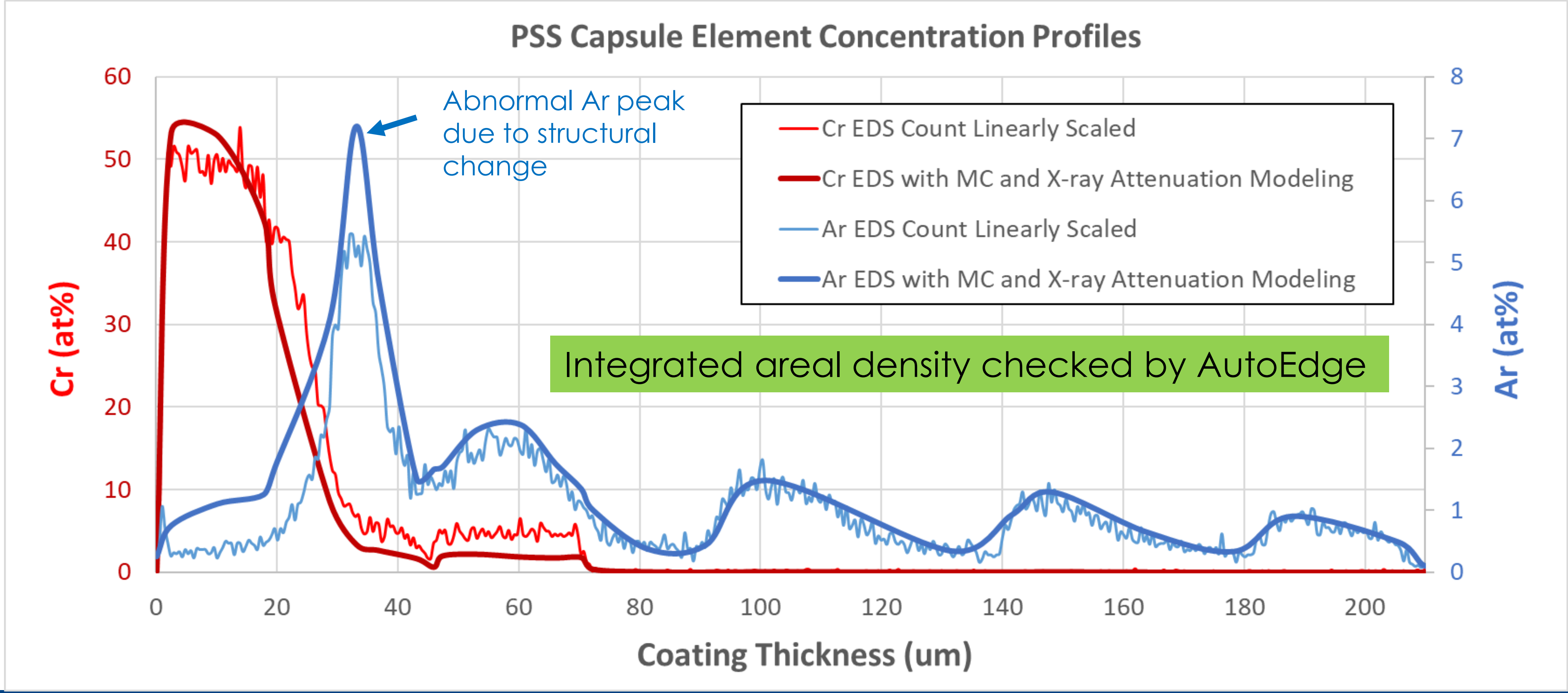
Actual coating more complicated: coating rate changes as target erode





