Device for In-Situ Coating of Long, Small Diameter Tubes

Project Summary

Award No. DE-SC0001571

H. Joe Poole, President
PVI System Technology
Oxnard, California
October 1, 2012

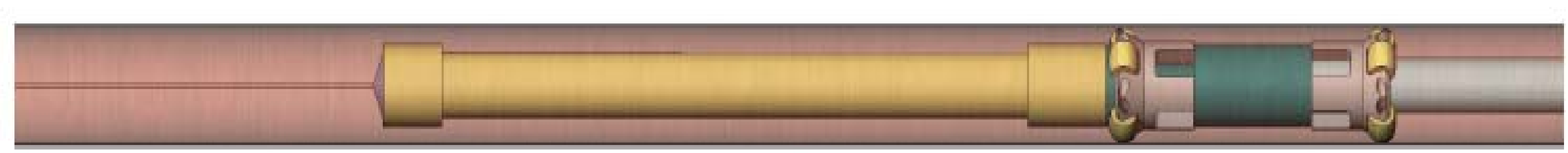
Outline

- Program goals and approach
- Design and results using initial prototype deposition source
- Measurements on test coatings
- Plans to coat 6.2 m long tubes

Program Goals

- Develop an *in situ* coating method for long, small diameter (2.75” ID) tubes
- Reduce secondary electron yield (SEY) to suppress electron cloud formation
- Reduce RF resistivity to reduce ohmic heating

Approach: Cylindrical Magnetron Sputtering



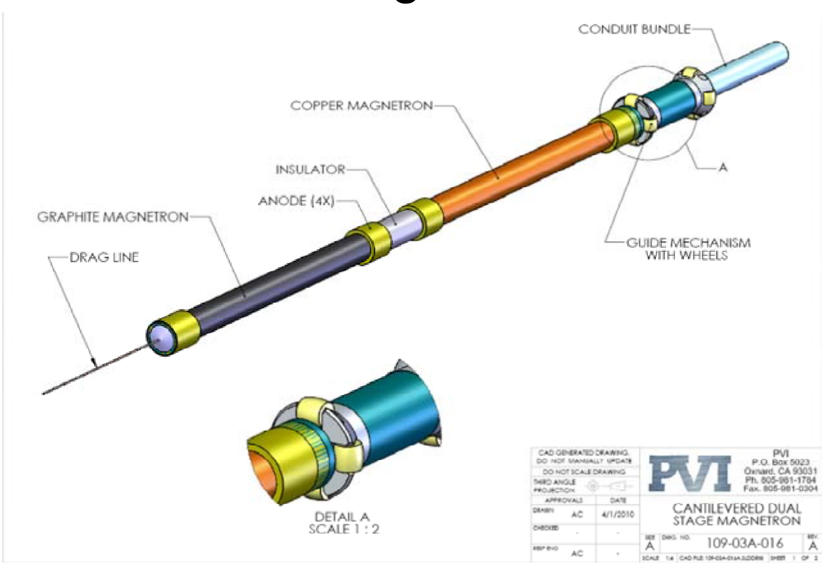
PVI System Technology

SBIR Phase II

- In the first phase of this program (SBIR Phase I) a small magnetron was designed and built that would function inside a 2.75” ID tube
- It was determined the 1.5” diameter cathode was a viable approach, but some more development was needed to optimize target material utilization
- During the SBIR Phase II (8/15/10 to date) program, several new cathodes were developed and various test samples have been coated and evaluated. PVI is currently scaling up to coat 6.2 m tubes

Planned Deposition Technique

- Original approach was to deposit ~5 μm of Cu to reduce surface resistance followed by ~0.1 μm of a-C to reduce SEY
- Use two cylindrical magnetrons connected by an insulator
  - 1st stage having an oxygen free high conductivity copper cathode
  - 2nd stage having a graphite cathode.
- Magnetrons to be mounted on a carriage (mole) pulled by a cable
- Spring-loaded guide wheels to accommodate diameter variances and bellow crossings



