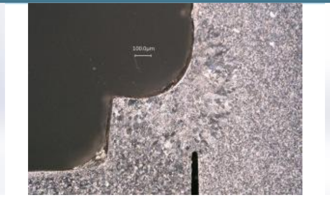
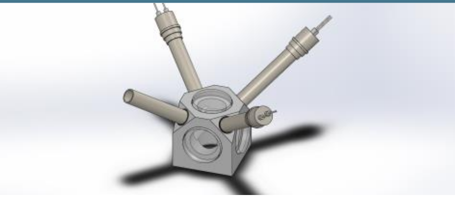
SAND2021-12250C

Sandia National Laboratories

Fabricating a passively pumped vacuum chamber for cold-atom experiments





***C Walker*, P Schwindt, J Lee, D De Smet, and L Johnson,** *Sandia National Laboratories, Albuquerque, NM 87185, USA company*

G Biederman, *Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma 73019, USA*

2021 International Brazing and Soldering Conference

October 3-6, 2021

Denver, Colorado

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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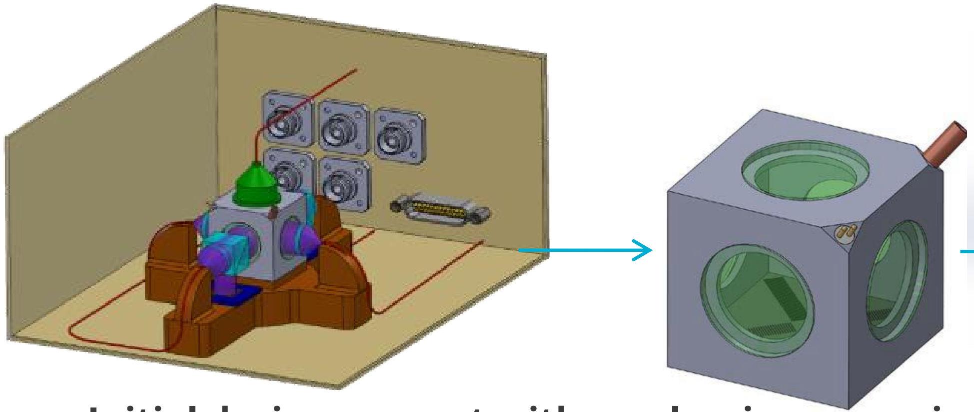
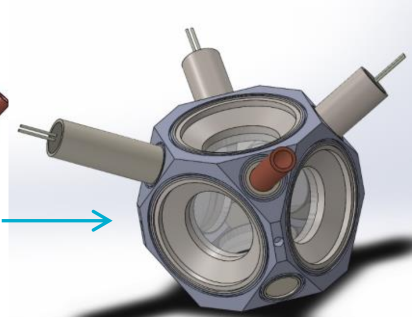
Vision/Motivation

"Build the world's first truly portable, compact atom interferometer inertial sensor."



Initial design concept with an alumina-ceramic vacuum package



Conceptual titanium package

Completed titanium vacuum package

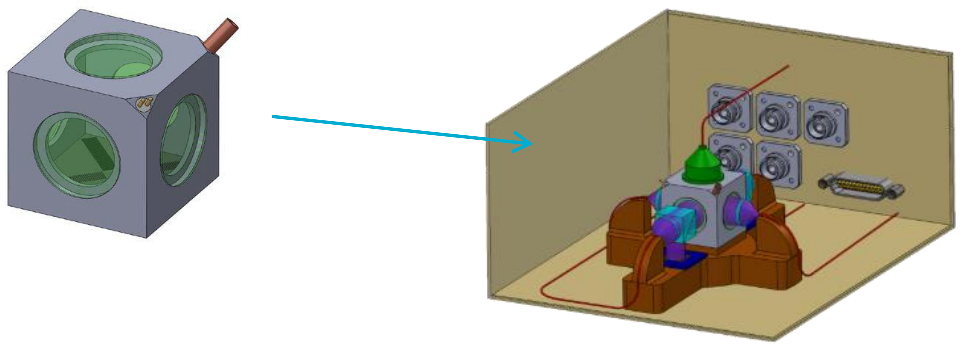
Because quantum sensors generally have at least 1-2 orders of magnitude better resolution than current state of the art techniques, they are uniquely suited to be used in such applications as:

Timing	Non Destructive Evaluation	Surface Science
Navigation	Trace Chemical Detection	Medical Imaging
Gravimetry		

This presentation, approximately 15 minutes in duration, will summarize a 3-year multi-person effort, describing how small vacuum chambers, capable of supporting a magneto optical trap (MOT), via laser-cooling*, were successfully fabricated.

*Temperature: ~5μK ($5x10^{-6}$ Kelvin)

Background:
High-vacuum Chamber Features



Required features

- Supply alkali metal (Rb) atoms
- Non or nearly nonmagnetic chamber and feedthroughs
- Small footprint, ~5 cm^3 volume to function as an atom interferometer (AI) accelerometer
- Must provide optical windows for laser access
- Must have negligible helium permeation
- ***Maintain high-vacuum for months**
  - **P_{Rb} ~10^{-7} Torr; $P_{background}$ ~10^{-8} Torr**

***Key Vacuum System Challenges**

Desired Features

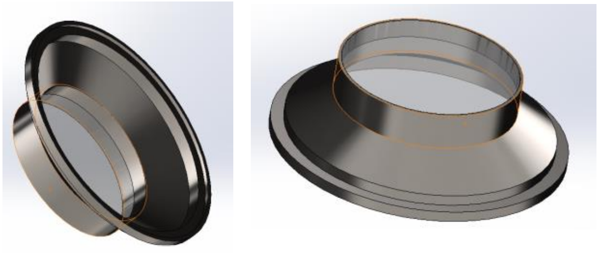
- ***Electrically activated contaminant-free alkali metal source.**
- 100% glass-free
- Windows with nearly zero helium permeability, AR coating, and no birefringence
- Include passive (getter) pumping
- Support up to 6 months “pumpless” vacuum package operation.
- MOT diffraction grating internal to vacuum package
- Copper pinch-off tube for sealing
- Bakeable to ~400˚C.
- Zero/low electrical conductivity (<<< eddy currents)

Materials & Components Selection

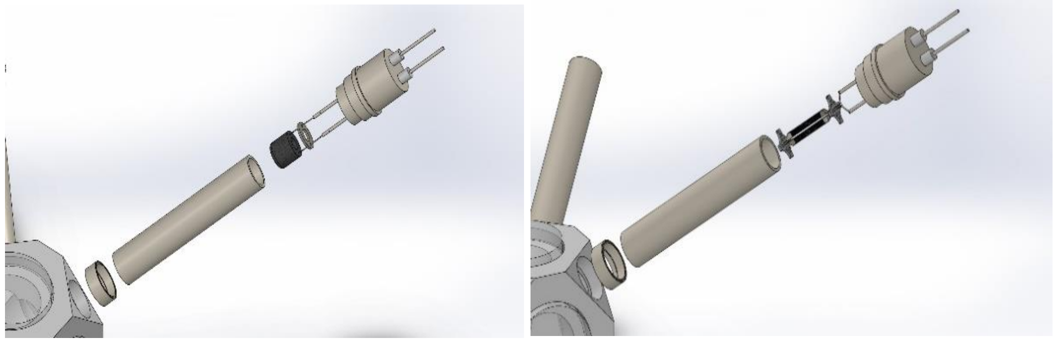
Component	Material	Heat sensitive	Atmosphere sensitive	Notes
Chamber	**Titanium***	No	No	Grade-2 (commercially pure). Can be welded without the formation of intermetallics
Chamber	Alumina Ceramic	No	No	94% - 98% Al_2O_3
Non-evaporable getters (NEG)	**NEG, St 172***	**Yes**	**Yes**	Sensitive above 250°C in O_2 containing environments
Alkali Metal Dispenser (AMD)	**AMD, Rb***	**Yes**	**Yes**	Sensitive above 250°C in O_2 containing environments
Window	**Sapphire w/Ti frame***	No	No	Brazed into frames. Able to withstand 450°C+ temperatures
Window	Sapphire w/o frame	Yes	No	CTE mismatch with Ti body could be problematic
Window	Fused Silica w/Ti frame	No	No	Brazed into frames. Able to withstand 450°C+ temperatures
Window	Fused Silica w/o frame	Yes	No	CTE mismatch with Ti body could be problematic
Grating MOT	**Si wafer***	**Yes**	No	Need to keep below 250°C
Electrical feedthroughs	**Ti bodies, Mo* conductors**	No	No	Grade-2 Ti, brazed to Al_2O_3 insulators and Mo pins
Electrical feedthroughs	Stainless-steel bodies	No	No	Used initially until Ti bodies became available. Pins are Mo.
NEG & AMD bodies	**Ti tubing***	No	No	Grade-2 Ti
Exhaust tubing	**Ti and/or Ti/Cu***	No	No	Brazed to adapters as needed.