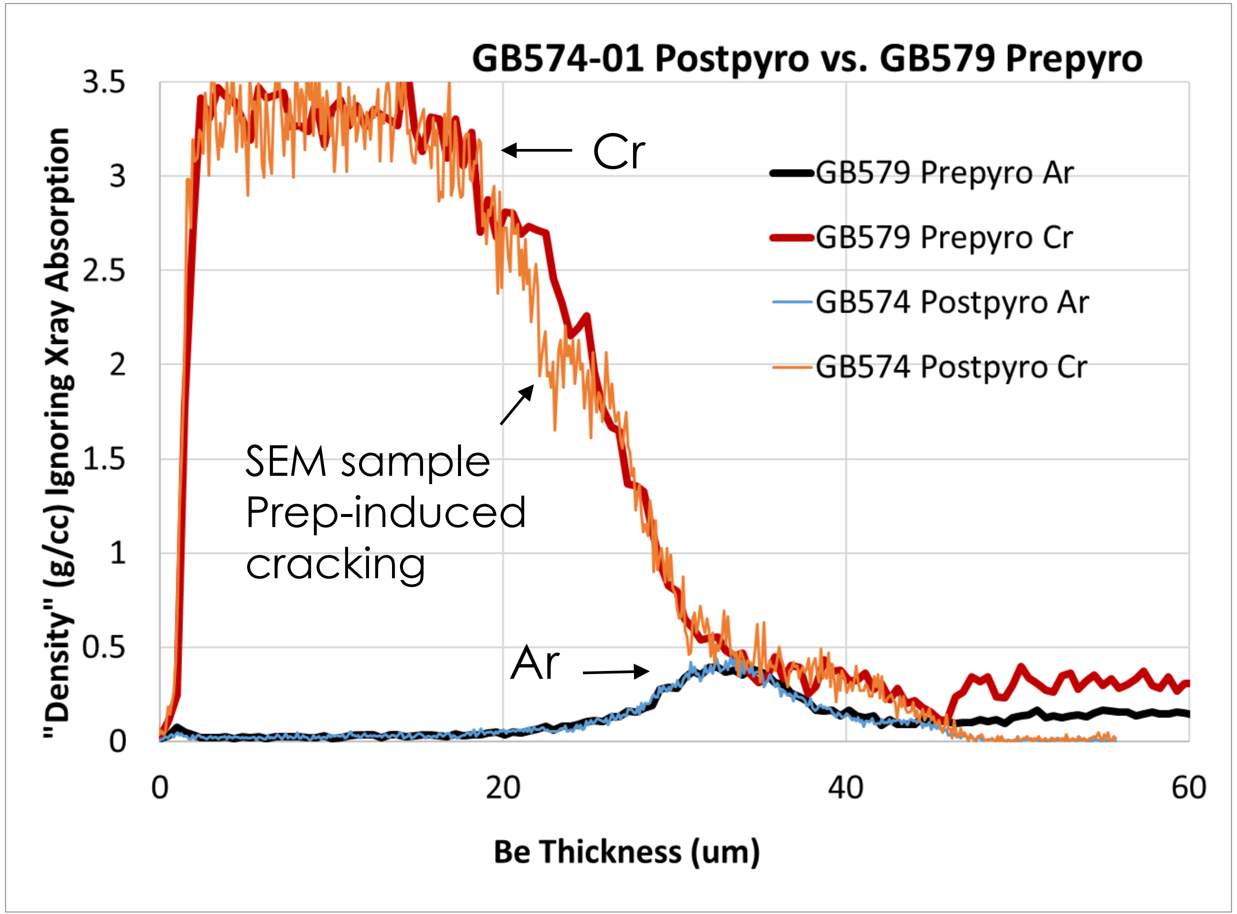
EDS modelling is required to convert x-ray counts into at%, (Linear count scaling will result in 2x error)

Xray generation: Using CASINO to perform electron-material interaction Monte-Carlo calculation
Xray attenuation: Using with instrument specific geometry and x-ray opacity database

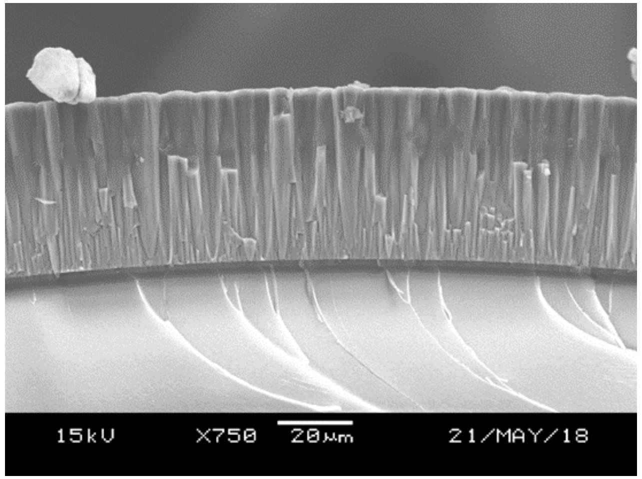


Good thermal stability, without observable dopant diffusion

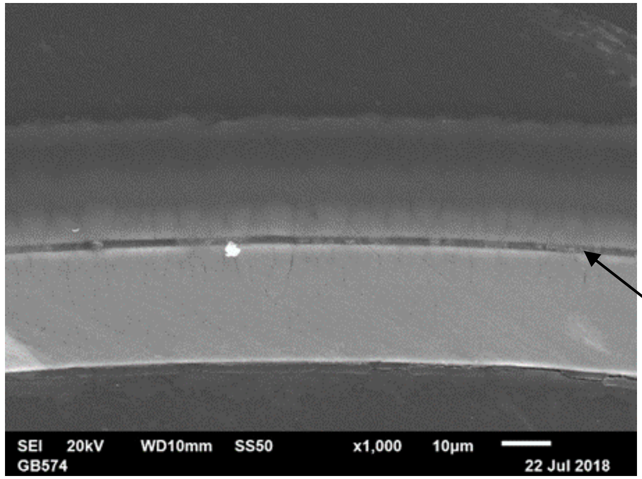
Pyrolysis induced no change in Ar/Cr profiles



