Minimization of Tritium Contamination on Surfaces

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Abstract

Tritium is a radioactive hydrogen isotope used in fusion reactions. Plasma decontamination is one of the methods used to remove tritium from the surface of objects. Although plasma decontamination is very efficient at removing surface activity, it cannot easily remove tritium beneath the surface of a material. To improve the process, the properties of the plasmas used in this process are being studied by varying the operating pressure of the plasma. The results of these experiments will be used to find the optimal settings for plasma decontamination so that the temperature of the item being decontaminated is at its highest. Hydrogen mobility increases with increasing temperature, enabling hydrogen present in the bulk to migrate more freely to the surface where it is removed by the plasma.

Introduction

Tritium is a radioactive isotope of hydrogen that is used in fusion reactions. It has a half-life of approximately 12 years and emits a low-energy beta particle. When tritium decays, it becomes helium-3. Tritium has the ability to spread through air. Cross contamination can occur if a contaminated object is present in the environment and is not in a sealed container. Tritium can also migrate into the bulk of a material. This can cause decontamination to be inefficient. If the surface of a contaminated material is

cleaned, surface contamination can re-appear due to tritium migration from the bulk metal.

Tritium has the ability to replace normal hydrogen atoms in molecules. This is known as tritiation. Polymers are at highest risk of tritiation, due to the high hydrogen content within the molecular structure. When tritium is incorporated in a molecule and decays, it changes the molecular structure. The site in the molecule that normally contains a hydrogen atom becomes unoccupied when the hydrogen transmutes to helium and diffuses away. This can weaken a material over time. Tritiation also presents a health hazard. When tritium is incorporated in water, the tritiated water can be absorbed into the blood stream, bringing tritium directly in contact with the inner body.

Plasma decontamination is a process by which particles are removed from the surface of an object through an event known as sputtering. Sputtering is the action of ions or atoms slamming against the surface of an object and removing particles from the surface. Plasma decontamination takes place in a vacuum, usually in the 10-90 mTorr range.

Experiment

The apparatus used in the research (see Fig. 1) is equipped with a voltmeter used to measure floating voltage, an ammeter, and a thermocouple. The gas used to generate the plasma was argon. The plasma was generated using an RF generator set to 100 watts. Experimental runs were conducted at 10 mTorr intervals starting at 90 mTorr and ending at 10 mTorr. During each run, voltage, temperature, and current data were recorded at five-second intervals. Most experimental runs ran for 1200 seconds (20 minutes); however, some were longer in order to obtain data on the end result of extended

decontamination. Typical results of an experimental run are shown in figures 2 through 4.

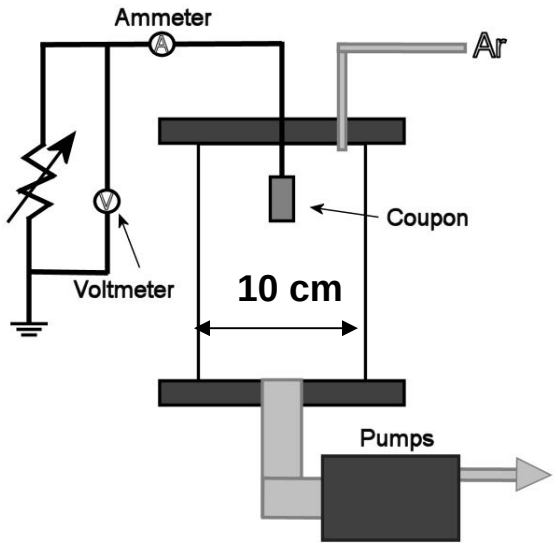

Figure 1. Diagram of experimental set up.