Concept of a plasma deposition device based on staged magnetrons

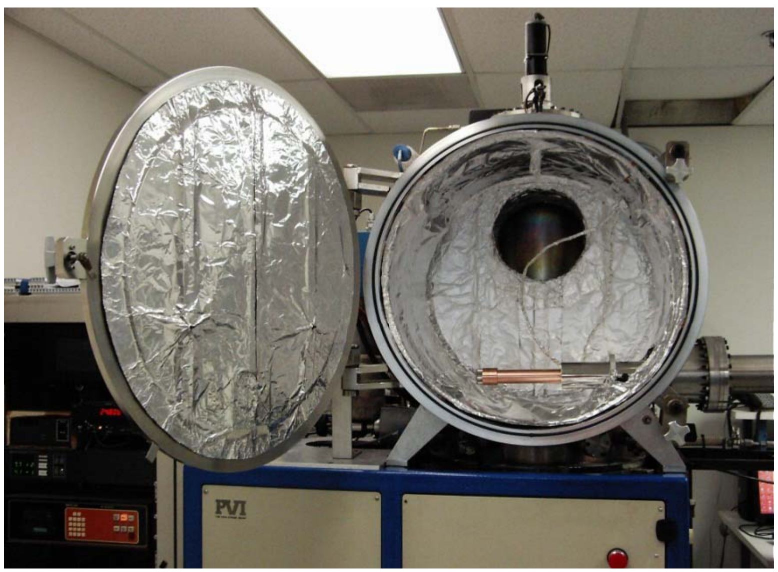
Initial Operation of Prototype Magnetron

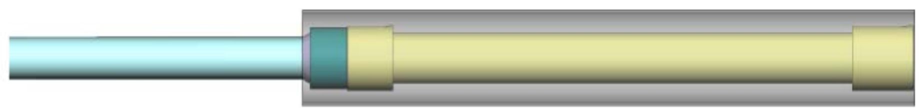
- First version of the magnetron used custom neodymium magnets to fulfill size and field strength requirements
- Demonstrated plasma ignition
- Large variation in magnet-to-magnet field strength limited maximum cathode radius that could provide continuous plasma without requiring re-ignition
- Tests were made with 0.2 inch Cu target thickness
- 0.1 inch Cu target thickness was chosen for initial prototype

PVI System Technology

Developing the Coating Process in an Experimental Chamber

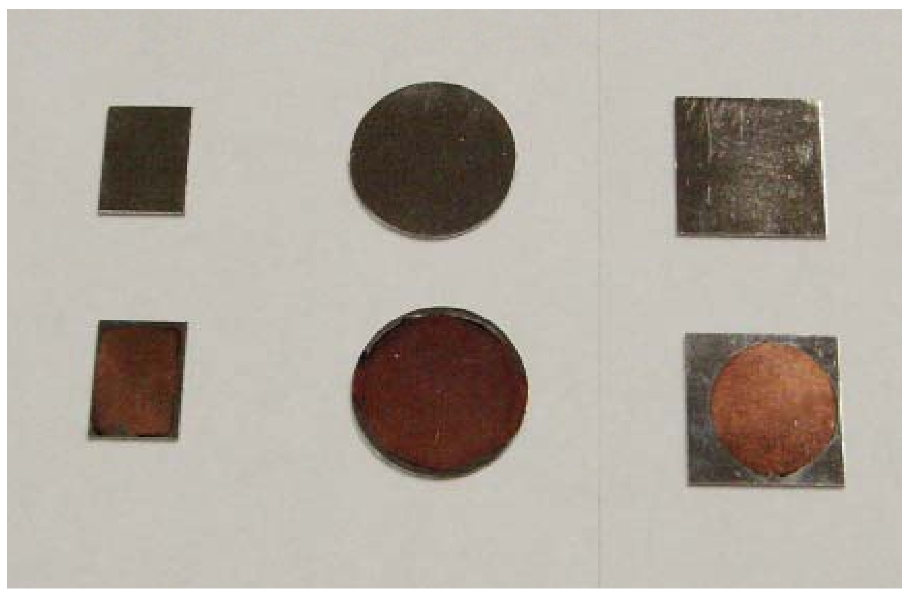
- Experiments coated a 30 cm L tube inside a vacuum chamber
- Tube was stationary and the magnetron was attached to a motion control system
- Enabled coating of entire tube or operation of the magnetron in a static location