SEM cross-sections



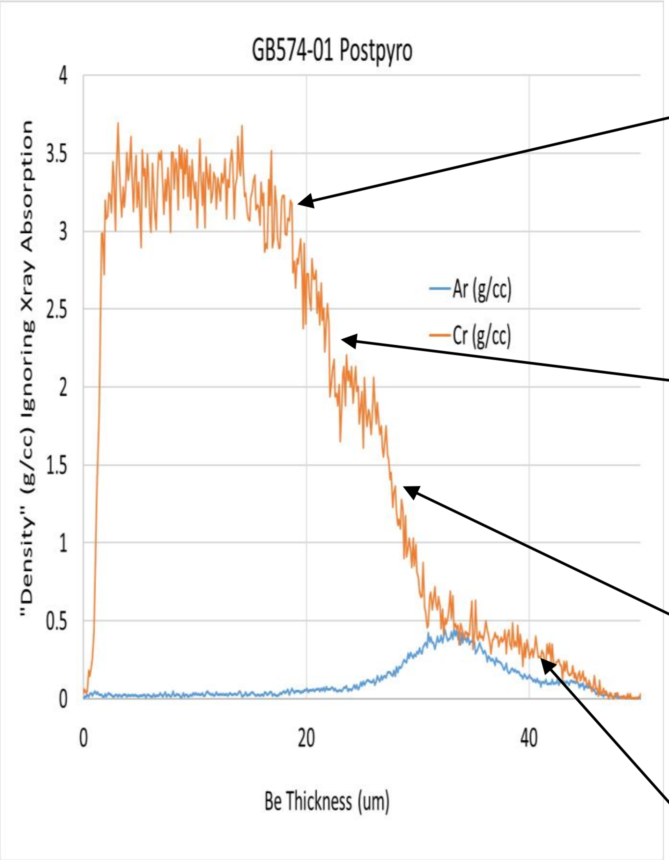
Pre-pyro



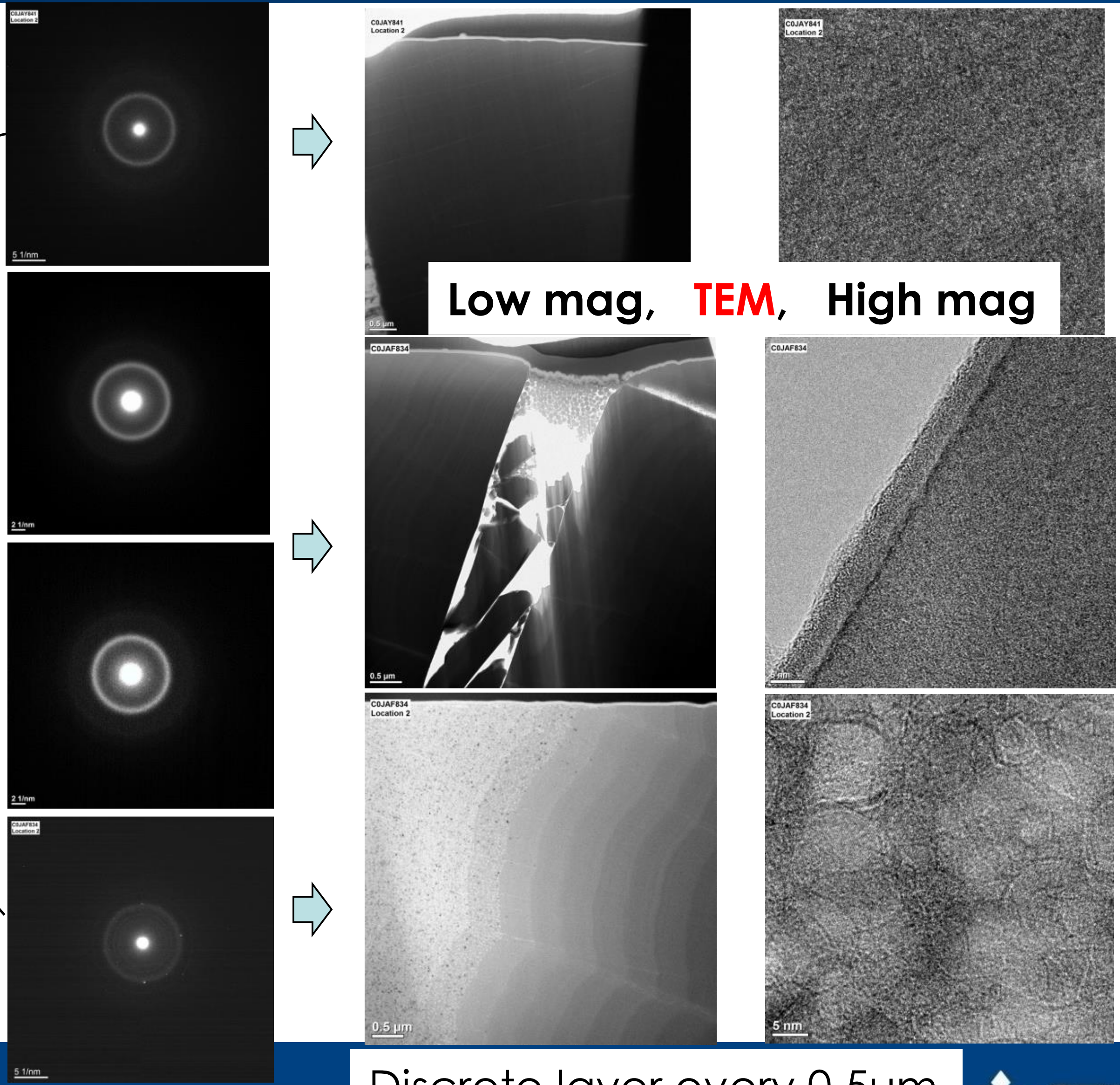
Post-pyro

Polishing induced cracking

Evolving microstructure in S-curve region, A mixture of amorphous or nanocrystals