*Candidate materials selected for first iteration of vacuum chamber assemblies

Chamber Components Construction

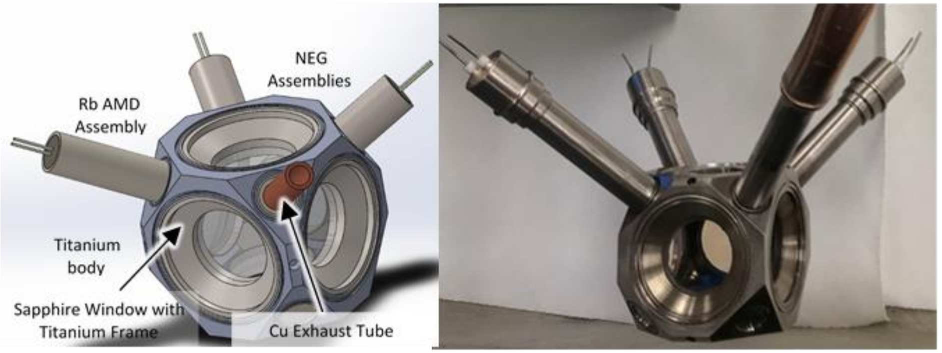


Sapphire window/CP titanium flanges



Non-evaporable getter assembly (L), Alkali metal dispenser assembly (R)

