LOW RF LOSS DC CONDUCTIVE CERAMIC FOR HIGH POWER INPUT COUPLER WINDOWS FOR SRF CAVITIES

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On behalf of Euclid Techlabs/JLab/FNAL/PSU collaboration

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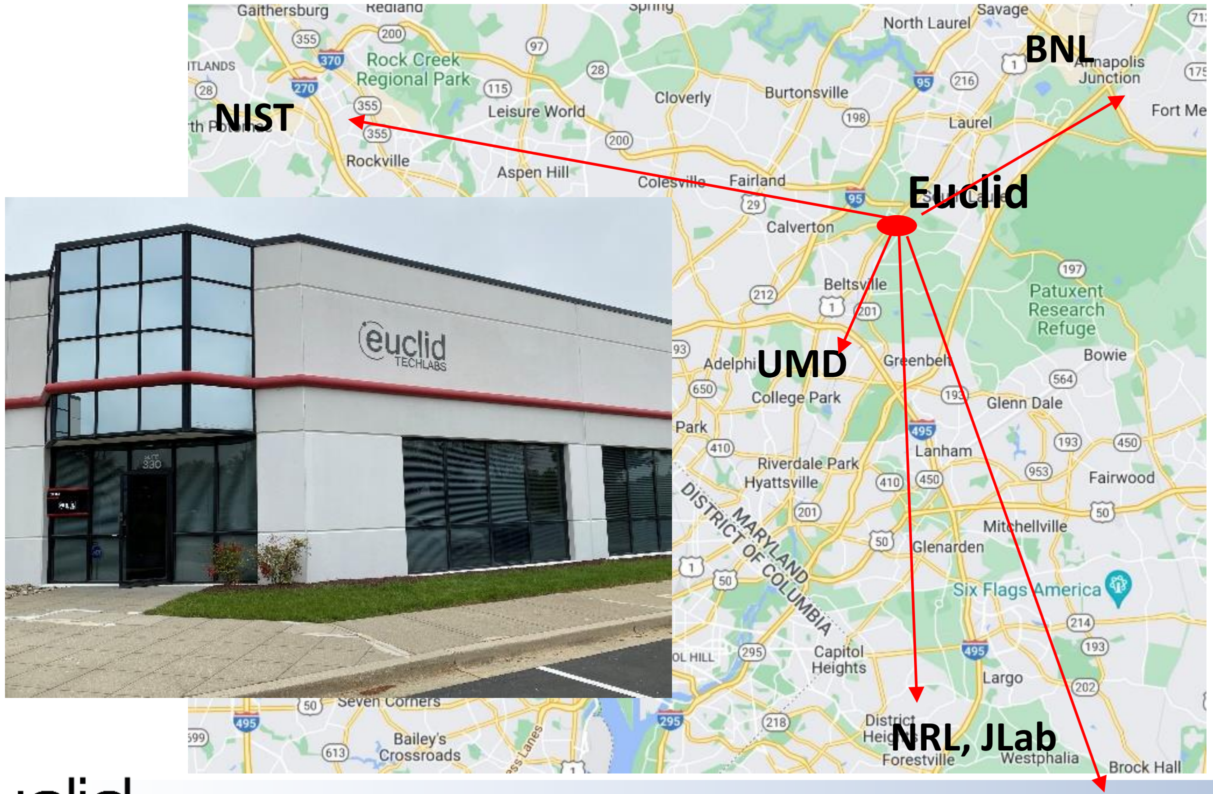
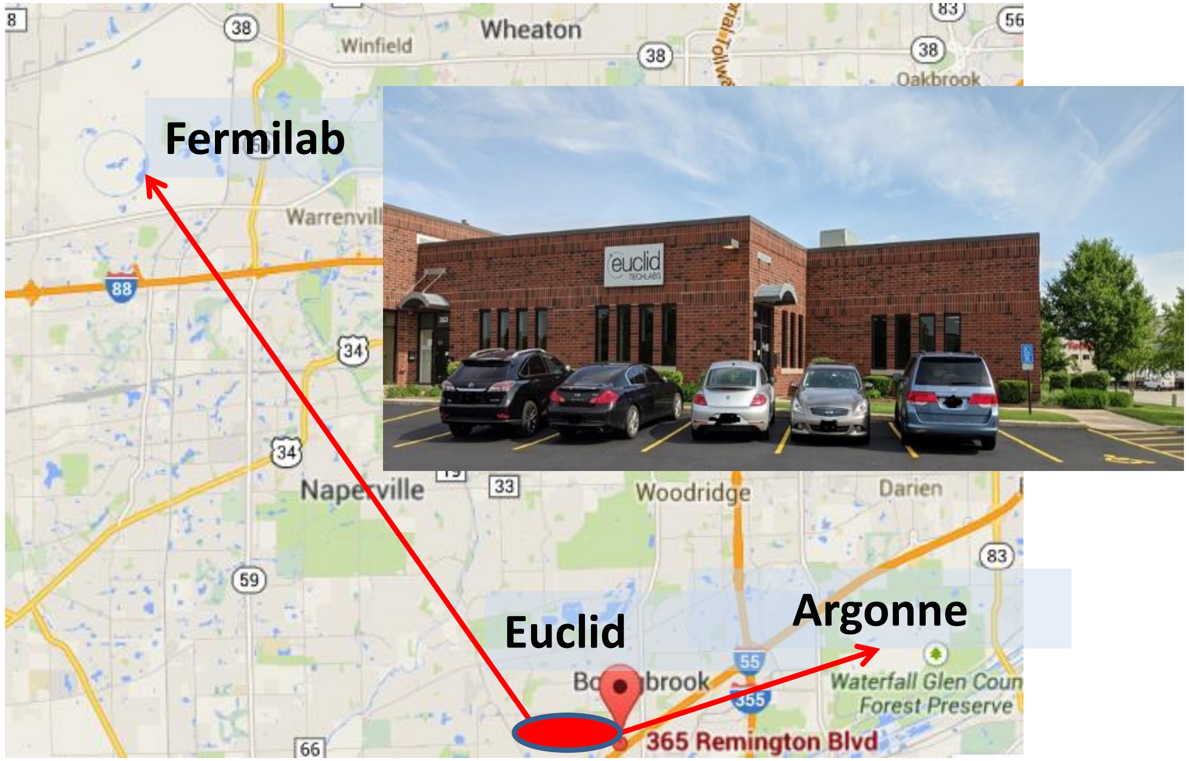
Outline

