Award # DE-SC0019651 Title: **Novel methods for i*n situ* high-density surface cleaning (scrubbing) of ultrahigh vacuum long narrow tubes to reduce secondary electron yield and outgassing**

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About PVI:

- PVI is a system engineering and manufacturing company specializing in high vacuum and thermal process technologies.

- Current and previous products include tools used for thin film deposition, thermal diffusion systems, rotating grade titanium processing systems, and a variety of high temperature vacuum processing equipment.

Abstract

- Electron clouds in accelerators limit machine performance through instabilities and vacuum pressure increases. Bare metal vacuum walls have shown to prevent electron cloud formation. Proper scrubbing of stainless steel or copper vacuum walls can reduce SEY. Scrubbing by ion beam-generate low density plasmas has resulted in unsatisfactory surface cleaning by not scrubbing all surfaces and poor debris pumping-out due to low-density plasma generation.
- **Novel plasma discharge cleaning techniques and tools are being developed for *in-situ* scrubbing long, small diameter tubes by generating high-density plasmas to completely affect each exposed surface. One technique involves high plasma density magnetron mole, the other is microwave** based **plasma injection that generates high-density plasma. High-density plasma scrubbing in the viscous gas flow range can reach all surfaces and pump out all debris effectively.**

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- **Relevance:**
  - Scrubbing in accelerators e.g. RHIC, is performed with ion beams by filling the rings with 25 GeV proton beams, filling RHIC with $2.2x10^{13}$ protons resulting in pressure rise of up to 10^{-7} Torr. Problems: gas is in molecular flow range; its plasma is confined by dipole magnetic fields. Consequently, plasma does reach all vacuum surfaces; there is very poor pumping out of debris.
  - Project guiding principle is to ensure plasma cleaning of all exposed surfaces and pump-out of debris by generation of non-magnetized high density, plasmas, which cannot sustain gradients, ensures complete coverage of all vacuum surfaces. The high-density results in viscous flow range of plasma/gas mixture that can be pumped-out effectively through 6.9 cm ID of the RHIC cold bore pipes.

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Two Approaches to Intense Discharge Cleaning Plasma Generation:

Magnetron Mole

Launching Microwaves

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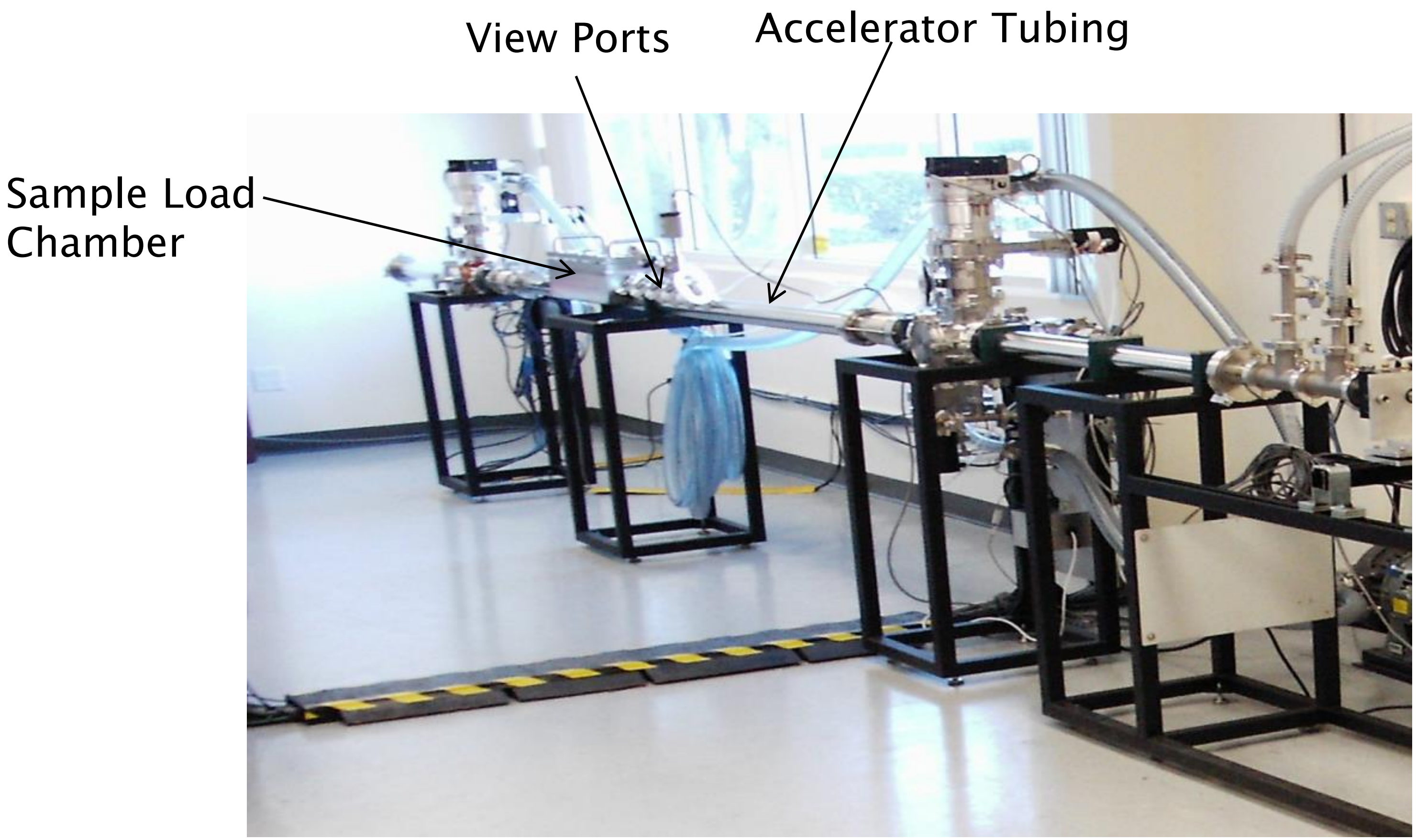
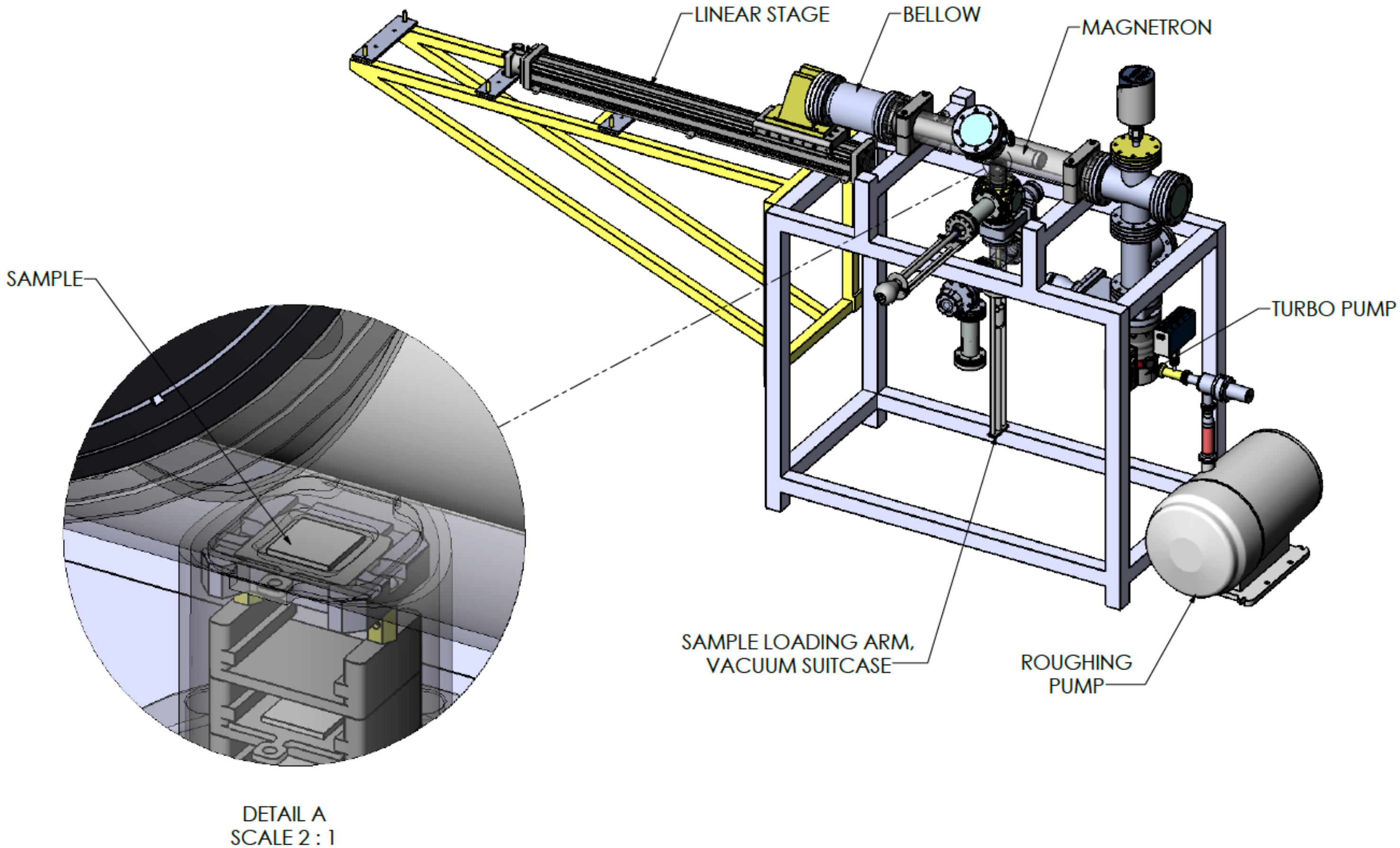
Magnetron Mole