Window Assemblies
Getter Assemblies
Alkali Metal Dispensers
Exhaust Manifolds

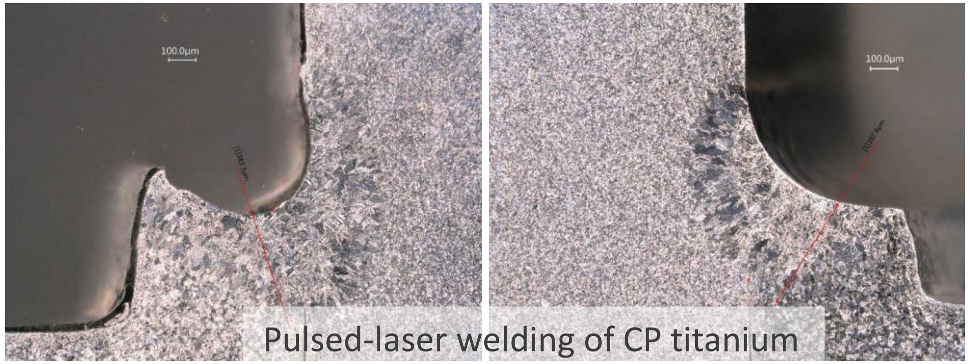


Sapphire window/CP titanium flanges

Joining Processes

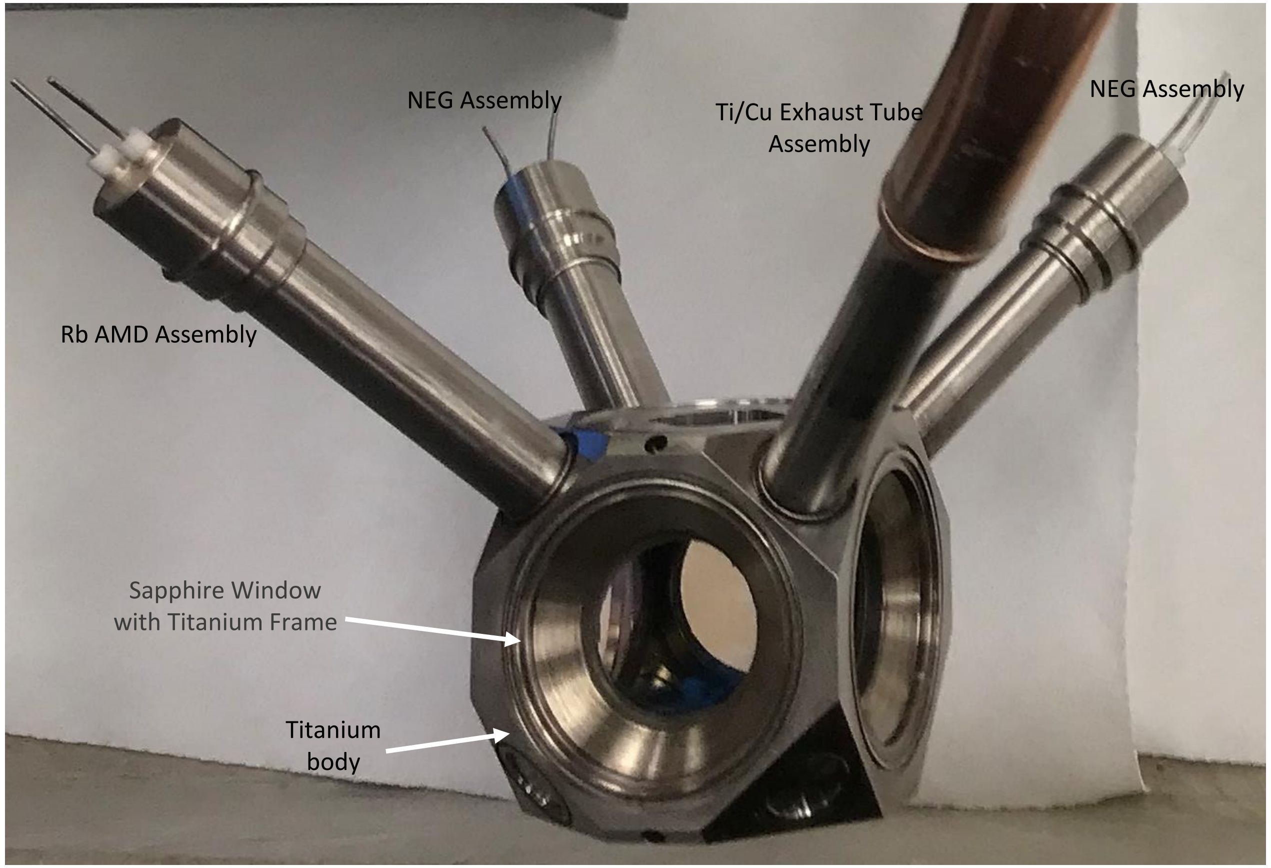
Welding Processes
- Pulsed-laser
- Resistance
- Orbital
- TIG