Initial Deliverable Coatings

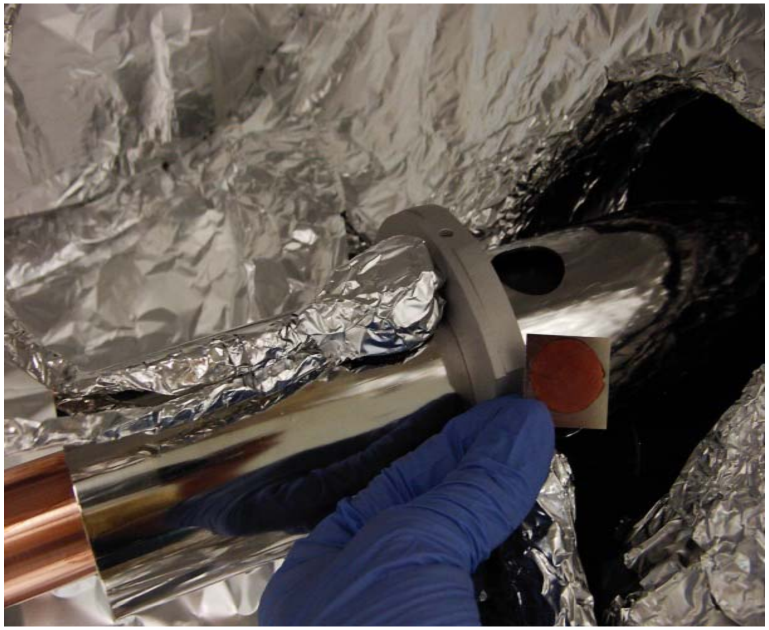
- After delivery of initial tube samples, effort shifted to flat samples for SEY measurements
- Testing at CERN was done at room and cryogenic temperatures
- Different sample shapes and sizes were required for the different temperature SEY measurements
- Coating thickness of 2, 5 and 10 μm prepared for each sample type



PVI System Technology

Coating of Flat Samples

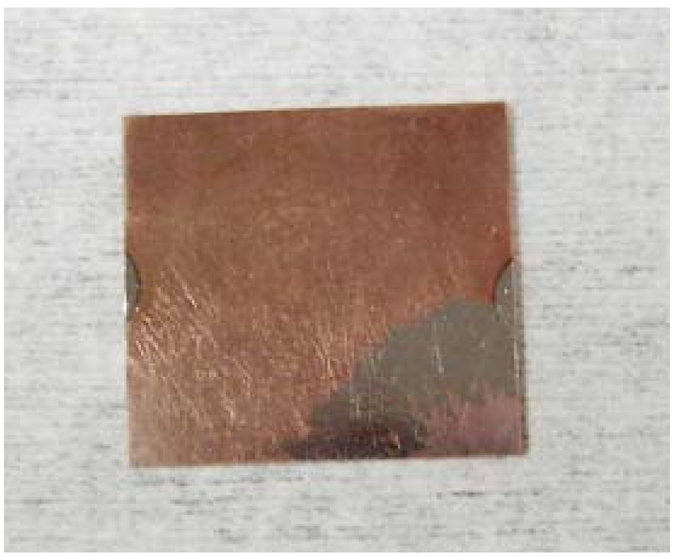
- Access ports were machined into a tube to coat the flat samples
- An additional hole was used to attach a deposition monitor to measure coating thickness and rate



PVI System Technology

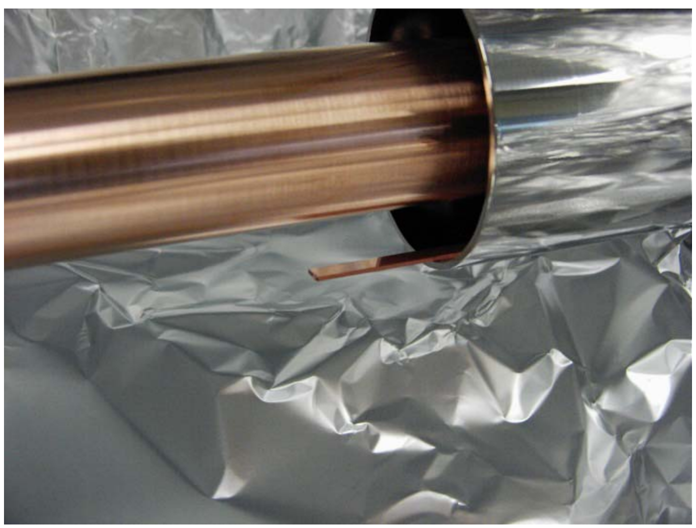
Difficulty with Adhesion

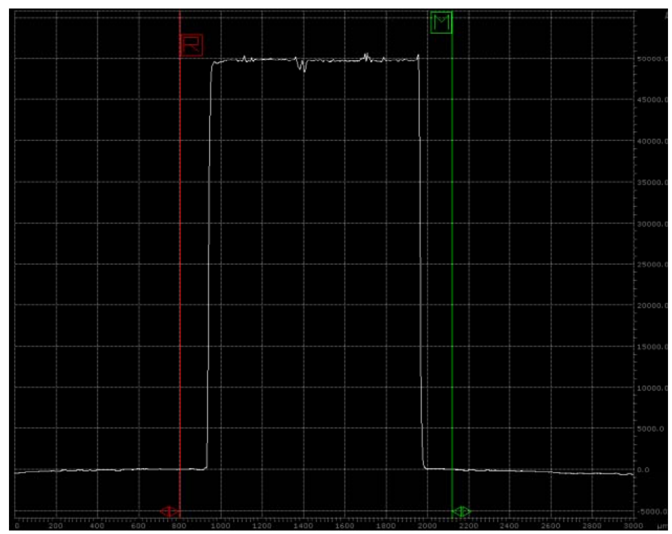
- Experiments were done using 0.5 – 1.0 kw from either an AC or DC supply
- DC power resulted in a controllable thickness but poor adhesion to both tubes or flat samples
- AC power provided better adhesion, but inconsistent results