- PVI has had good experience with magnetron mole discharge cleaning!
- System is shown in photo



Magnetron Test Concept Drawing

Fabricated suitcase can test 3 samples sequentially under different discharge conditions without breaking vacuum



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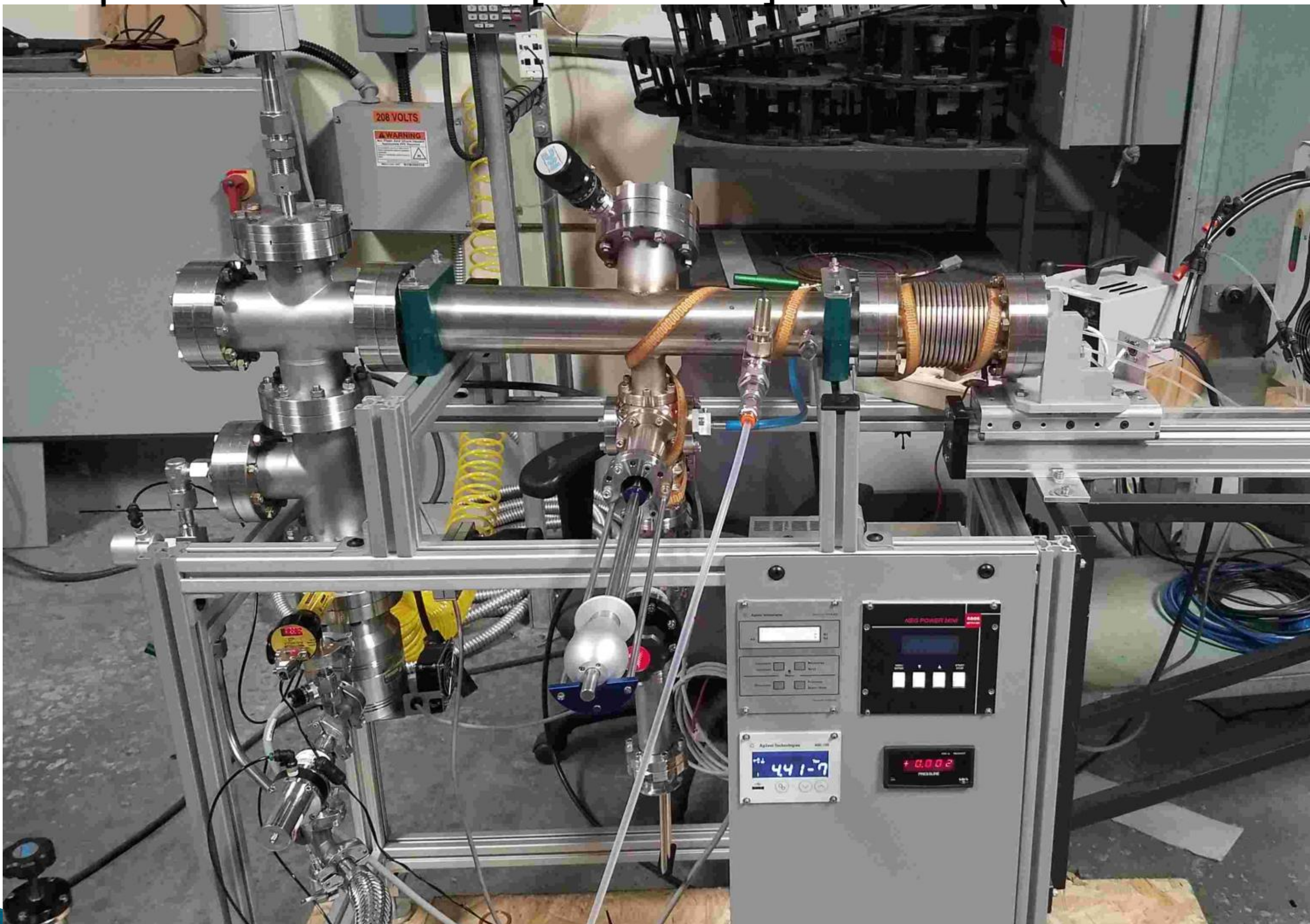
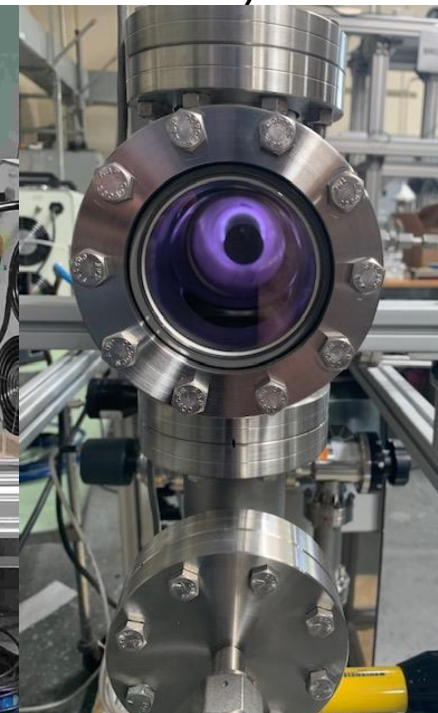
Magnetron Test Stand & Discharge Photo