Brazing Processes
- Vacuum Furnace
- Hydrogen/Oxygen Torch
- Hand-held Induction



Pulsed-laser welding of CP titanium

Titanium Vacuum Chamber Fabrication



Completed Titanium Vacuum Package

Solid-model of Titanium chamber/UHV manifold assembly

Sapphire-Alumina Ceramic Braze Development

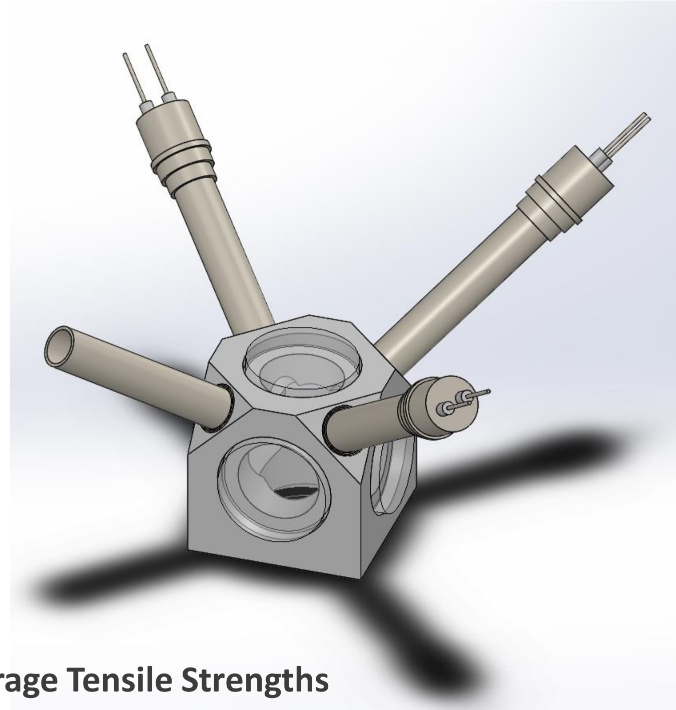
Alumina-ceramic chamber design restrictions:

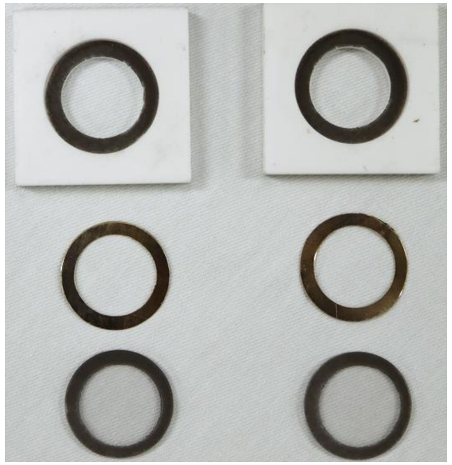
- Ten simultaneous active filler metal brazements (6 ea. sapphire window, 4 titanium weld sleeves) was determined to be too risky, as any leaks detected would be difficult to repair.
- The requirement that any metallization system used be nonmagnetic eliminated those utilizing nickel plating.

Solution:

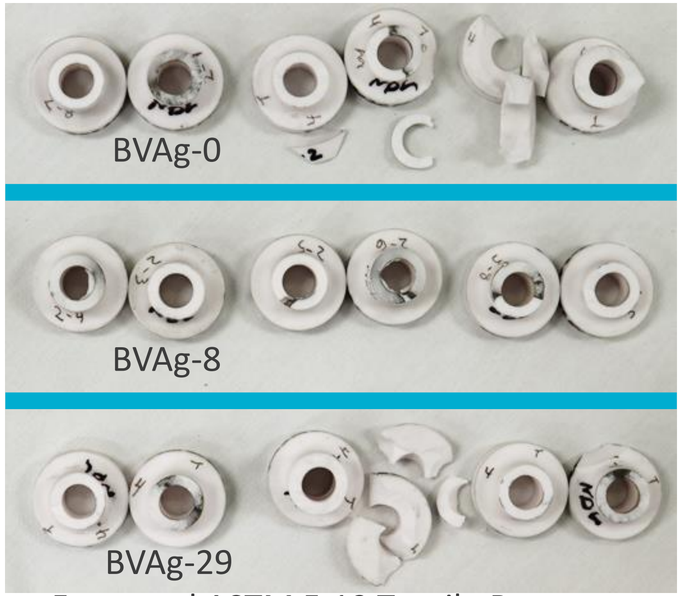
A COTS titanium-hydride/organic carrier metallization system (Tiger Ink) was selected for use after robust testing using with conventional silver-based brazing filler metals (BVAg-0, BVAg-8, and BVAg-29).

