Investigation of Fusion Ash Removal via Palladium Membranes

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Background

While the D-3He fuel proposed for some fusion reactors is aneutronic, deuterium (D) ions in the plasma can fuse with each other to produce either tritium (T) or 3He. The T fusion ash must be extracted to avoid energetic neutron production in the plasma. D is low energy, ~50eV, while T is high energy, >100 keV One way of separating T from D is by introducing a high H permeability, usually high-Z, material to prevent energetic fusion ash from re-entering the core plasma. Palladium (Pd) is a strong candidate. Pd has a high H sorption rate and permeability through conversion to a metallic hydride when heated to high temperatures, increasing H diffusion. Pure Pd would not separate the D from the T. However, introducing a thin (~0.1 μm) diffusion barrier beneath the surface would suppress the back-streaming of deeply implanted T.

Permeability

Permeability – the penetration of gas atoms through a solid by diffusion, the product of solubility and diffusion

$$P = S \times D$$

Dependent on the partial pressure of the gas permeating through;

$$Temperature \uparrow = \frac{Diffusion\uparrow}{Solubility\downarrow}$$

Generally every 10°c increase in temperature causes permeation rate to double

$$J = -D\frac{dC}{dx}$$

Solved using Fick's first and second law.

$$\frac{\partial c}{\partial x} = D\frac{\partial^2 y}{\partial x^2}$$

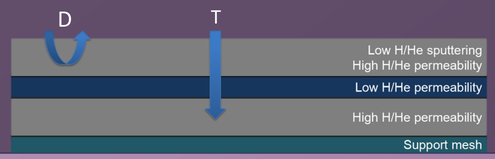
Palladium & ZBZ Configuration

Palladium:

- **High Z material and low sputtering yield;**
- **Converts H to metallic hydride, which increases diffusion**

ZBZ Configuration

- **A permeation barrier prevents diffusion back into the plasma**

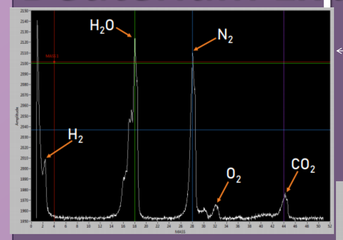


References

[1] Fischer, Joel. "Permeation and Measurement Techniques." Presented at the PLACE Conference, St. Louis, MO., September 2007

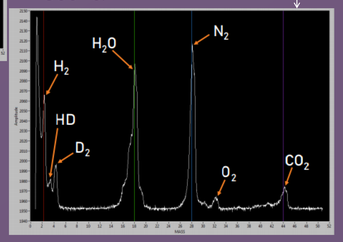
[2] Diffusion and solubility of hydrogen in palladium and palladium-silver alloys. Gerhard L. Holleck. J. Phys. Chem. , 1970, 74 (3)

Deuterium Experiment Results *-Summer 2018*

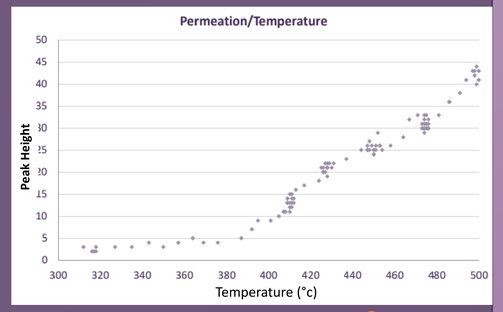


Spectra #1: Chamber side 2 prior to deuterium gas at 200°c

Spectra #2: Chamber side 2 deuterium permeation at 500 °c.



