Effects of Ambient Gases On ICF Target Capsules

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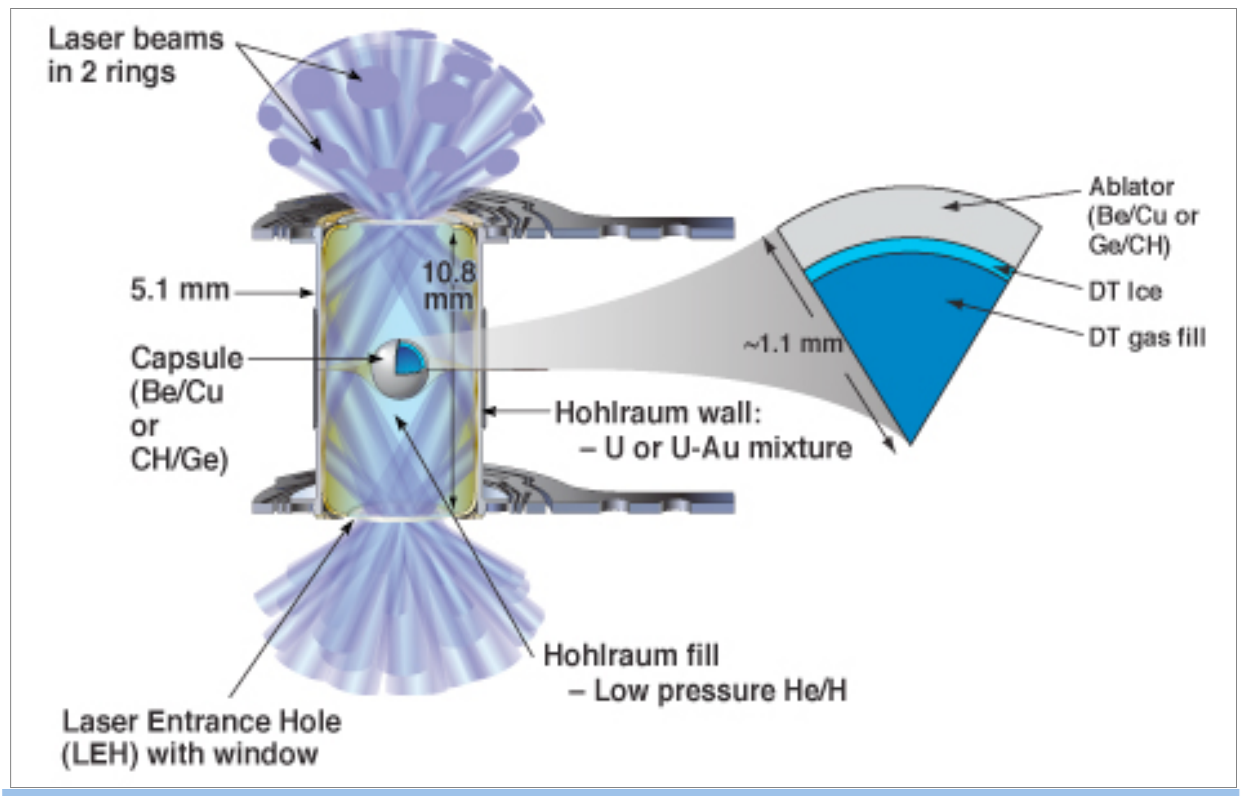
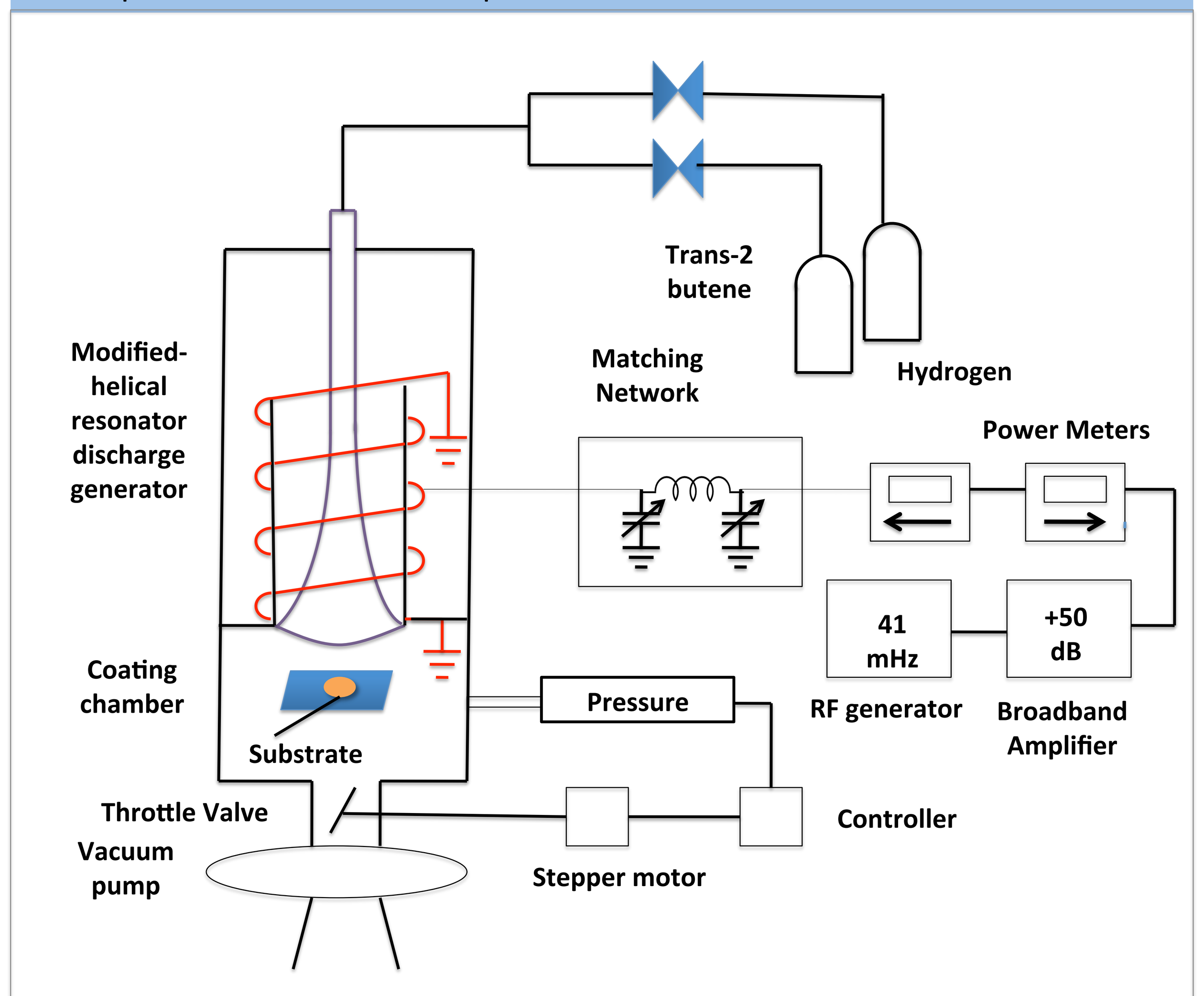
Introduction