“Optimized” Plasma [8-8-2023] 250 mTorr (100 mTorr suffices)





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Microwave Plasma Generation Approach:

- Since RHIC cold bore is 6.9 cm first explored 18 GHz 1.66 cm wavelength
- Cleaning 8 RHIC arcs require about ½ MW microwave power. High frequency systems are cumbersome probably won't fit in the RHIC tunnel (gyrotrons); very expensive $170M not palatable to end user.
- Similar power 2.45 GHz microwaves will cost about $1M.
- But, 2.45 GHz has a wavelength of 12.24 CM > 6.9 cm

Microwave Plasma Generation Approach Continued:

- Nevertheless in collisional plasma 2.45 GHz has been absorbed in tubes of less than 4 cm (exceeding plasma frequency factor more than 20) and even factor of 103 [N. Chalyavi, P. Doidge, R. Morrison and G. Partridge, *J. Anal. At. Spectrom.*, 1988 **32**, (2017)]. Furthermore the 2.45 GHz microwaves generate these plasmas without seed plasmas; we plan to generate first generate seed plasma with electrodes (BPMs in RHIC) (successfully shown in phase I) before microwave injection.
- The collisional approach is being pursued first.
- Backup revert to the original plan of using a grating Yury Bliokh's grating concept system to convert 12.24 cm wavelength to shorter plasma waves, it simpler to launch the 2.45 GHz microwaves into a relatively dense seed plasma, since microwave absorption is likely to succeed due to plasma collisionality.