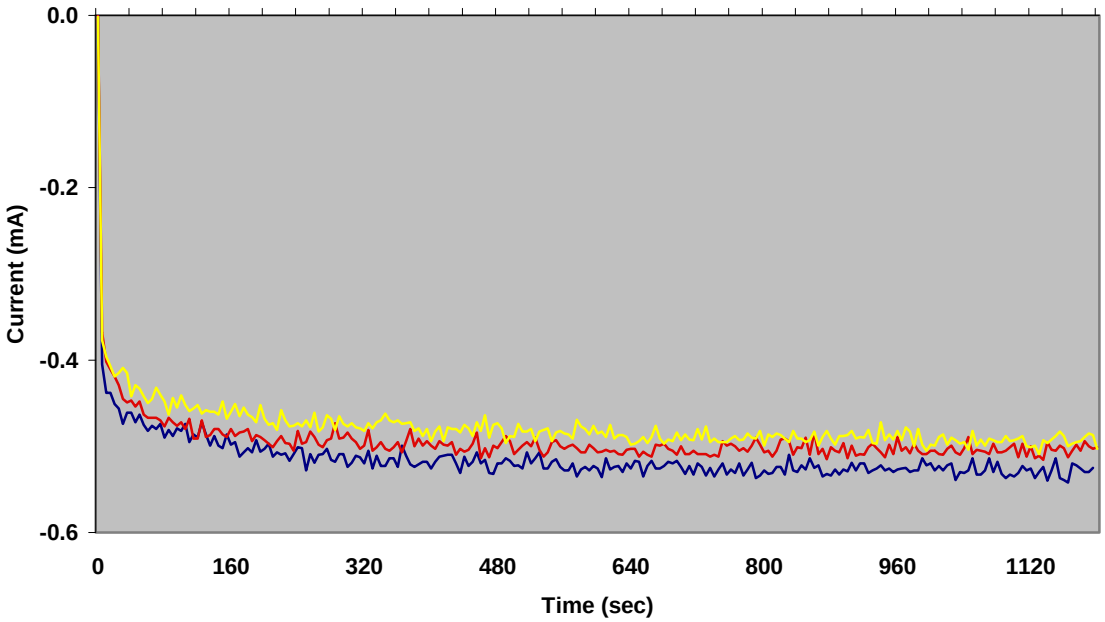

Figure 2. Current in milliamps over time of three experimental runs at 70 mTorr

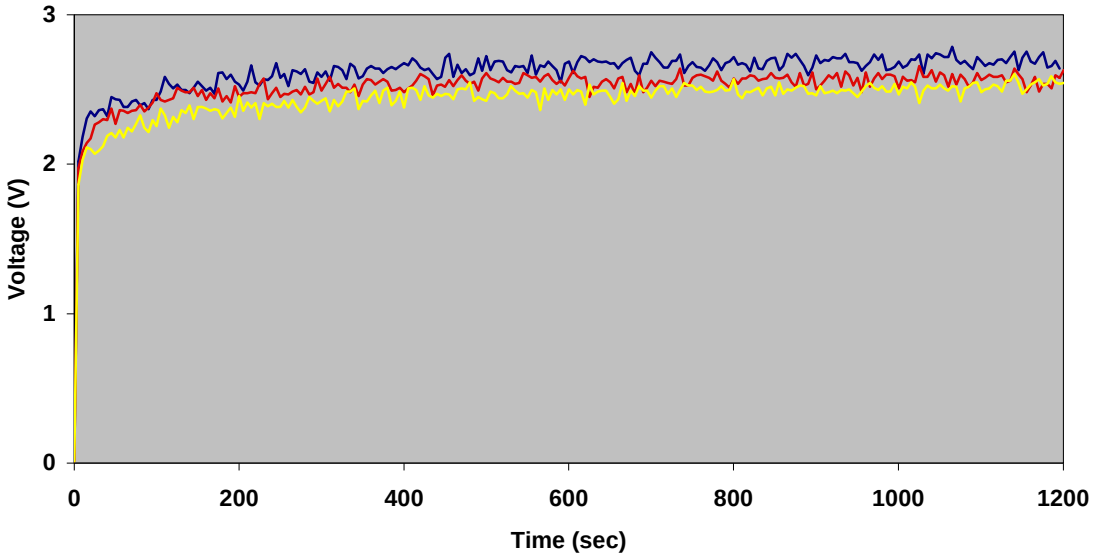

Figure 3. Voltage data of three experimental runs at 70 mTorr.