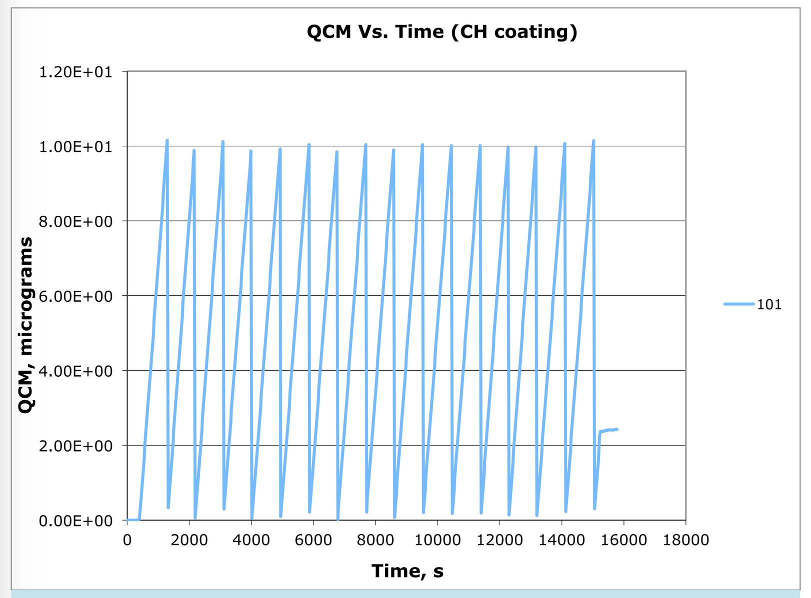
In our research we are investigating the chemical and physical properties of a plasma polymer fuel capsule (CH) as a function of environmental exposure (nitrogen, oxygen, water). CH fuel capsules are the at the heart of Inertial Confinement Fusion (ICF) at NIF as they are the ablation material that provides the shock pressure to the DT fuel upon absorbing the UV lasers. Variations in the composition and chemistry of these capsules plays an important role in determining the results of the laser induced ICF reactions. Our goal is to better understand the role of environmental factors and exposure time on the composition of the CH material.