Areas with stronger TEM diffraction ring has higher amorphous content



Higher Cr, mostly amorphous

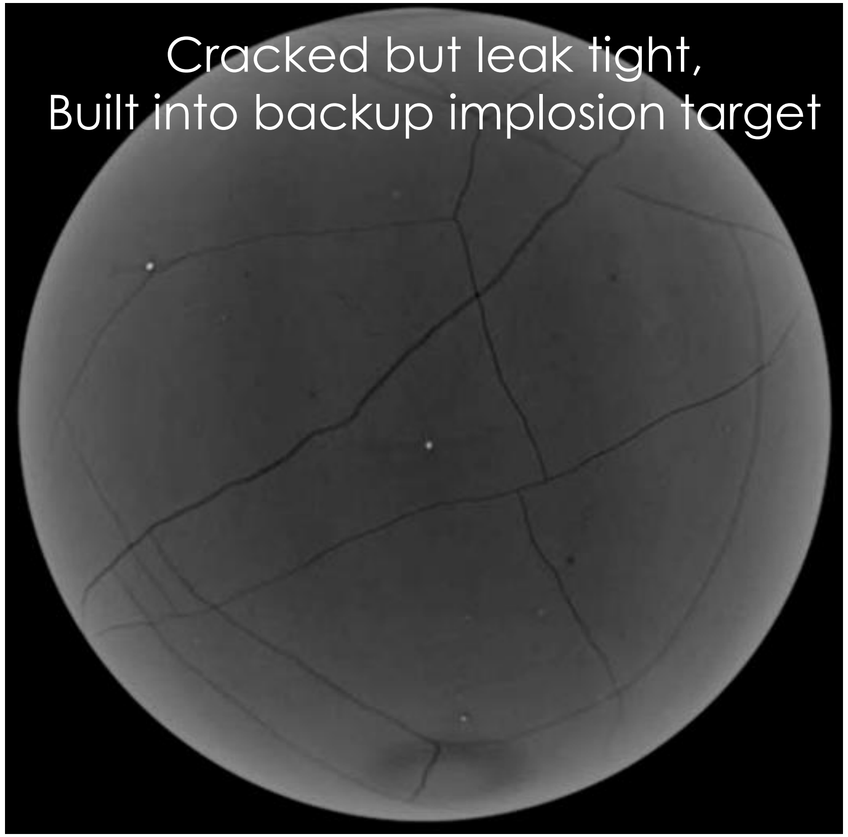
Near crack, mostly amorphous

Lower Cr, nanocrystal embedded in amorphous

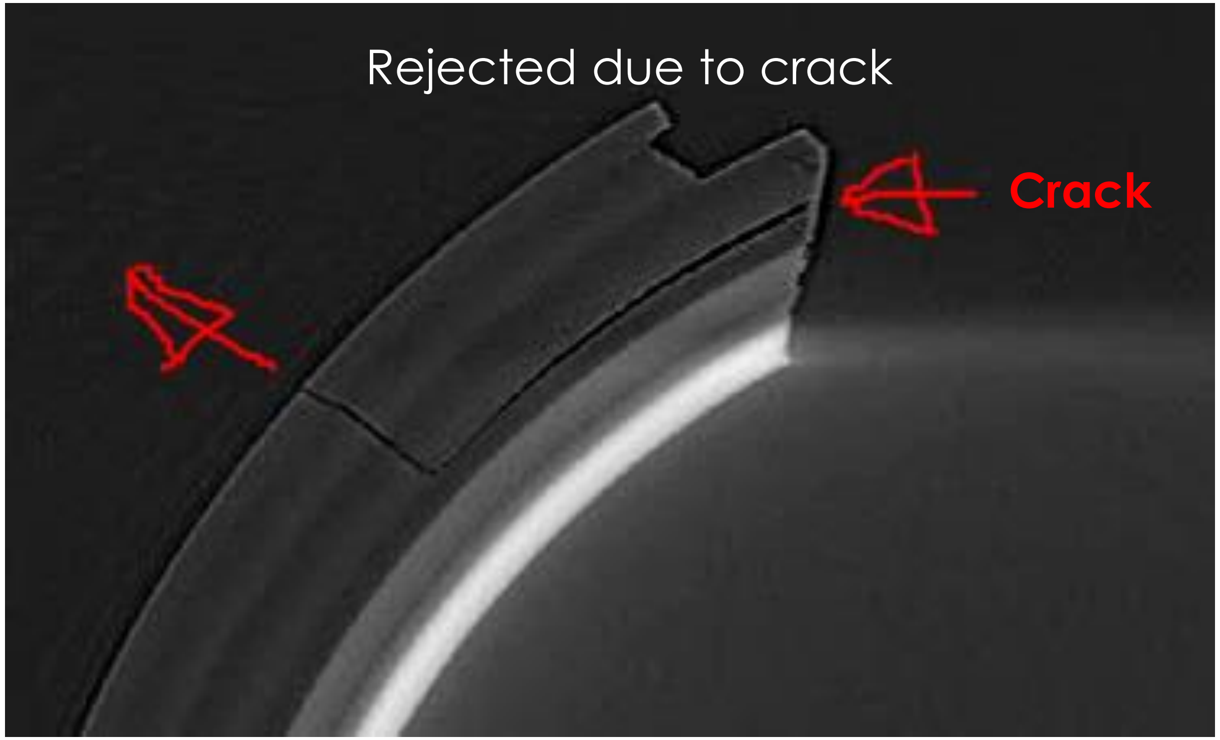
Discrete layer every 0.5um

Shell cracked during GDP mandrel removal and machining

Current: **Normal pyrolysis: In oxygen @ 380C**



Keyhole cutting



Future: **Ozone at lower T** **More glue support on shell**