Rate Calibration and Coating Uniformity

- To obtain a deposition monitor tooling factor and determine the coating uniformity a film thickness measurement technique had to be developed
- ¼” wide glass substrates were coated on the bottom of the tube
- The film was then etched to form steps at 1 cm intervals
- A Dektak IIA diamond profilometer was used to measure the etched film thickness





Profile of a 5000 nm step

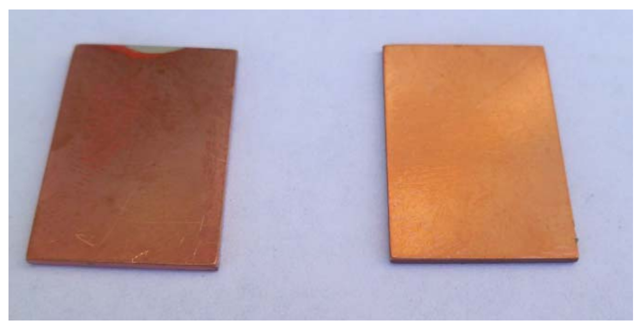
Sputtered Film Morphology

- The morphology of sputtered copper varies with deposition conditions
- At higher pressures copper films have a lower density, a columnar microstructure, are rougher and appear matte
  - Collisions of the energetic copper atoms with background gas reduces the adatom energy and its mobility on the growing surface
- At lower pressures copper films have a higher density and are shiny
  - Copper atoms arrive with more energy
- Films generally become rougher as they grow thicker
- There is evidence that rougher films will have lower SEY

SEY Testing at CERN

- Two sets of samples were sent to CERN for SEY testing
  - First “shiny” set deposited using DC power at low pressure
  - Second “matte” set deposited at high pressure using both DC and AC power
- Sometimes the high pressure conditions did not produce matte films

Dull Cu **Shiny Cu**



SEY Results

- Initial SEY results were unexpected
  - Shiny films exhibited lower SEY than matte ones
  - Thicker matte films had higher SEY than thinner ones
- Sample contamination prior to the SEY measurements may be responsible
  - Roberto Flammini (CNR/INFN, Italy) evaluated the test samples
  - Contamination is known to reduce SEY
  - Baking a 2 μm thick coating reduced its SEY from 2.15 to 1.55
- Explanation of results
  - More porous, matte samples and those that are thicker adsorb more contamination leading to higher SEY