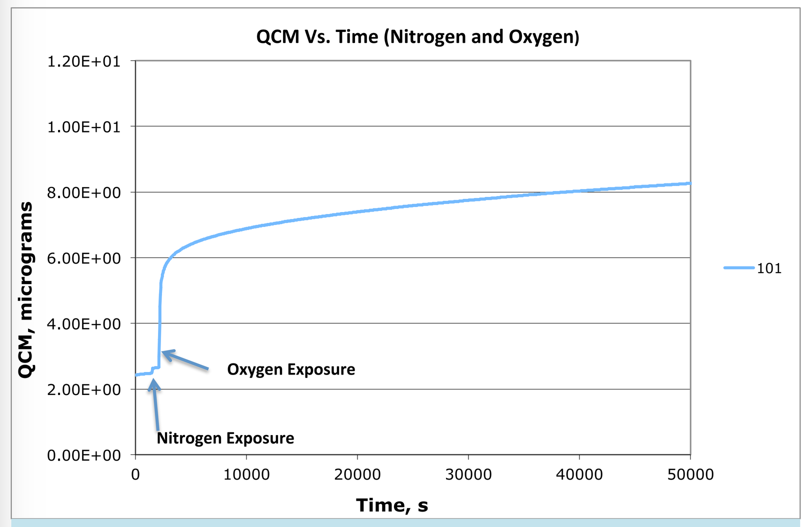
A schematic of the experimental apparatus is depicted above. Trans-2 butene and hydrogen provide the source for the CH polymer. This gas is injected into the resonator cavity where high electromagnetic field pulses thermally excite the gas atoms creating ionic discharges, i.e. plasma. The ions next combine and create a polymer, some of which is collected on the surface of the substrate. A quartz crystal monitor (QCM) serves as an accurate measuring device to determine the weight of polymer material collected on the substrate.

Experimental Approach

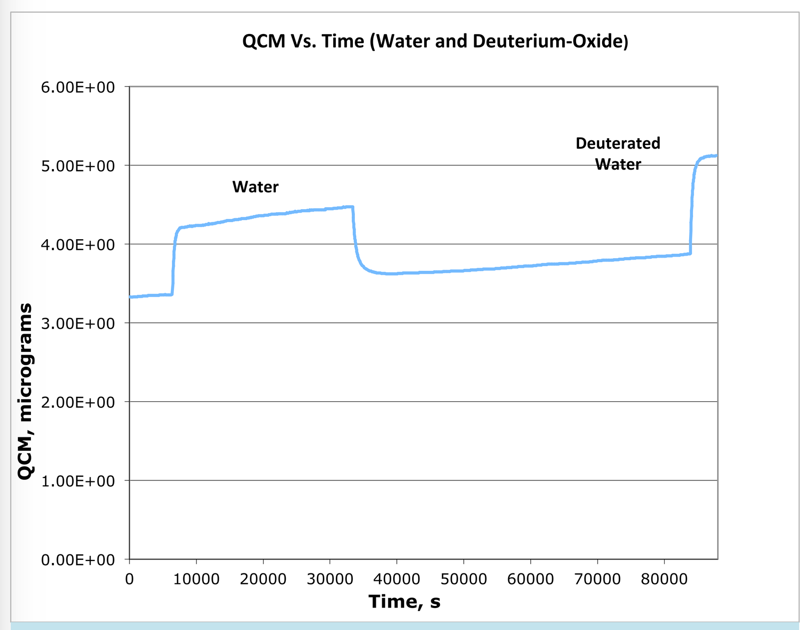
- **Deposit plasma polymer on quartz crystal microbalance**
- **Allow material to remain in vacuum for preset time**
- **Vent system to dry nitrogen**
- **Begin dry air (controlled amount of oxygen)**
- **Begin humid air flow (capsules spend some lifetime in water for polishing)**



This plot shows the increase in mass measured by the QCM as polymer is deposited on the substrate. Each peak represents an increase of 10 micrograms.

