Capsule Laser Drilling Progress and Improvements

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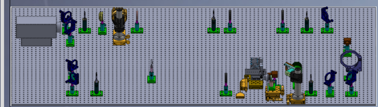
GENERAL ATOMICS

PROCESS & EQUIPMENT UPGRADES

The capsule drilling station uses a single or pair of 532-nm nanosecond lasers with precise laser focusing and capsule positioning capabilities. A LabView GUI, mechanized controls, and an improved optical and beam profiling camera have been incorporated. Future phases include autonomous control and data capture for machine learning

HDC (and beryllium) capsule drilling station



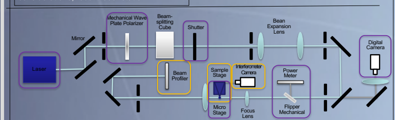
Completed early 2022 Phase 1
Manual and analog processes → digital software platform

Phase 1 – Digital Controls (LabView)
I. Laser Controls & Shutter
II. Mechanical Waveplate & Power Meter
III. Digital Camera

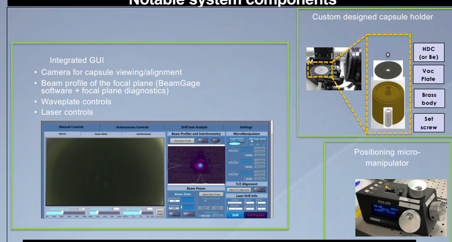
2024 Phase 2
Focus on adding all upgrades to the table. Machine learning projects

Phase 2 – Autonomous Controls
I. Interferometer for focus
II. Beam Profiler
III. Sample Stage

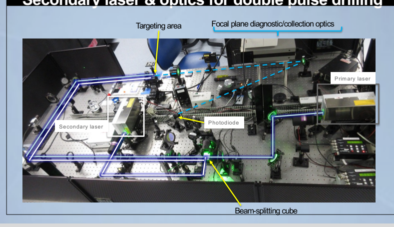
Setback: 10/30/2022 laboratory fire
Smoke, water damage → moved labs, safety considerations, rebuilt laser station



Notable system components



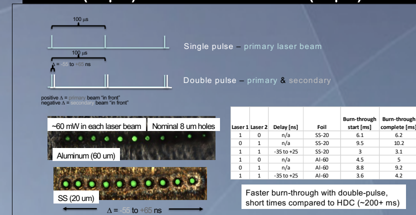
Secondary laser & optics for double pulse drilling



DOUBLE PULSE DRILLING & MATERIAL BURN-THROUGH EXPERIMENTS

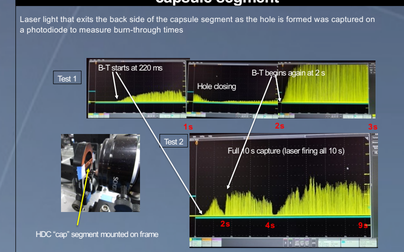
A pair of co-aligned lasers ("double pulse") were used to drill holes with reduced laser energy and dwell times. This can lead to reduced heat-affected zones and improved hole quality. Experiments to optimize the pulse spacing and measure the burn-through times in both surrogate materials (aluminum, stainless steel) and HDC capsules were performed

Burn-through/double-pulse timing test in Aluminum (60 µm) and stainless-steel foil (20 µm)

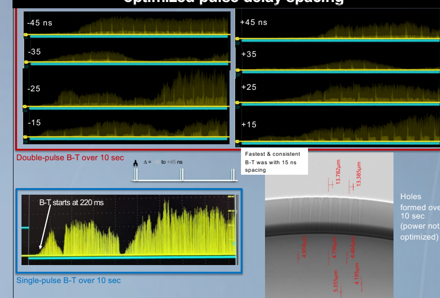


Burn-through/double-pulse timing test in HDC capsule segment

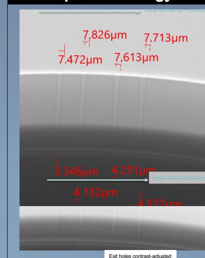
Laser light that exits the back side of the capsule segment as the hole is formed was captured on a photodiode to measure burn-through times



Burn-through times in HDC capsule segment reduced with optimized pulse delay spacing



HDC capsule drilled for 2 µm fill tubes with lower deposited energy with double pulse method