All of the ceramic tensile button samples and sapphire window-ceramic window frame samples fabricated using the Tiger-Ink metallization were hermetic (Helium leak rate <5E-12 atm/cc-sec).





Metallized ceramic and sapphire windows with BFM preforms

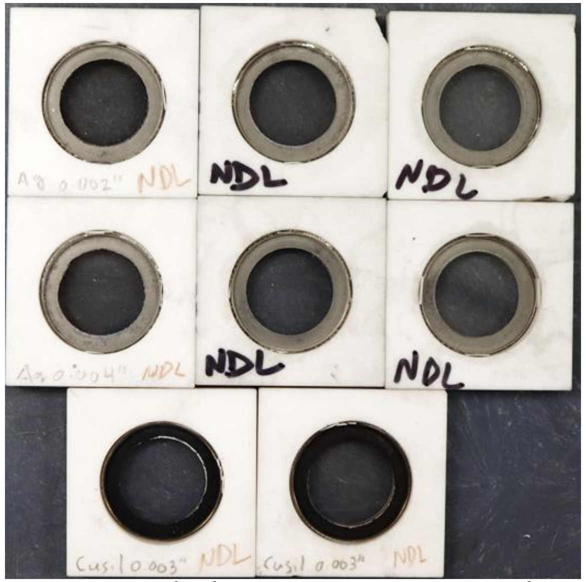


Fractured ASTM F-19 Tensile Buttons.

Average Tensile Strengths

96% Alumina Ceramic ASTM F-19 Tensile Buttons w/TiH_2 metallization. No metal interlayers.	
Braze Filler Metal AWS Classification	Stress at failure KSI / MPa
BVAg-0	21.4 / 147.5
BVAg-8	23.7 / 163.4
BVAg-29	22.8 / 157.2

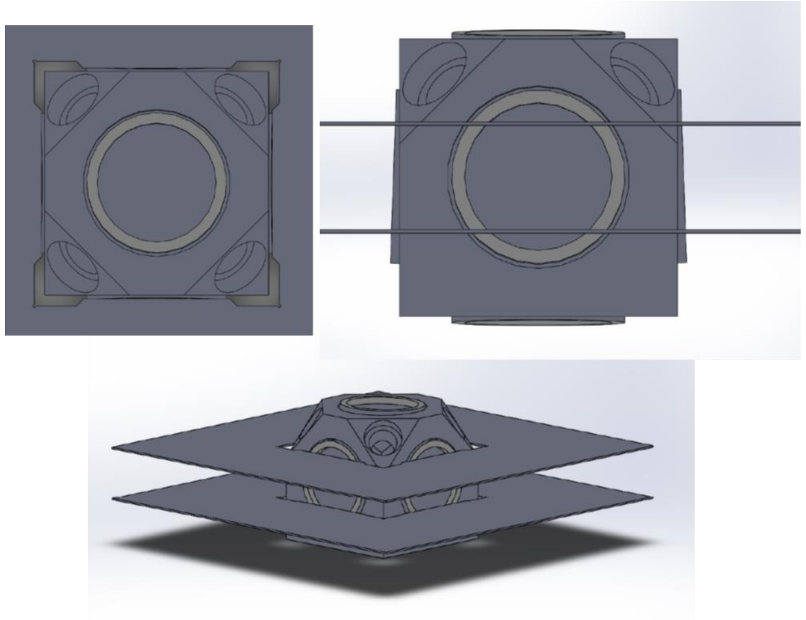
Tensile testing (ASTM F-19)
Instron 5969, Rate: 3 x 10^{-4} inch/sec



Brazed Alumina ceramic-sapphire window samples.

Tiger Ink is a product of Lucas Milhaupt, Inc.