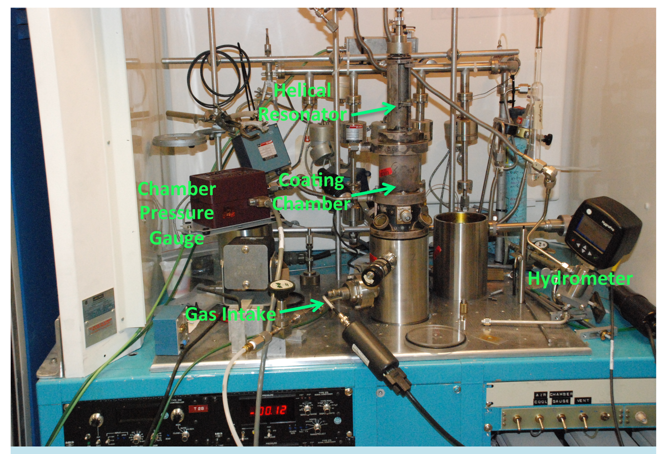


This plot shows the increase in mass measured by the QCM as firstly nitrogen, followed by oxygen is deposited on the substrate. The amount of nitrogen absorbed is only a fraction of the oxygen absorbed.

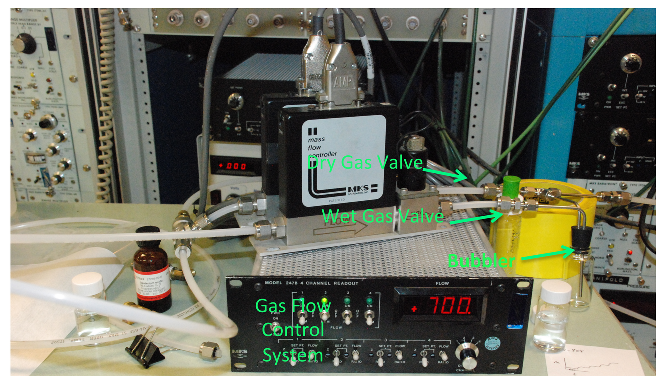


This plot shows the increase in mass measured by the QCM as firstly water, followed by heavy water (deuterium) is deposited on the substrate.

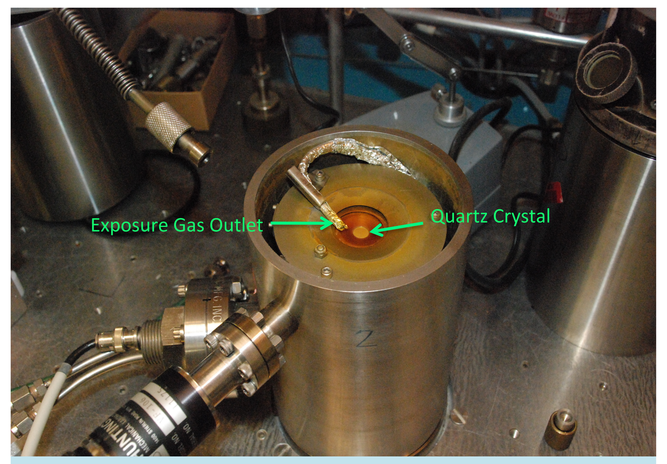
Apparatus Photos



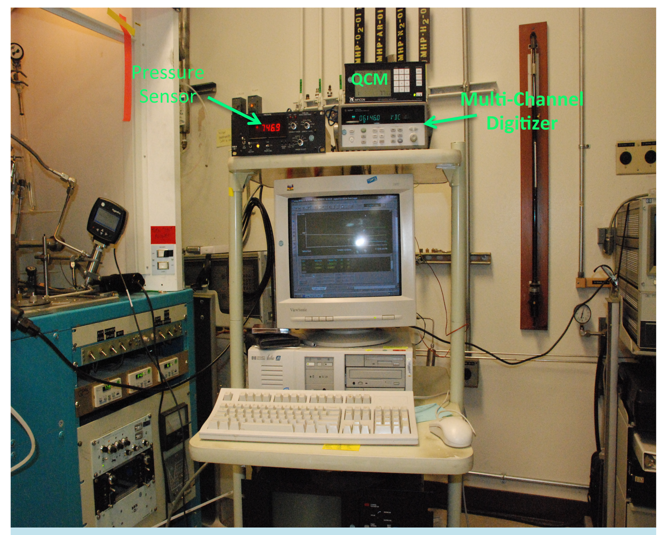
This photo shows the main components of the experiment. The exposure gases (nitrogen, oxygen, vacuum, and water vapor are injected through the intake valve)