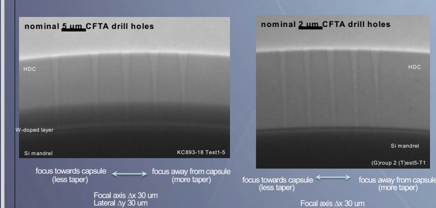
Overall reduction
Power ~10%
Dwell time 75%

Current 2 um hole spec in pre-leach manual Xradia measurement
7.5 ± 0.8 µm (entrance)
4.0 ± 0.8 µm (exit)

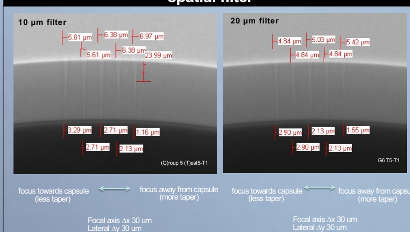
FILL TUBE HOLE SHAPING

We successfully drill HDC capsules for 2 µm fill tubes (700+ in 2023). The fill tube hole size and profile is affected by the laser focus, pulse energy, and laser beam filtering. The re-definition of the hole specification has increased the yield of successful mandrel leaching

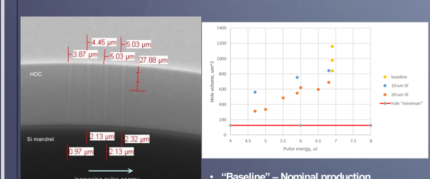
Fill tube hole shape can be tailored with laser focus



Taper in the hole entrance was reduced with a localized spatial filter

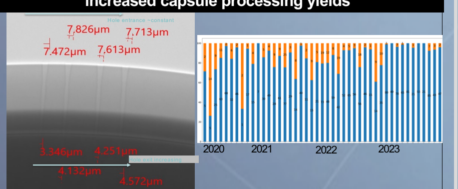


Overall hole size and volume can be changed by varying pulse energy



- "Baseline" – Nominal production capsules for 2 µm CFTAs
- "Hole minimum" – Ideal hole that tapers from 2 µm (entrance) to 1 µm (exit)

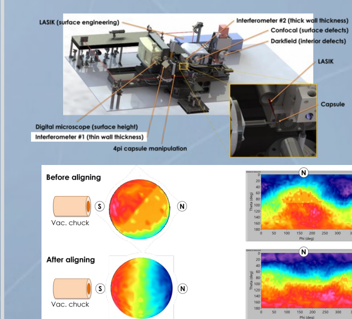
Adopting a formalized hole specification (Rev 1) has increased capsule processing yields



Current 2 µm hole spec for HDC capsules.
Hole Specification established 2023
7.5 ± 0.8 µm (entrance)
4.0 ± 0.8 µm (exit)

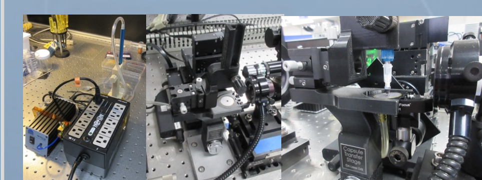
SITE-SPECIFIC (ALIGNED) HOLE DRILLING

HDC capsules can be aligned with the P1 nonuniformity axis (or other feature) placed in a specific location relative to the drill hole/fill tube



4Pi multi-instrument capsule analysis

Deterministic positioning of P1 axis



Mobile vacuum pump holds orientation

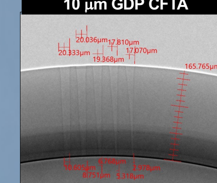
Vacuum wand holder mates with capsule holder

Capsule transferred to drilling holder with P1 axis maintained

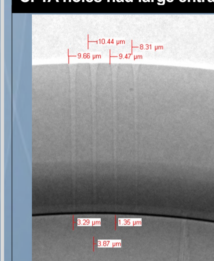
GDP CAPSULE DRILLING

Ignition experiments with GDP ablators are of increased interest in the upcoming years. Initial tests have been to recreate standard 10 µm CFTA drill holes. We have made progress towards demonstrating drill holes for 2 µm & 5 µm CFTAs

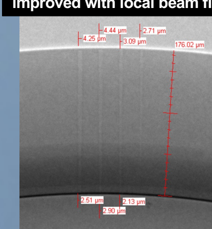
Variety of hole profiles for 10 µm GDP CFTA



Initial drill test towards 2 µm CFTA holes had large entrances



Hole entrance reduced & shape improved with local beam filtering



Demonstration of 2 µm drill holes in GDP capsules
2.7 to 4.3 µm (entrance)
1.0 to 2.5 µm (exit)

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