Alumina-Ceramic Vacuum Chamber Assembly



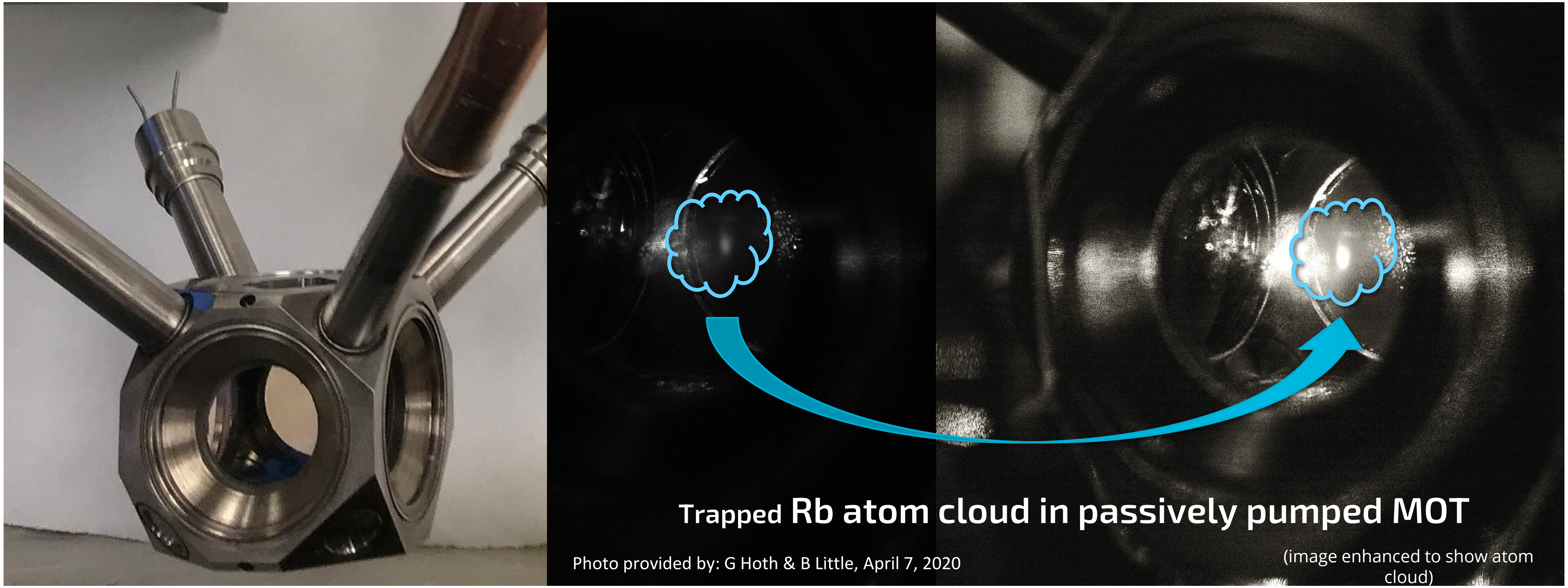
Solid Model of Ceramic Chamber with Laser-Machined Alumina Ceramic Fixturing

Alumina Ceramic Chamber with Laser-Machined Alumina Ceramic Fixturing Prior to Brazing

Brazed Ceramic Chamber

Conclusion

- Multiple small titanium vacuum chambers, capable of supporting a magneto optical trap (MOT), via laser-cooling were successfully fabricated and tested.
- Alumina ceramic chambers were partially constructed, but not competed.
- Chambers removed from external vacuum sources have been supporting a MOT for over 450 days.



Thank you for your time & attention!

Technical assistance and expertise from the following people helped make this program a tremendous success:

Justin Christensen, Peter Duran, Jack Herrmann, , Greg Hoth, Toby Johnson, Peter Kinney, Jongmin Lee, Bethany Little, Christina Profazi, Mark Reece, Jeff Rodelas, Peter Schwindt, James Scott, Dan Tung, Matt Vieira