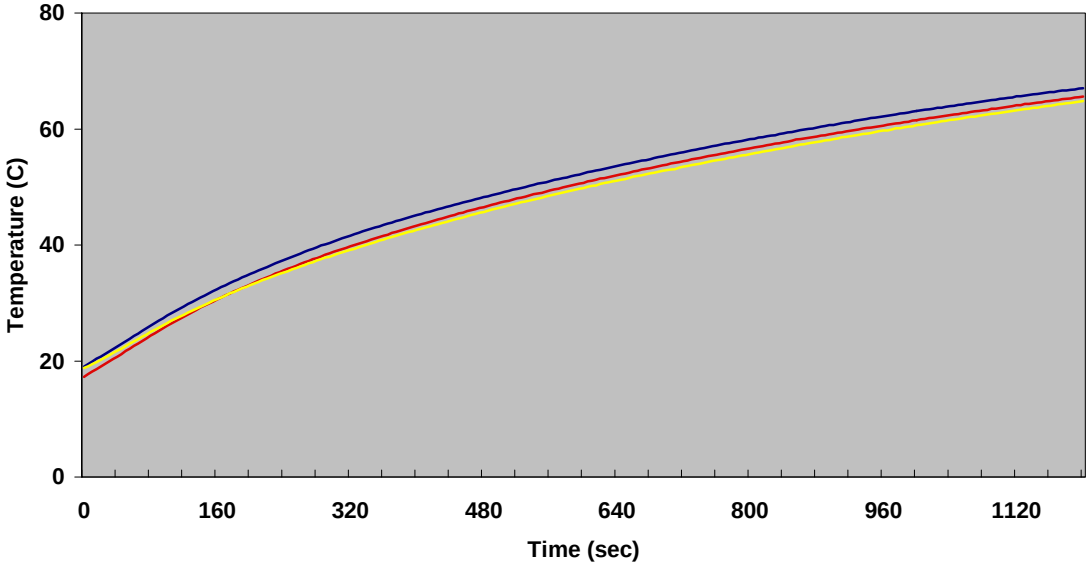

Figure 4. Temperature data of three experimental runs at 70 mTorr.

When sputtering occurs, it takes approximately 25 seconds to remove one monolayer of material. It was calculated that any particles in the chamber will only be in the chamber for approximately 0.3 seconds. Based on this, it can be assumed that the majority of the particles removed cannot reattach to the metal coupon.

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Previous studies show that when a sample is subject to plasma decontamination, surface activity, radiation on the surface of an object, decreases rapidly within the first few minutes and decreases at a slow rate past the first few minutes. This occurs due to the rapid removal of surface activity and the slow removal of tritium from within the bulk of the sample. Sputtering is effective at removing surface activity; however the rate of removal from the bulk is reliant on the rate of tritium migration to the surface. The easiest way to influence the rate of migration is by changing the temperature of the sample.

Varying the neutral gas pressure changes characteristics in the plasma such as the rate of energy deposition by the ions on the metal coupon. By changing the energy deposition, one can control the temperature gain or loss of a sample immersed in the plasma. By increasing the temperature, the rate of tritium diffusion from the bulk increases, thereby increasing the overall efficiency of the decontamination process.

Figure 5 shows temperature over time as a function of pressure. The graph indicates that at 50 mTorr pressure, the average coupon temperature is highest. This means that at 50 mTorr, tritium removal from the bulk is highest. Figure 6 shows a graph of power delivered to the coupon as a function of pressure. As pressure increases, the rate of power injection into the coupon decreases until the mean free path of the neutral particles in the plasma is equal to the radius of the chamber. Beyond this point power injection becomes independent of pressure.