The flow rates of the gases is controlled here. We can choose whether to vent dry air, humid air, varying rates of both, vacuum, or nitrogen through this system. To humidify the gas we send it through the bubbler that contains de-ionized water.

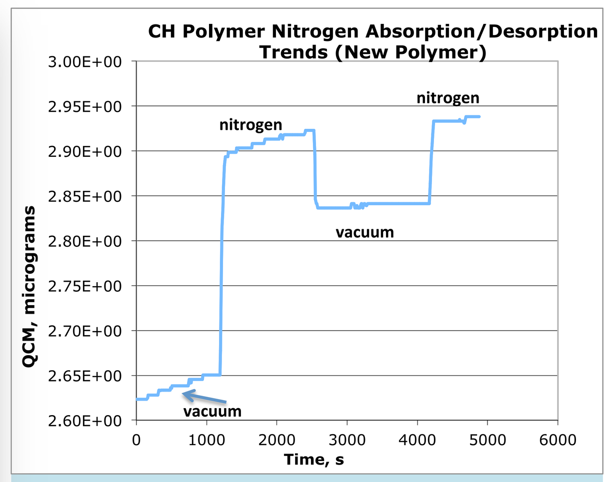


Here is photo of the quartz crystal holder (inside view). The quartz crystal goes in the center and the plasma polymer is collected on it. Exposure gases flow directly onto it from the outlet valve.

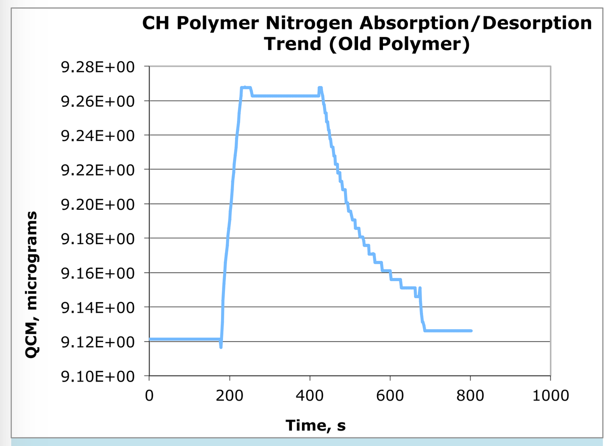


This photo shows the workstation. Our apparatus is on the left, data is collected at the computer. The pressure sensor tells us the pressure inside the chamber and the multi-channel digitizer converts analog signals to digital ones that the computer can process.