Alternative: PAMS mandrel with room-temperature solvent removal

CTE mismatch in metal gradient causes very large shear stress during pyrolysis that cracked the shell

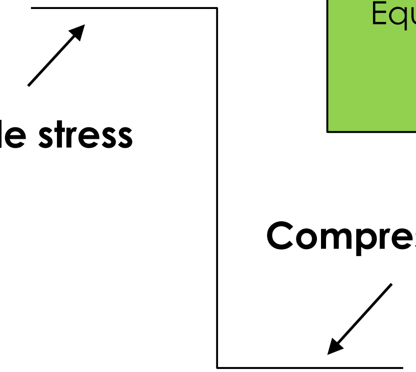
Thermal stress can be modelled

Reducing pyro temp reduces thermal stress

$$\varepsilon_m = (\alpha_s - \alpha_f)\Delta T$$

Equi-biaxial stress in the film

$$\sigma_m = \varepsilon_m M_f$$

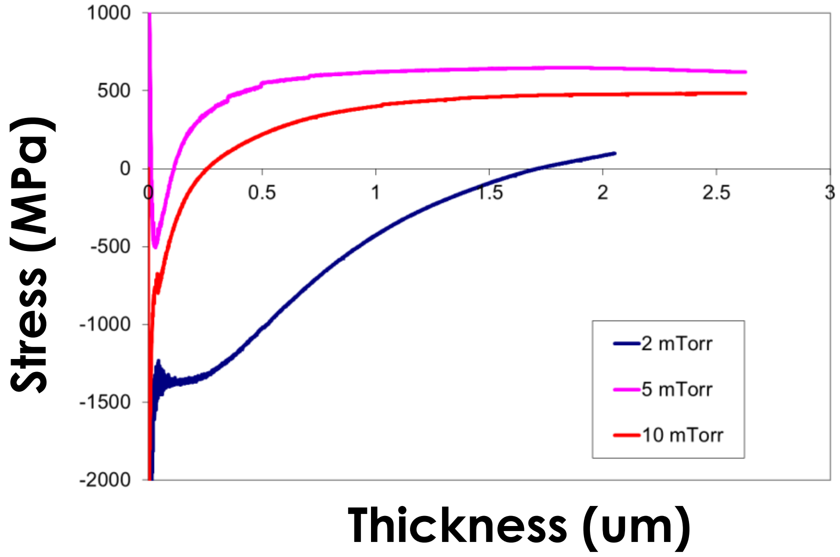


At pyrolysis temperature, thermal stress:

$\Delta T = 380C$ $\sigma_m = 333Mpa$

Deposition stress also contributes

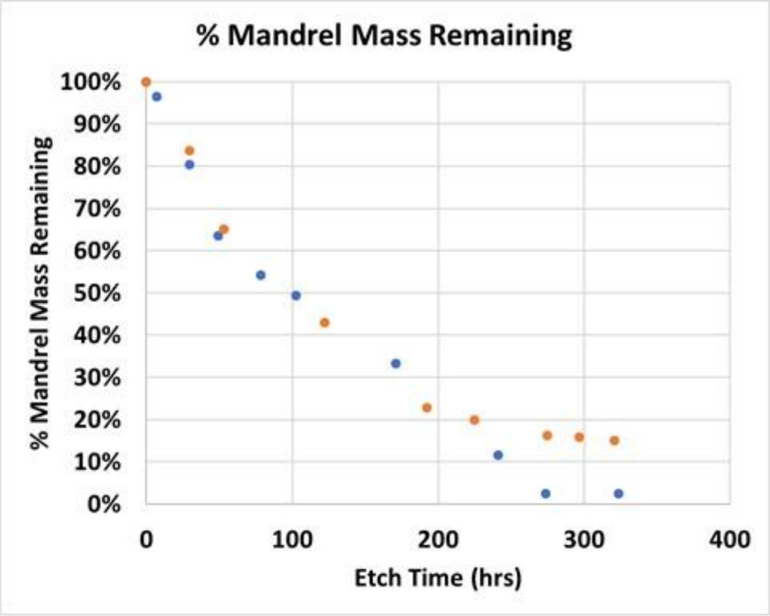
Typically stress curve on flat Be coating: Tensile stress saturates at ~300-500Mpa.

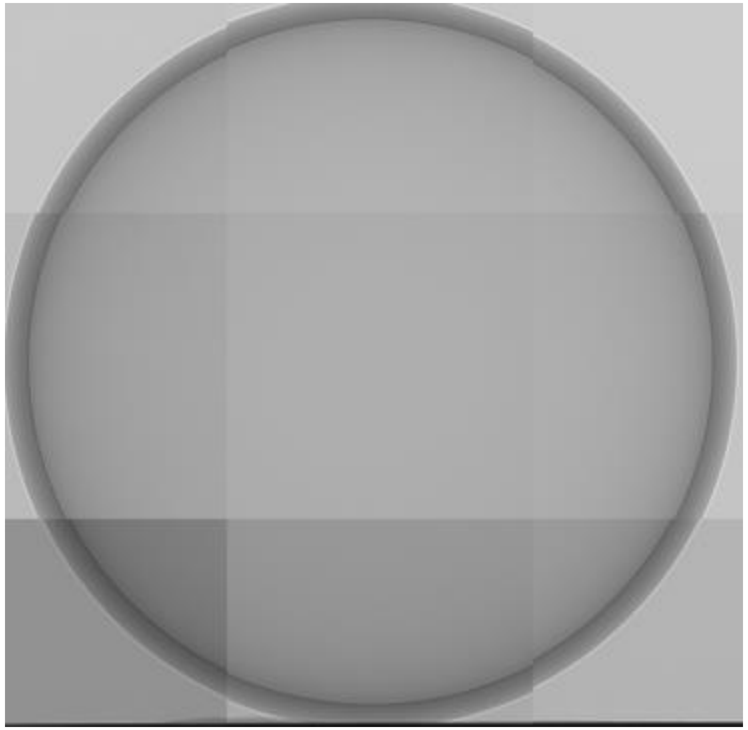


Cracking happened in S-curve region where both deposition and thermal stress are high whereas mostly amorphous structure is weak

Be-Cr PSS Keyhole without cracking demonstrated, Using ozone pyrolysis at 80C lower temperature than in oxygen

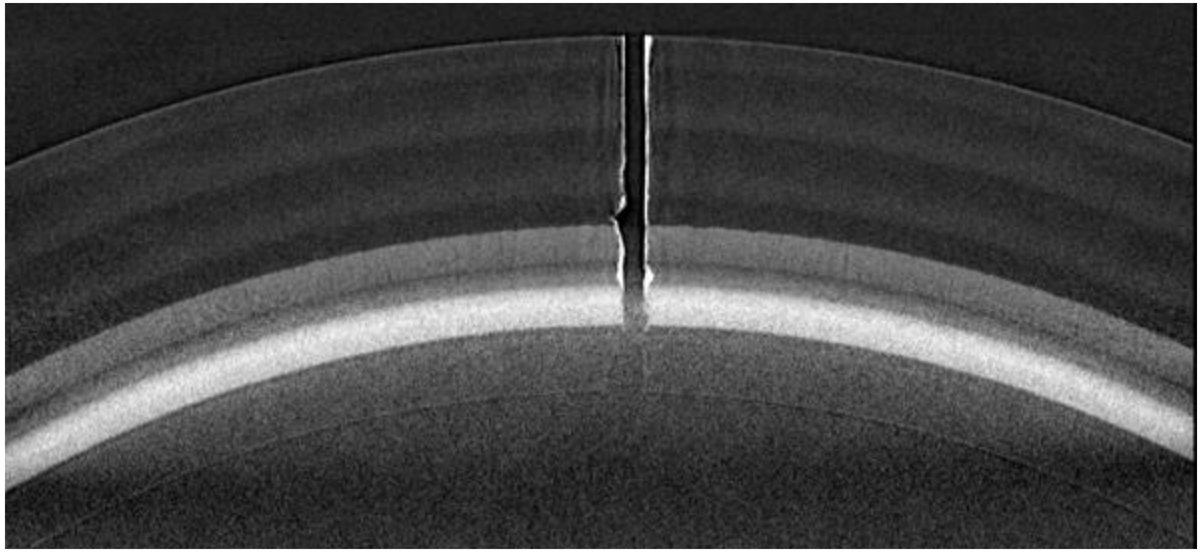
Potentially extendable to small hole capsules