New measurements indicated that the discontinuity previously observed between 50 and 60 mTorr is not evident (figure 7) and may be related to an offset in the

measurements. The new measurements suggest that the heating effect discussed above increases continuously with increasing pressure over the pressure range 10 to 57 mTorr.

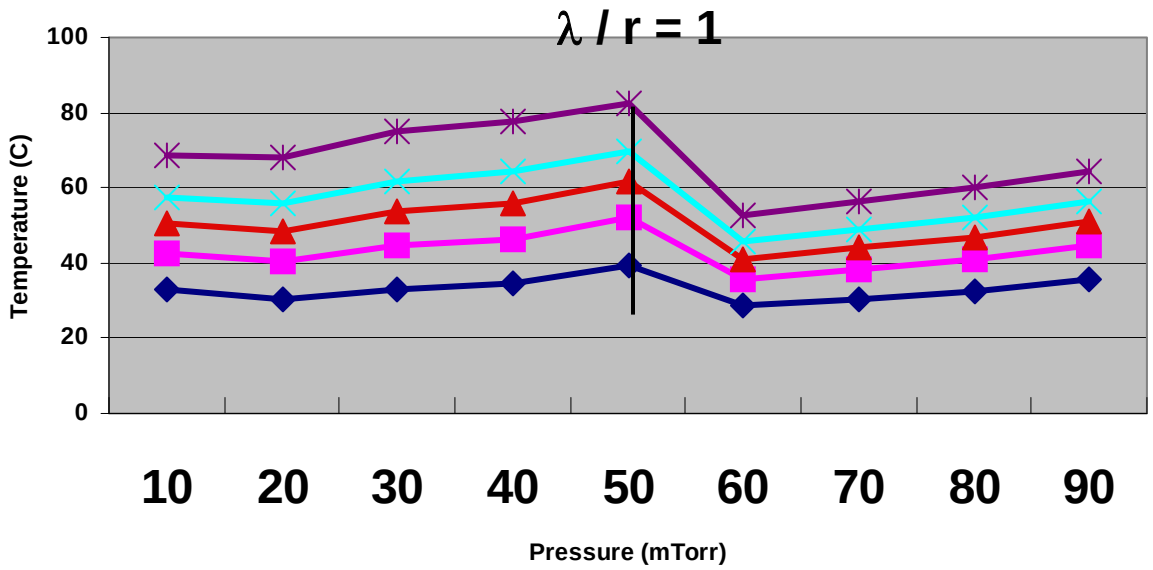

Figure 5. Graph of temperature over time as a function of pressure. The blue line represents the average temperature at 300 seconds into the experiment at various pressures. The pink line represents 600 seconds, the red is 900 seconds, the teal is 1200 seconds, and finally the purple line is 1500 seconds.