1. Euclid Techlabs background and capabilities
2. Motivation for low loss conductive ceramic windows
3. Review of work completed in Phase I & II
4. Results over the past year (Year 2 of Phase IIA)
5. Summary

Euclid Techlabs

Euclid Techlabs, LLC is a research and development company specializing in linear particle accelerators, ultrafast electron microscopy, and advanced material technologies. Euclid has developed expertise and products in several innovative technologies: time-resolved ultra-fast electron microscopy; ultra-compact linear accelerators; electron guns with thermionic, field emission or photo-emission cathodes; fast tuners for SRF cavities; advanced dielectric materials; HPHT and CVD diamond growth and applications; thin-film for accelerator technologies; Present: 27 research staff (researchers, engineers, technicians) and 5 administrative. 16 PhDs in accelerator physics and material science. 2 labs: Bolingbrook, IL (accelerator R&D lab) and Beltsville, MD (material science lab). Long term collaborations with National Labs and Institutes: ANL, Fermilab, BNL, JLab, LBL, SLAC, LANL, NIST, NIU, IIT, etc.





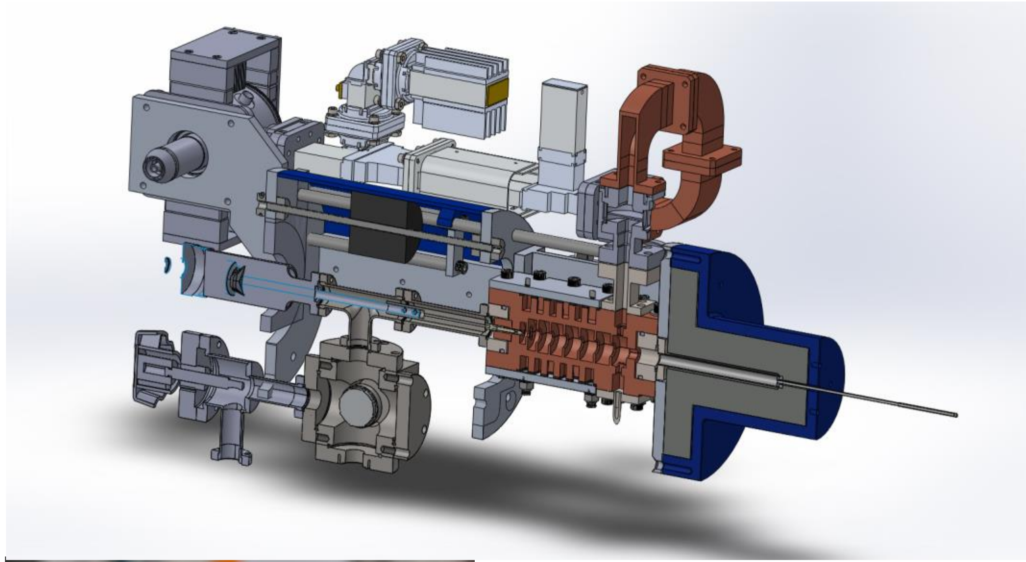
Products & Capabilities Snapshot

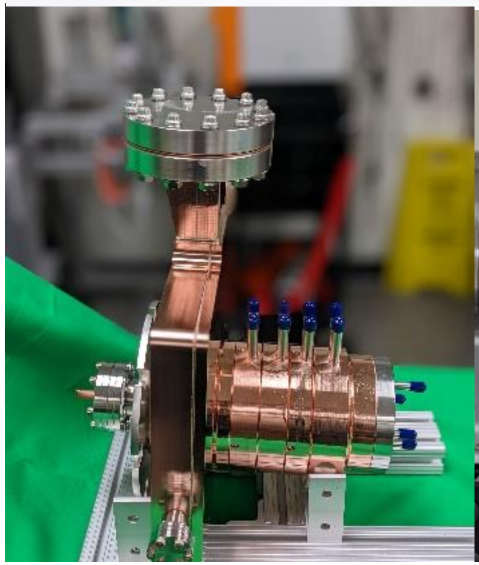
Products

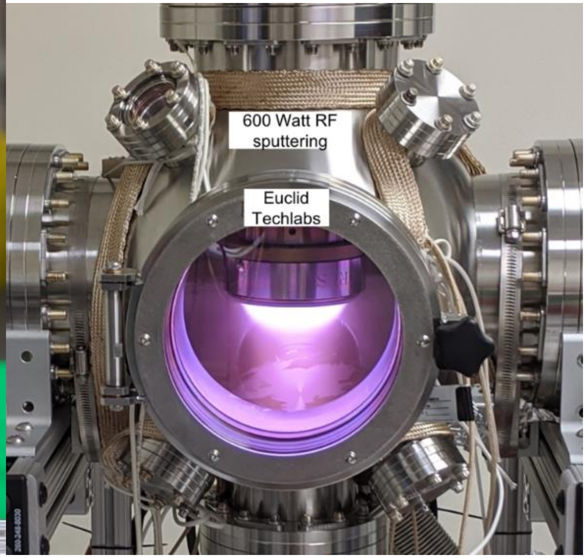
- UltraFast Pulser (UFP™) for TEM
- Compact X-Ray Source
- Low loss ceramics (linear and non-linear)
- Ultra-Nano Crystalline Diamond FE cathode
- L-band High Peak Current LINAC
- UHV L-band RF window
- BPM compact readout

Capabilities

- Femtosecond Laser Ablation System
- Thin Film Deposition Lab
- EM Testing Lab
- Radiation Shielding/Testing Lab
- Experimental electron beamlines

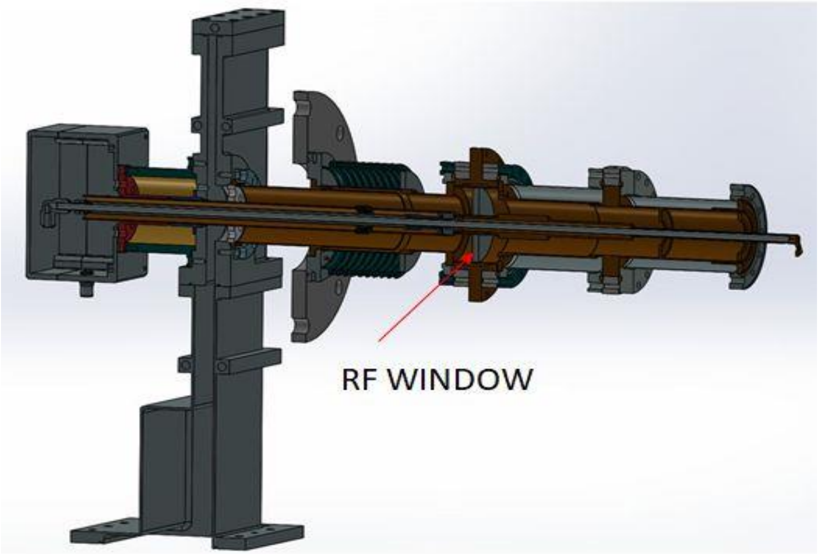


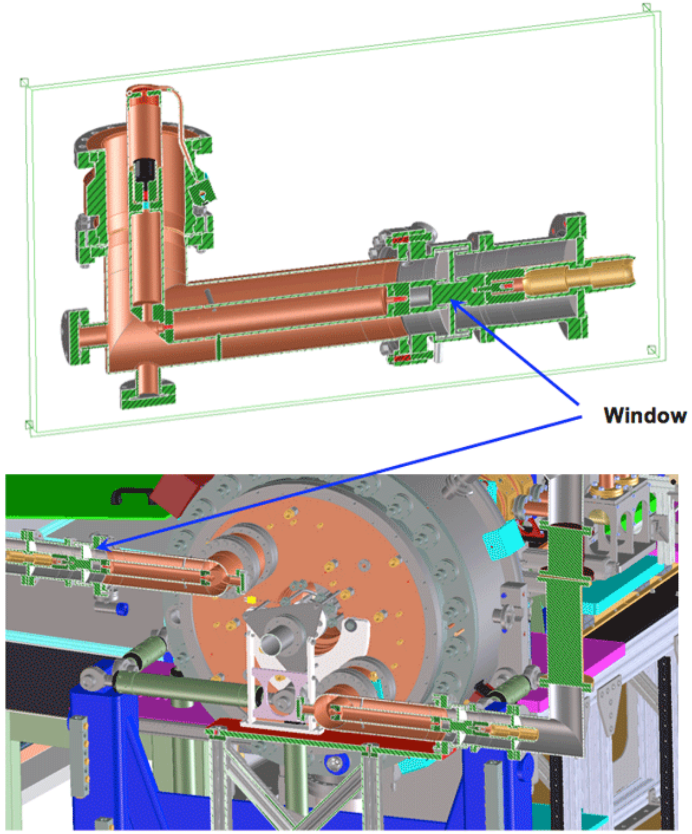




Motivation

- High power RF couplers connect RF transmission lines to SRF cavities, providing RF power and vacuum barrier for the beam vacuum using ceramic windows.
- Coupler RF windows experience breakdown (arcing and surface flashover) at much lower voltages than comparable insulators in DC fields. Major reasons for window failure include charging from the "triple junction“, multipacting and electron halo.