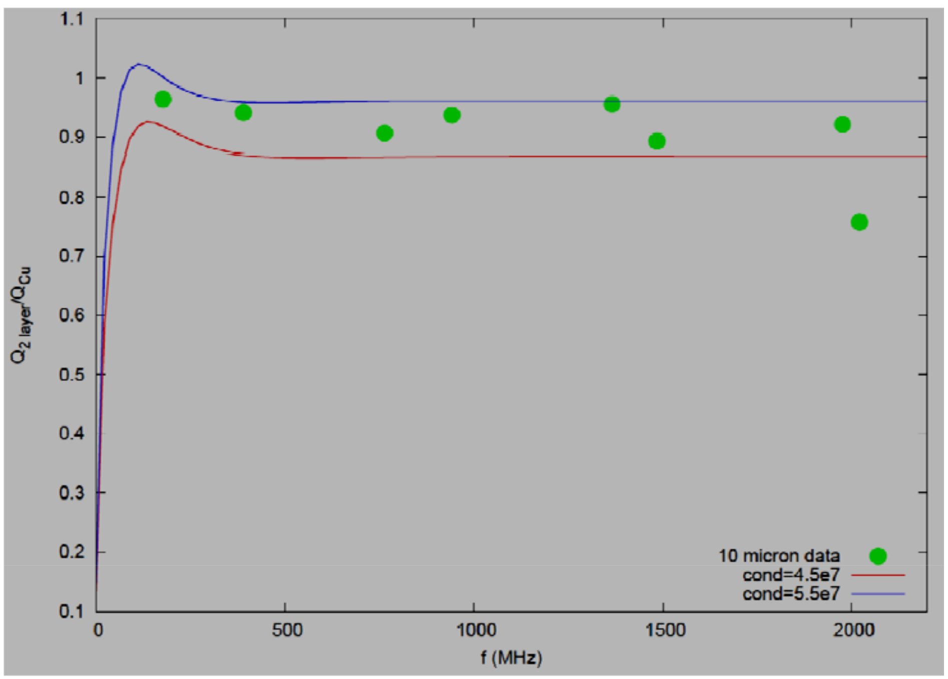
PVI System Technology

RF Resistivity Samples

- RF resistivity measurements required 32 cm L tubes
- To eliminate the possibility of edge non-uniformity, 50 cm tubes were coated and a 9 cm L section was cut from each end of the tube

RF resistivity of 10 µm thick films approaches bulk copper values

- Data is represented by green dots
- Red and blue lines are theoretical values based on σ = 4.5 and 5.5 x 10^7 mho/m, respectively
- Theoretical values do not take into account the resistivity of joints



Ratio of resistivity to bulk copper vs. frequency

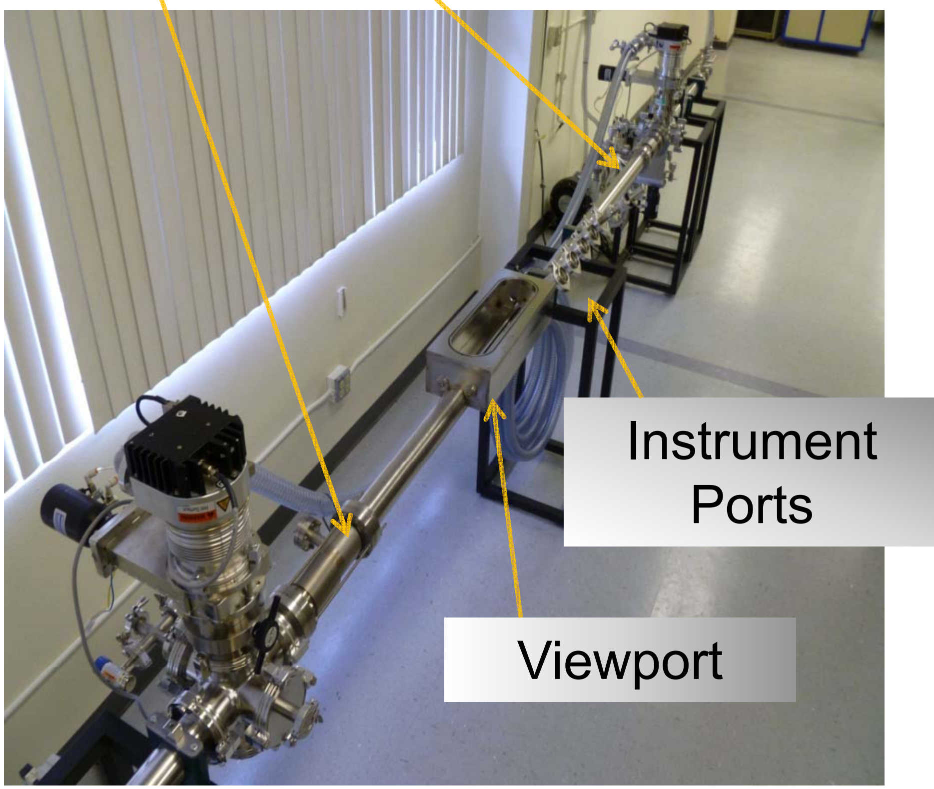
6.2 Meter Coating System Development

- Presently scaling up to coat a 6.2 m long tube
- Dual pumping system

Designed for Diagnostics

- Removable diagnostic section with plasma viewport

Removable diagnostic tubes



Plasma viewport

Current Status

- During the preparation of the 32 cm tubes for RF resistivity testing, the coating process demonstrated repeatable and consistent performance
- Room temperature RF resistivity very similar to pure Cu
- Ability to deposit thick Cu coating inside tube with good adhesion
- Low SEY
- Thickness gauge technique provided accurate calibration
- Wheeled magnetron (true mole) has been fabricated and will begin testing in October 2012
- Wheeled magnetron motion control system is in process

Scaling Up Further

- Experiments with the 6.2 meter system will help to determine how to deal with even longer tubes
  - Concern is pressure differentials
- Measurements of the rates and heat loads vs. power will provide estimates of the time required to coat very long tubes
- Development of a spooling system for water/power will be necessary for Phase III

PVI System Technology