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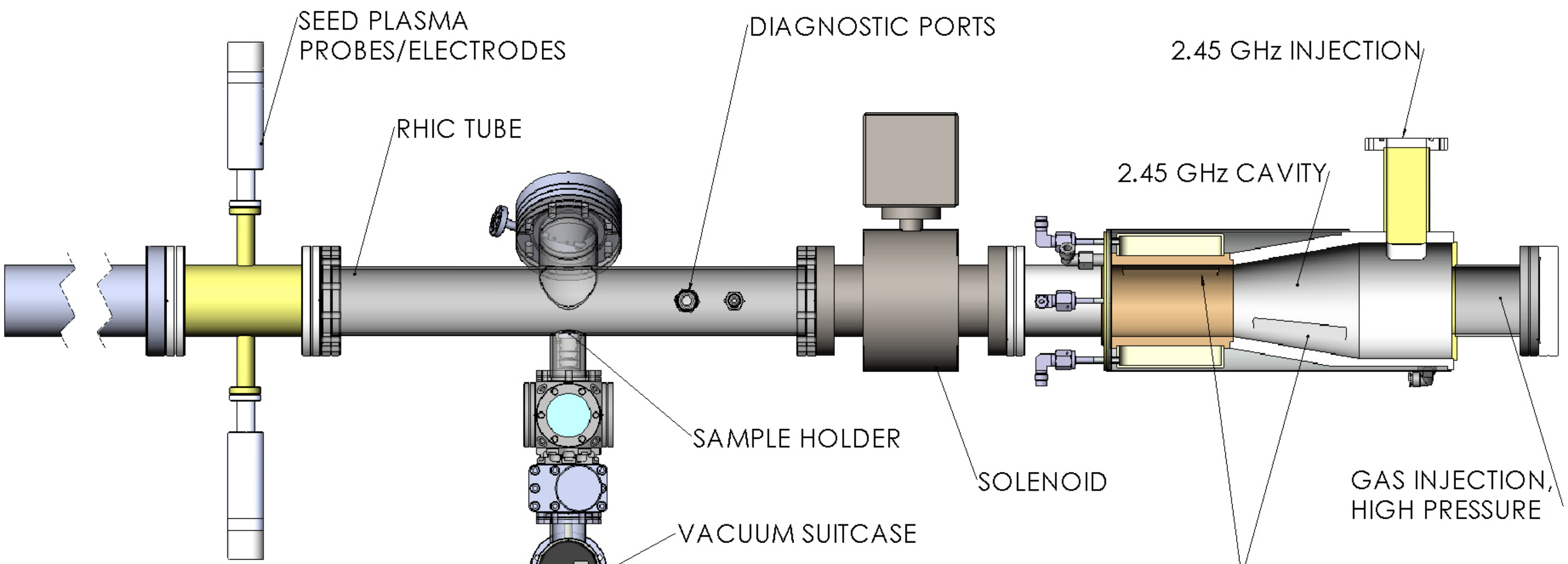
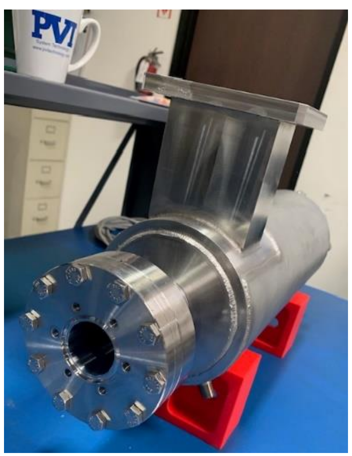
- Initial 2.45 GHz microwave injection setup drawing & stainless steel cavity photo (for gas vortex optimization; needed for plasma propagation)





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Plasma Propagation Simulations

Computational fluid dynamics indicated that gas injection through nozzles in the cavity at 100 Pa and 1000 Pa indicate that at pressure of 7.5 Torr (or higher) vortex formation that propels the plasma into the RHIC Pipe.

Utilize solenoids **ExB** for propagation enhancement. Testing plasma propagation in old long setup (slide 6).

Seed plasma generation was successfully demonstrated in phase I with RHIC CeC Beam Position Monitors. Here retractable probes utilized for seed plasma generation and possibly diagnostic (depending on plasma parameters)

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Photo of the 2.45 GHz Generating Equipment

6 KW capability purchased from Malachite Technologies

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Summary

- Differentiating features of our technology are: high density unmagnetized plasma in the viscous flow range, which reaches all surfaces and pumps-out all debris [presently used plasmas do not reach all surfaces (magnetized); molecular flow range].
- Magnetron mole discharge cleaning of long narrow tubes is “well-known” technology at PVI: excellent results for coating surface preparation. Still needs testing SEY reduction by the technique.
- **Status: testing system is operational** about to commence sample preparation.

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Summary continued

- Although 2.45 GHz microwave wavelength is larger than the RHIC (or EIC) cold bore tube, there is strong evidence that 2.45 GHz microwaves can be absorbed in small tubes containing high density collisional plasmas (DC seed plasmas generated in phase I); backup grating that converts long to short wavelength.
- **Status: subscale system ready for assembly** (including seed plasma generation). **Initial operation with stainless steel cavity followed by copper cavity and long tube propagation study**.

Copper just purchased; supply chain problems.