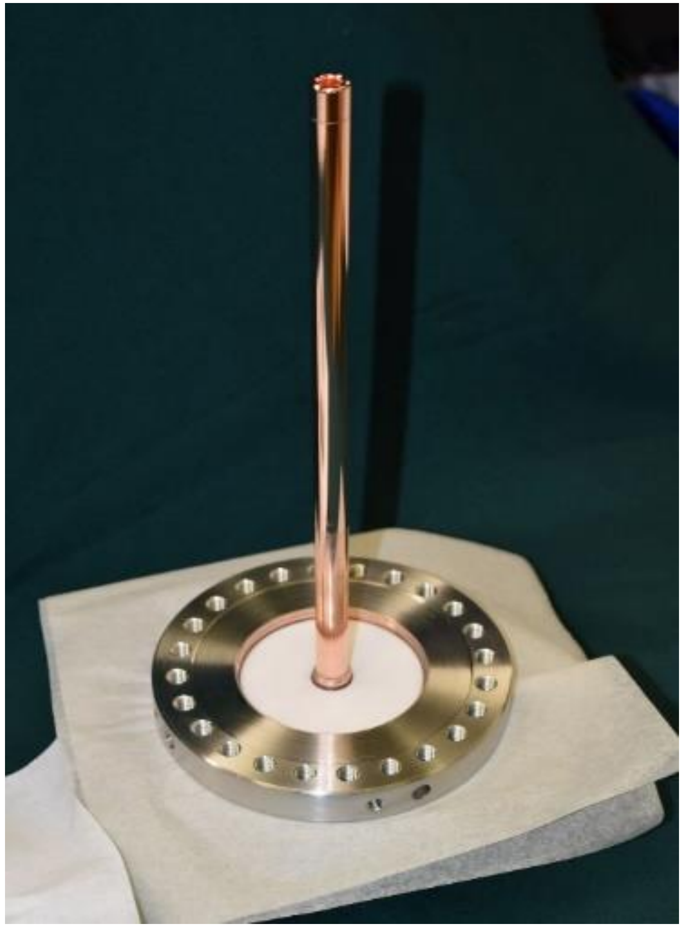




Example: the Advanced Photoinjector Experiment’s VHF gun in the LCLS-II injector. Window broke: charging because of the direct line of sight for the beam. A new 90-degree coupler will keep ceramic vacuum window out of harm’s way

A Solution

- *Mitigate charge accumulation on RF windows by using a conductive ceramic that avoids the need for complicated geometry*
- The main innovation of the proposed approach is the following: a new low-loss microwave ceramic material with increased DC electrical conductivity and low loss tangent for use in high power coupler windows. *The electrical conductivity will drain the accumulated charge. The low loss tangent will allow for high efficiency RF power transmission.*

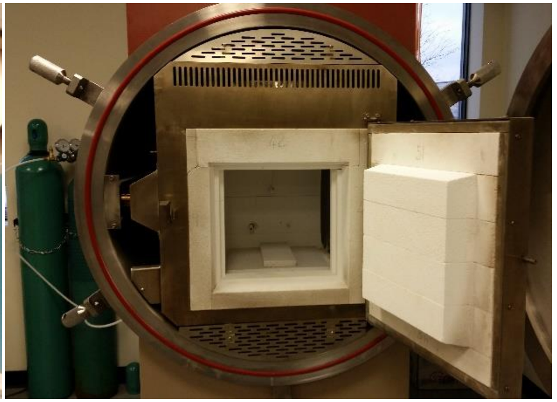


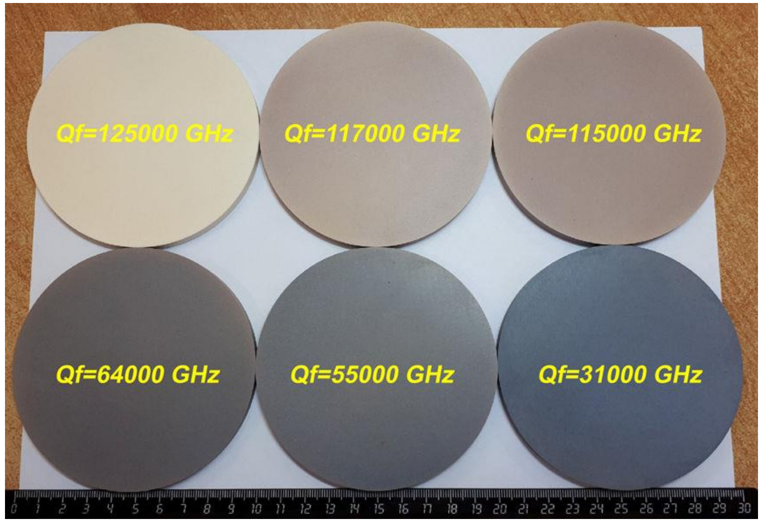
In Phase II of the project:

- Fabricated ceramic samples with controlled resistivity in the range 10^8 - 10^9 Ω·m (3-4 orders of magnitude less than traditional ceramics)
- Conducted a beam test of the discharging properties of the ceramic components using Euclid’s TEM DC gun
- Collaborated with JLab and Fermilab on the design and fabrication method for their high-power windows
- Fabricated MgTi ceramic components for 650 MHz & 1.5 GHz high power RF windows; Tested the electrical properties