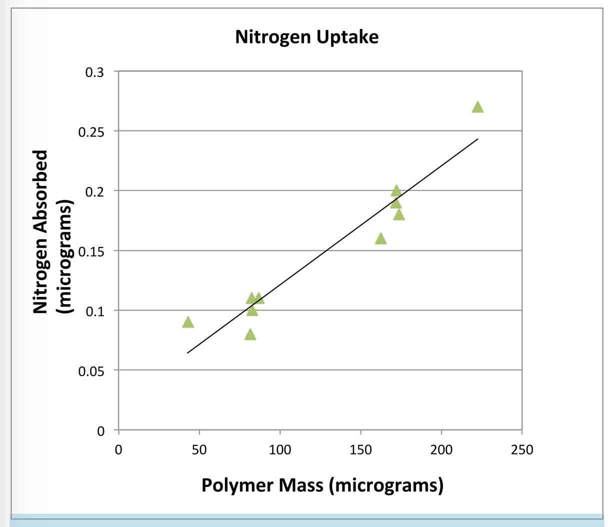
Nitrogen Absorption



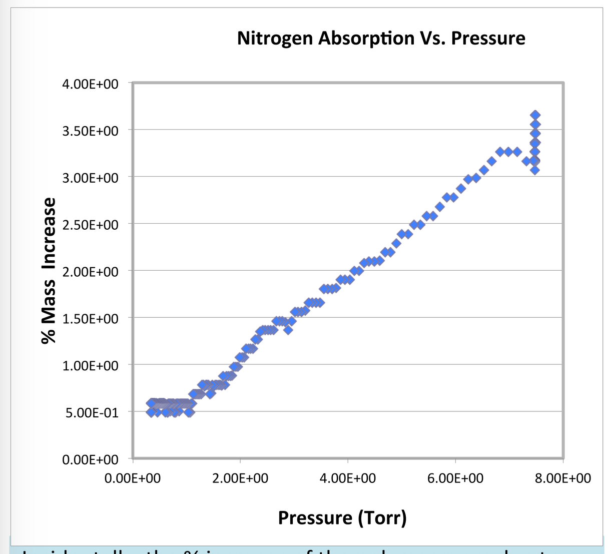
As the polymer exposure alternates between vacuum and nitrogen there is a net absorption early on. This is probably because there is a high free radical concentration in the newly created polymer that is reacting with residual ambient oxygen.



In this case we expose an older polymer (5 days) to nitrogen in between vacuum exposures and we see that most of the nitrogen does get desorbed when going back to vacuum.

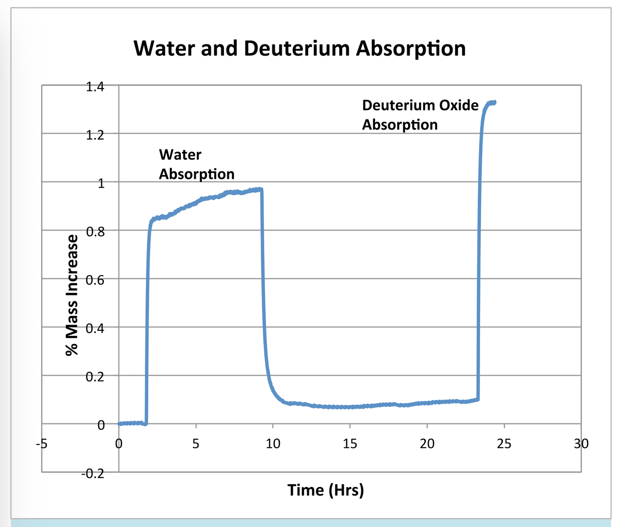


How much nitrogen gets absorbed depends on the thickness of the polymer as shown above.

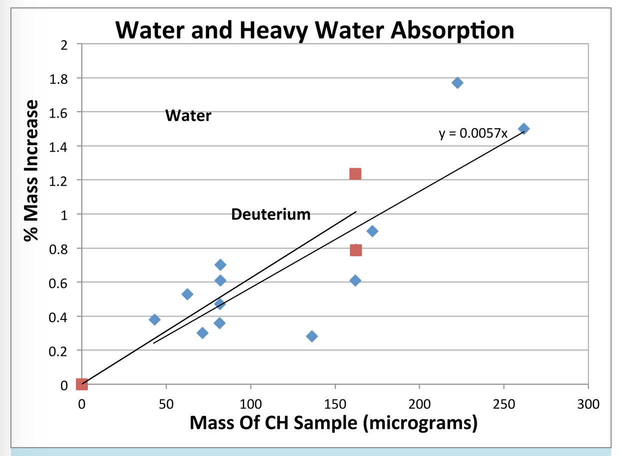


Incidentally, the % increase of the polymer mass due to nitrogen absorption also depends on the pressure of the gas chamber. This relation is reversible as well.

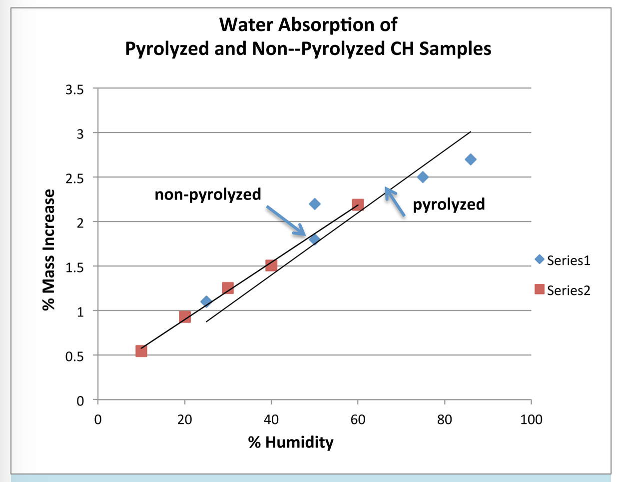
Water Absorption



In this experiment we saturated a sample of CH polymer initially with water then back to vacuum, after that we expose it to deuterium oxide (heavy water). We can see from the plot that the process is essentially reversible and that heavy water adds more relative weight to the polymer sample than water.