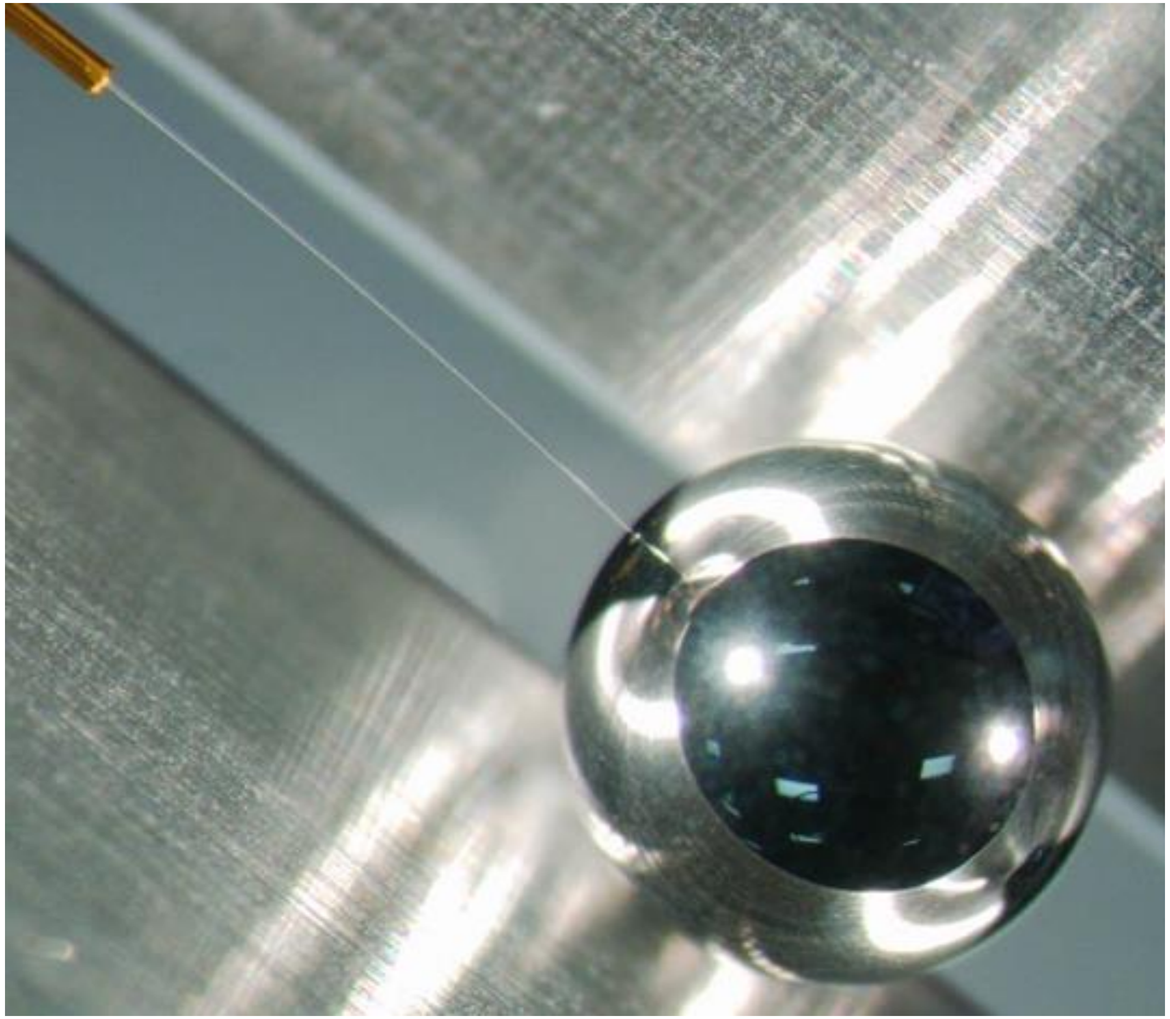




Demonstrated: <20% mandrel mass remain

Gas-tight capsule demonstrated in two stages of leak tests





- **Kr permeation testing after first 8um**
  - If leaky, no need for further coating
- **CFTA leak test after coating**
  - At room and cryo temperatures