Fabrication and Sintering of MgTi Conductive Ceramic

- Euclid fabricated the MgTi ceramic elements with
  - Increased conductivity from 10^{-12} to 10^{-8} S/m
  - Relative dielectric constants $\varepsilon_r=15$
  - Figures of merit, Q×f, in the range 30,000–60,000 GHz, providing tan $\delta \sim 10^{-5}$ @ 650 MHz
- Electrical and microwave properties of ceramic window components optimized using procedure developed in Phase I





5.2x10^-6	5.5x10^-6	5.6x10^-6
1.0x10^-5	1.9x10^-5	2.1x10^-5

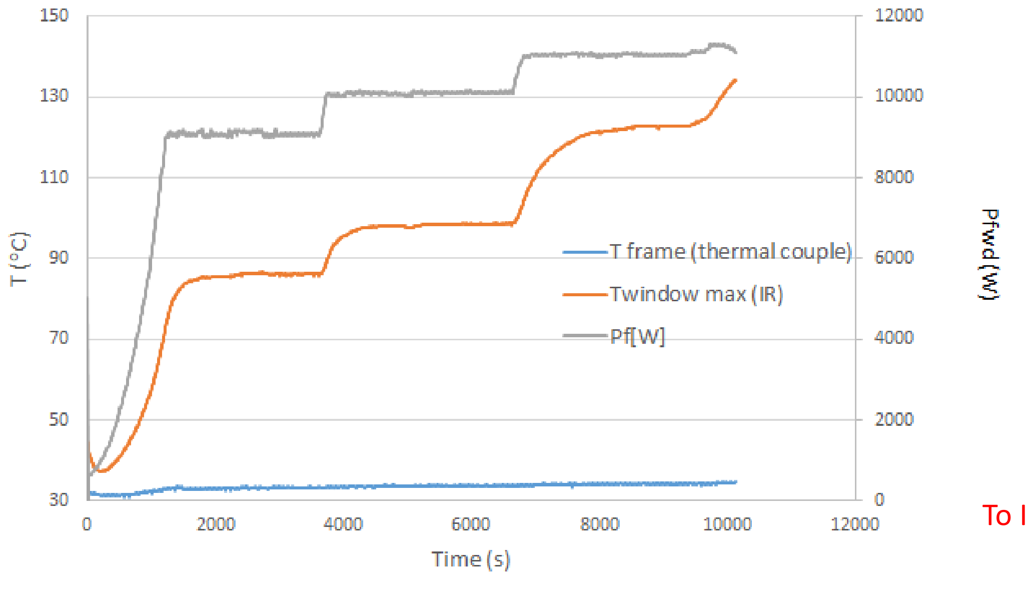