- Experiments conducted with an ion beam current from 0-14mA.
- D_2 permeation ranging in temps from 300-500°c. Increase in temperature increased permeation, showing



D_0 = Frequency Factor [m2/s]
Q = Activation Energy [eV]
T = Foil Temperature [eV]

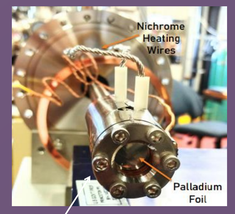
$$D = D_0 \exp\left(\frac{-Q}{T}\right)$$

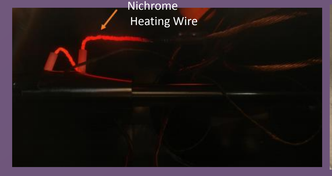
Experimental Values:
Do = 2.4E-6 ± 2E-6 m2 /s
Q = 0.30 ± 0.05 eV

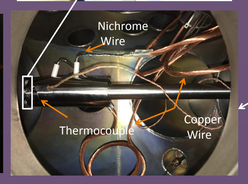
Literature Values:
Do = 2.4E-7 ± 1E-6 m2 /s
Q = 0.25 ± 0.05 eV

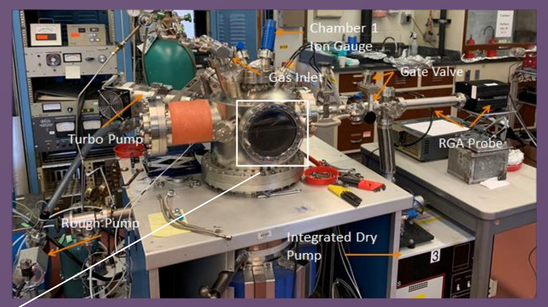
Experimental Setup- *Summer 2019*

- 1 mm thick palladium foil
- Two ion gauges were attached to each chamber to measure and monitor the pressure
- Replaced UTi RGA probe with an Inficon mass-spec analyzer.





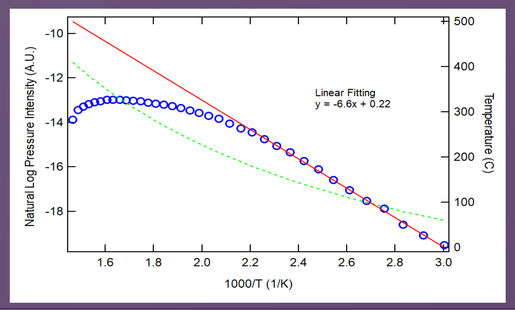


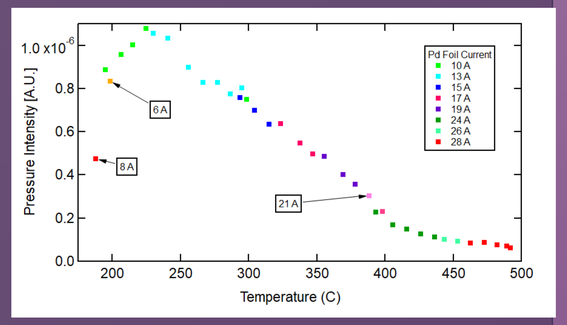


Two chambers separated by a holding pipe with a 1cm diameter palladium foil sealed in between two mini-conflats. Chambers pumped down to 10^{-8} torr

Helium Experiment *–Summer 2019*

- Experiment conducted without a plasma source.
- Helium permeation experiment ranging in temperatures from 200- 500°c and varying the Nichrome wire current from 6-28 amps to heat up Pd foil.





Graph showing the inverse temperature vs permeation rate of the data taken when the nichrome wire heater was cooled down from 500°c

Conclusion

- **Palladium has selective permeability to H/He;**
- **For hydrogen, the rate of permeation through palladium foil is directly proportional to the temperature of the foil;**
- **Palladium has shown to be a strong choice for a high-z material**
- **Helium appears to permeate through palladium at lower rates at higher temperatures.**

Future Work

- Test the experimental chamber design in the exhaust stream of the Princeton Field Reversed Configuration (PFRC) reactor;
- Adapt the foil to a ZBZ configuration;
- Examine the role of partial pressures in H/He;
- Test stability and permeability of palladium implanted oxide;
- Vary palladium foil thickness to confirm transportation rate;
- Research stable palladium compounds for permeation experiments

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