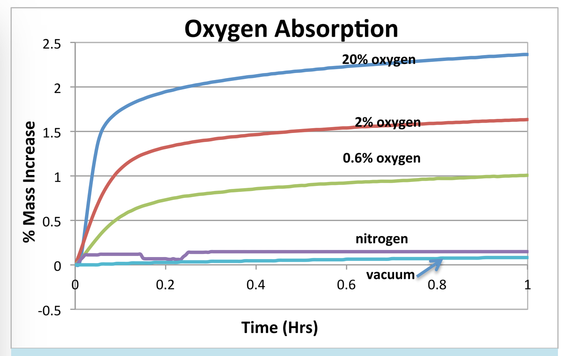


In this experiment we investigate investigated how much water a sample absorbed as the mass of the sample increased. We found a linear relationship as expected. The more sample there is the more water can diffuse into it. We don't expect there to be a chemical reaction since the process is reversible but if the water contained oxygen it would react with the sample more readily especially if the sample was new. We also experimented with deuterium and found that it is absorbed slightly more heavily than water as expected.



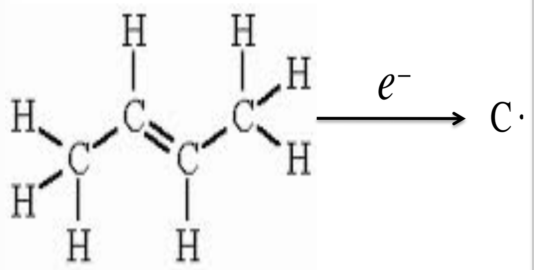
One of the ambient gases that capsules are often exposed to is water. It is inevitable that when they are removed from a fabrication chamber they will encounter some. They are also placed in water for smoothing and polishing effects. It is crucial to know how the capsules respond physically and chemically to water. The materials division investigated this and we found that water is absorbed depending on the concentration of the water vapor in the air. We controlled this by venting varying controlled amounts of dry air vs. hydrated air into the chamber and recording the results of the absorbed amounts. We also were wondering whether pyrolyzing (fire furnace treating) the material affected how it would later absorb water. It seemed to make very little difference as shown in the graph above.

Oxygen Absorption



The plot above shows how the general growth of a plasma polymer depends on the relative amount of oxygen in the chamber during the first hour of the experiment. The general trend continues for extended amounts of time.

Free Radical Creation



Inside the helical resonator the trans 2-butene is bombarded by energetic electrons which break apart bonds and create a free radical in the compound.

Oxidation Reactions

$$C\cdot + O_2 \rightarrow COH$$
$$C\cdot + O_2 \rightarrow C{=}O$$

The carbon 'free radical' that was incorporated in the polymer is highly reactive with oxygen. We know from using Fourier transform infrared spectroscopy (FTIR), that hydroxyl (CH) and carbonyl (CO) groups are created in the reaction.

Other Results with Oxygen

Many experiments and test runs focused on the oxidation of polymer samples. Variables were changed from one experiment to another such as the thickness of the polymer, the power supplied to the helical resonator, and the pre-exposure time to vacuum and nitrogen, yet many of our results were inconclusive. Comparisons between experiments were limited by the accuracy of the measurements of the QCM instrument technique and varying amounts of residual oxygen residing in our vents and chambers, etc.

Conclusion

We Investigated the effects of gas exposures on plasma polymer material used for ICF fuel capsules. Nitrogen reversibly sorbs into plasma polymer. The amount is pressure dependant. Oxygen reacts irreversibly with free radicals. The rate depends on the oxygen concentration. Water reversibly sorbs into plasma polymer. The amount is humidity dependant. We hope to continue researching oxidation rate constants, oxygen concentration gradients, and mathematical modeling of plasma polymers.

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