tan δ at 650 MHz

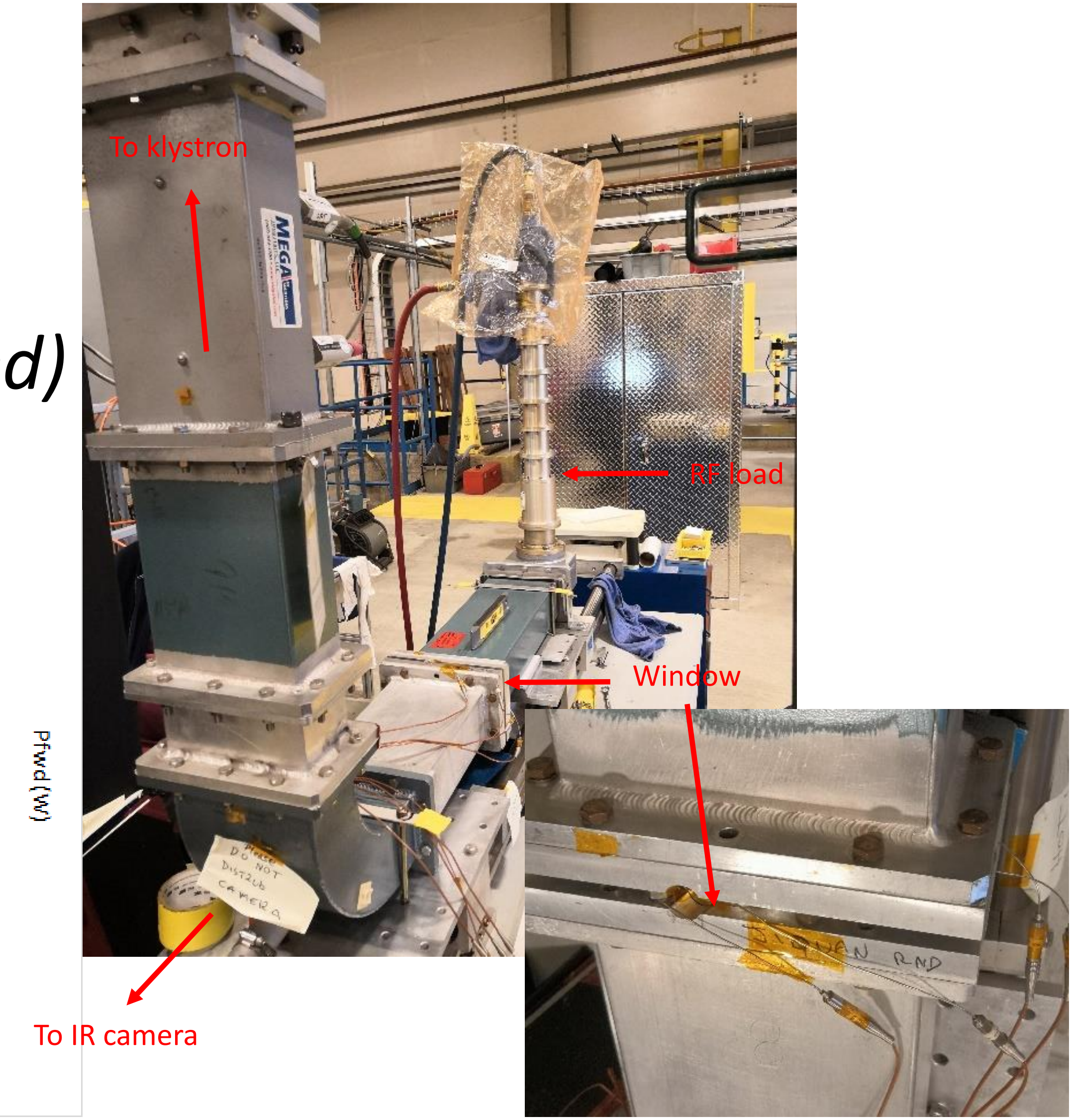
Key Accomplishments

- *Over the past year, we have:*
  - <u>Completed first successful high power test in air</u>
  - Fabricated/are producing several window assemblies
  - Investigated brazing & soldering procedures
  - Developed in-house brazing

High Power Test at JLab

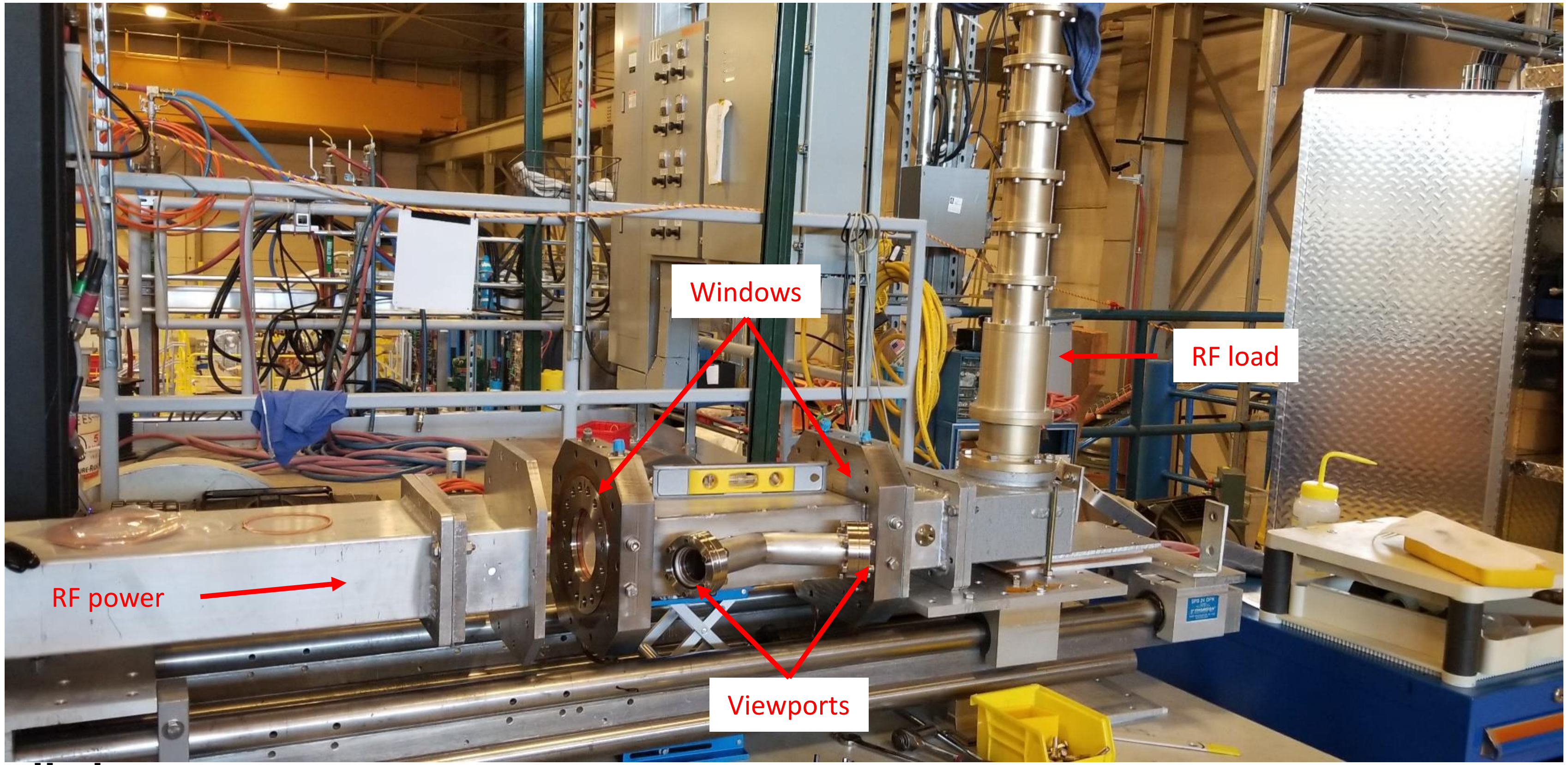
- Soldered window assembly
  - Water cooled frame
  - Tested in air
- *Achieved 11 kW CW TW (klystron limited)*
  - No negative behavior observed