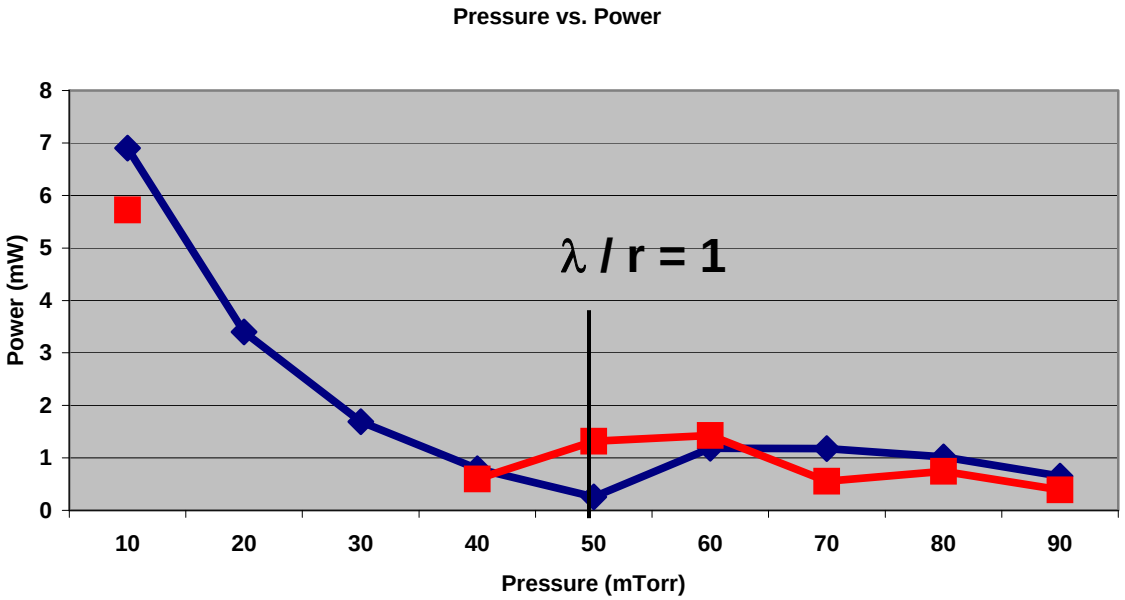

Figure 6. Graph of average power as a function of pressure. The blue line represents the first set of data collected, whereas the red line represents the second set.

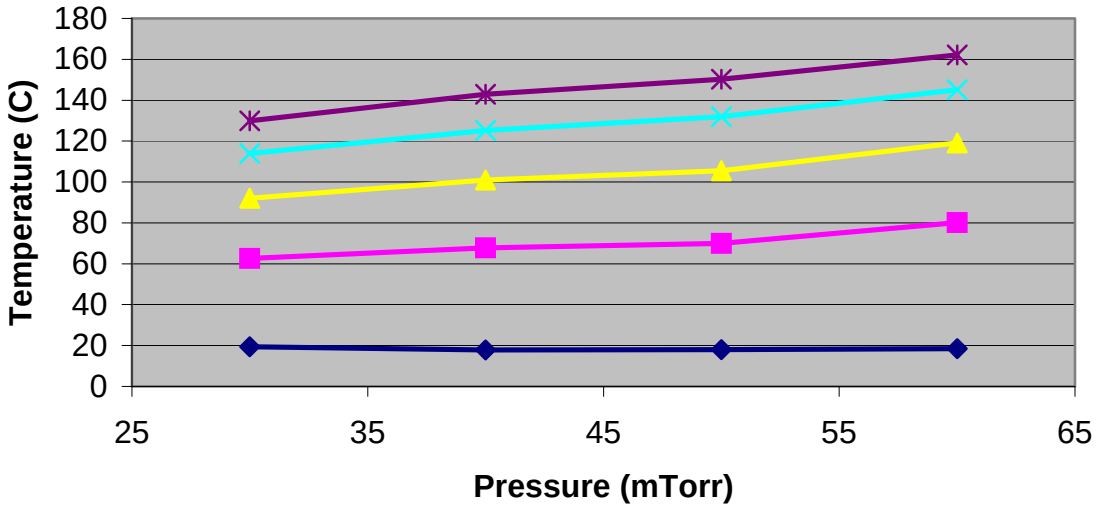

Figure 7. Graph of temperature over time as a function of pressure. The blue line represents the average temperature at 0 seconds into the experiment at various pressures. The pink line represents 300 seconds, the yellow is 600 seconds, the teal is 900 seconds, and finally the purple line is 1200 seconds.

Conclusions

The temperature of a metal coupon immersed in a low pressure, RF driven plasma increases as the neutral gas pressure increases. As coupon temperature increases, the rate of tritium diffusion from the coupon increases. The highest temperature change of the coupon occurred at 50 mTorr, where the mean free path of gas ions is equal to the radius of the chamber. Recent data, however, have shown that the discontinuity in the previous measurements observed at pressures above 50 mTorr may be related to a zero shift in the diagnostic. This conclusion needs to be verified by additional measurements.

Acknowledgements

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