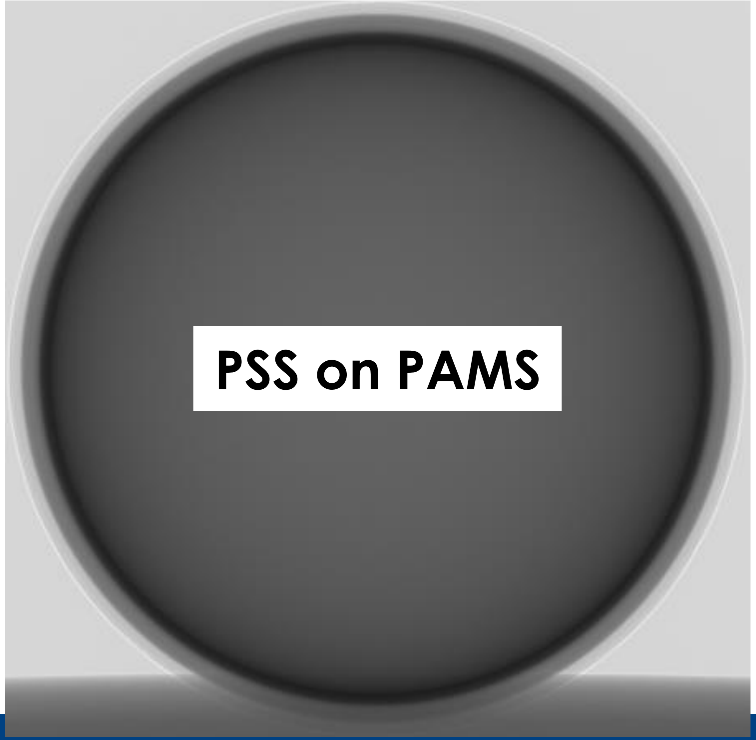
Shots and Future Development

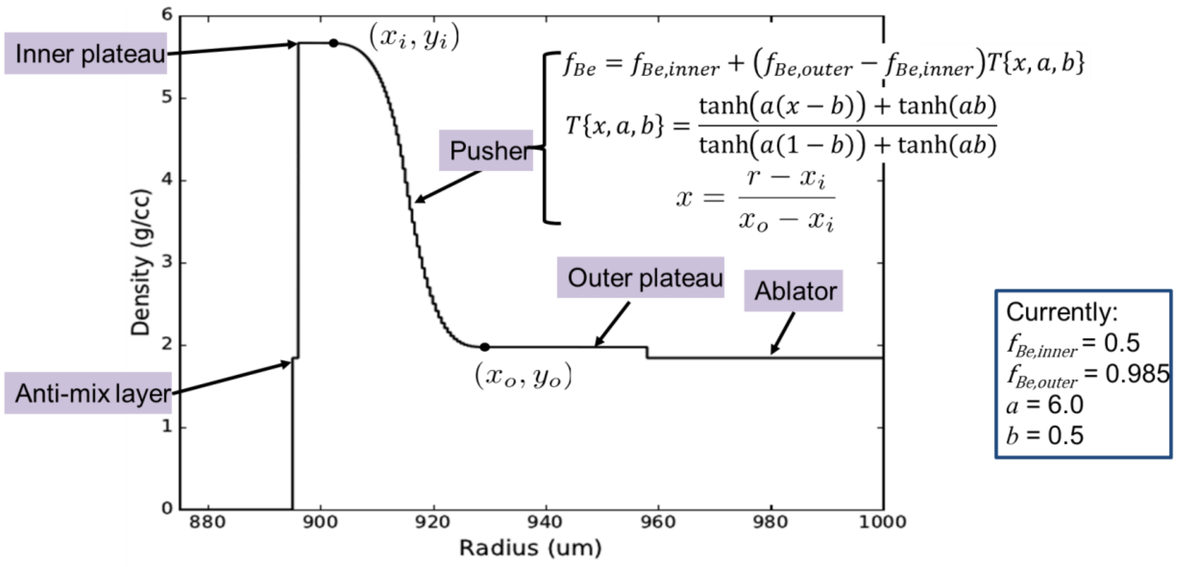
Shot Scheduled

- 1DConA with mandrel (March)
- 1DConA without mandrel (July/Sept)
- Keyhole (July)
- Symcap (Sept)

Development

- Coating on PAMS mandrels, with solvent removal
- Parameterizing gradient profiles, instead of discrete layers
- Mo-Be and W-Be capsules





Paramerterized gradient function