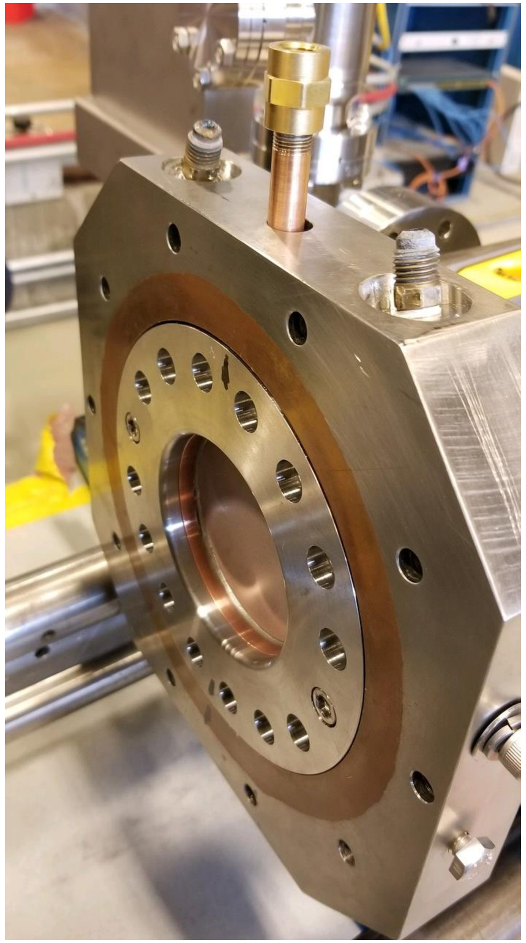




Upcoming High Power Test at JLab

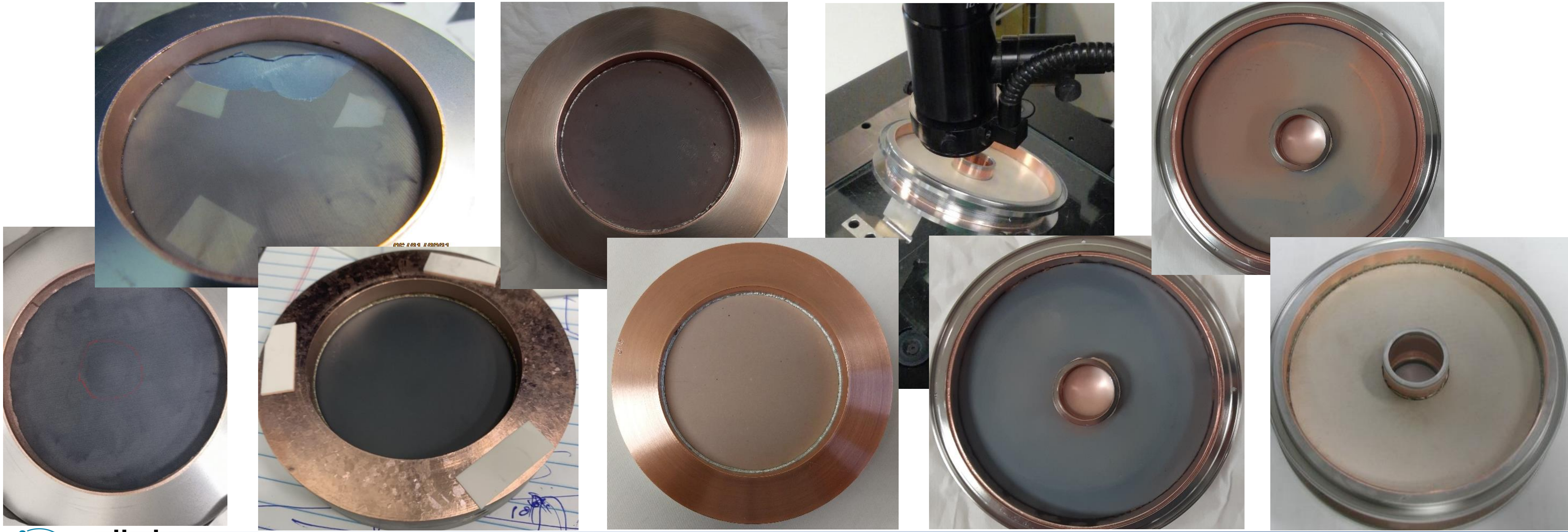
- First high power test of pair of windows in vacuum scheduled for next week





Window Assembly Fabrication/Production

- Several window assemblies (& coaxial) have been fabricated or are in production
- Many fabrication techniques and window conductivity values tested

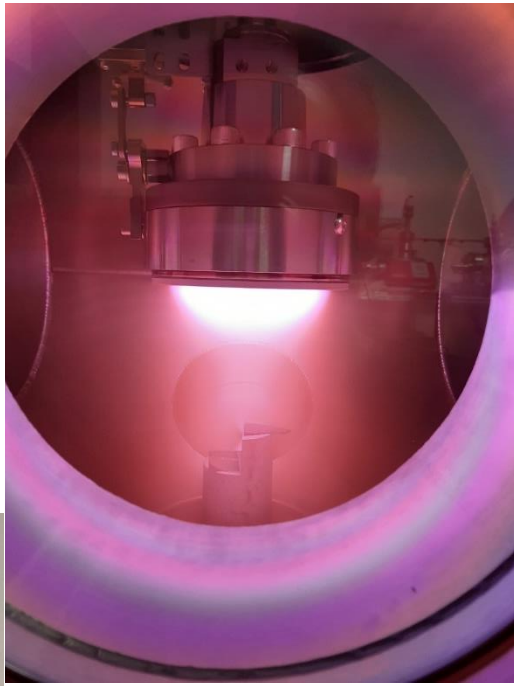


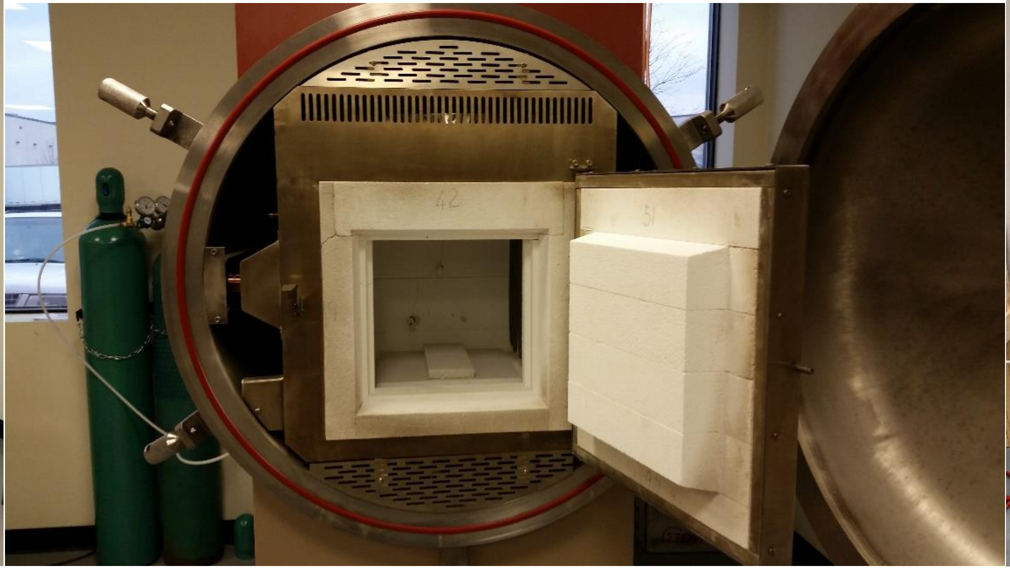
Past & Present Window Assemblies

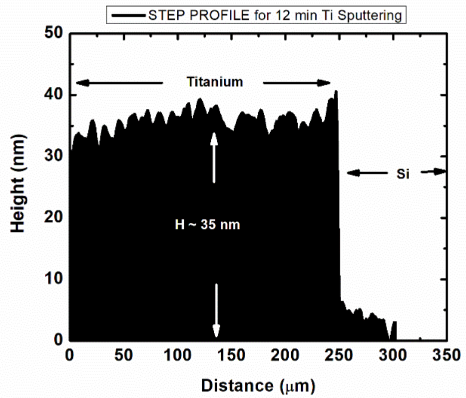
- Past:
  - Successful:
    - Sn-Ag-Ti-Mg active solder @ 250°C
    - In-Cu-Ag-Ti active braze @ 740°C
  - Not successful:
    - Au-Sn w/ Ag metallization @ 350°C
    - Cu-Ag w/ Ag metallization @ 750°C
    - In-Cu-Ag active braze @ 750°C
    - Ti-Cu-Ag active braze @ 950, 980 & 1000°C
- Present:
  - Coaxial, Sn-Ag-Ti-Mg active solder
  - Waveguide, In-Cu-Ag-Ti active braze

In-House Brazing Development

- Euclid owns/operates 3 furnaces for ceramic development and brazing
  - 1500°C, 12x12x16” controlled atmosphere box furnace
  - 1200°C, 5.6” diameter vacuum tube furnace
  - 1200°C, 1” diameter vacuum tube furnace
- Euclid owns/operates 3 sputtering chambers for metallization
- Brazing operations being relocated to Euclid to improve turnaround time & cost







Summary

- Accomplishments during Phase IIA:
  - Two high power tests in air
    - 11 kW CW achieved
  - Several window assemblies brazed/soldered
    - Two successful sealing techniques identified
  - In-house brazing capabilities expanding
    - Rapid prototyping & cost reduction
- In progress / planned during Phase IIA:
  - Fabrication of additional window assemblies
  - High power tests of waveguide & coaxial window assembly pairs in vacuum

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