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Lawrenceville Plasma Physics, Inc

High technology research, development and consulting in plasma physics, X-ray sources, and Focus Fusion

LPP Focus Fusion Report
December 7, 2016

Summary:

- **Assembly Begins for New Tungsten Experiments**
- **Observations Strengthen Theory**
- **Calculations Explain Destruction of Filaments**
- **Meetings Help Spread Word on Focus Fusion**
- **Focus Fusion Song and Poetry Contest**

Assembly Begins for New Tungsten Experiments

LPPFusion’s research team started to re-assemble our experimental fusion device, FF-1 at the beginning of December to prepare for new experiments with pure tungsten and a shorter electrode. The first step is to coat part of the 10-cm long tungsten anode with indium, a soft metal. The indium will be squeezed against narrow circular ridges in a steel plate to form an excellent electrical contact. The combined assembly will then be mounted at the center of the FF-1 device, attaching the new anode to the electrical circuit that powers the device. The next steps will be mounting the tungsten cathode, sealing up the vacuum chamber and checking for leaks. Following that, we’ll take the important steps to eliminate oxygen from the electrodes with a bake-out and microwave treatment (see next section).

Part of the preparation for the new experiment involves repairing and upgrading our instruments. Based on discussions with our colleagues in Poland, LPPFusion Research Physicist Syed Hassan has designed and built a self-contained isolation box for our ICCD camera and its battery-based power supplies. The elimination of external power lines will prevent large electromagnetic pulses from disrupting the camera’s operation, as occurred in the last experiment. The ICCD can provide sharp images of the plasma in the device with an exposure time of 0.2 ns (billionths of a second). In addition, work is still underway to repair our residual gas analyzer (RGA), a sensitive instrument used to find vacuum leaks, and to upgrade the operation of our photomultiplier tubes, which detect x-rays and neutrons. All of this takes time—a bit longer than we expected, so our planned experiment is now likely to start in early January. More funding, allowing us to hire more skilled staff, would get things done faster!

Observations Strengthen Theory

New observations over the past month have lent support to the hypotheses LPPFusion Chief Scientist Eric Lerner has put forward to explain the erosion of the tungsten electrodes in the last experiment. In turn, the strengthening of these hypotheses has concretized plans for the next experiment. First, at the ICDMP conference in Poland, Dr. Monika Vilemova of the Institute of Plasma Physics in Prague had offered to analyze deposits on the windows of the FF-1 vacuum chamber. The analysis was performed using energy dispersive x-ray spectroscopy (EDS), a technique in which an electron beam causes atoms in the sample to emit x-rays, which allows identification of the emitting atoms.

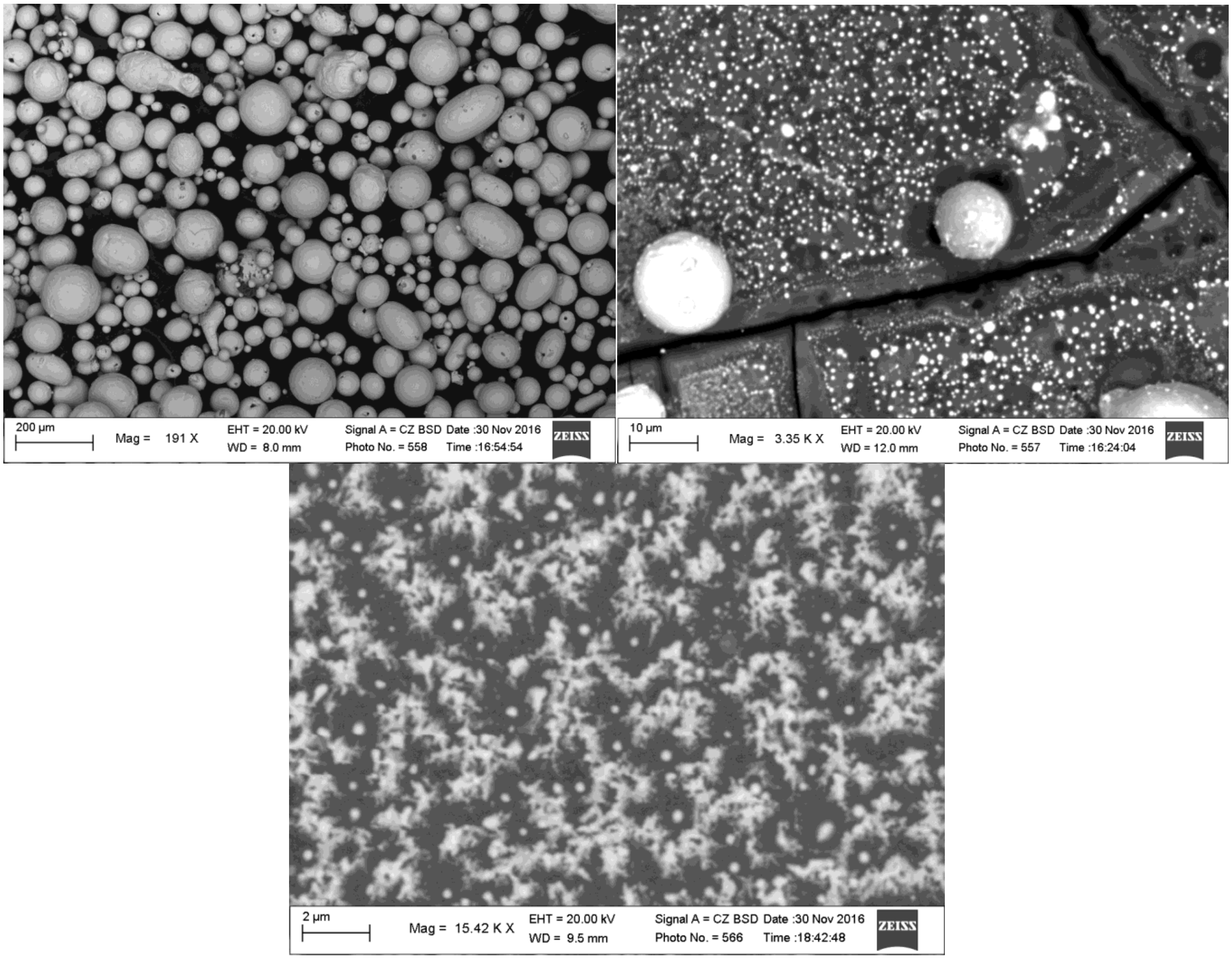


Fig. 1 Scanning electron micrographs of deposits eroded from FF-1 tungsten electrodes. Upper left loose debris from bottom window—scale 200 microns (8 thousandths of an inch). Upper right: deposits on bottom window—scale 10 microns. Lower center: deposits from upper trigger window near insulator—scale 2 microns. Much smaller scale of particles from upper region indicates a different erosion process than in the lower region.

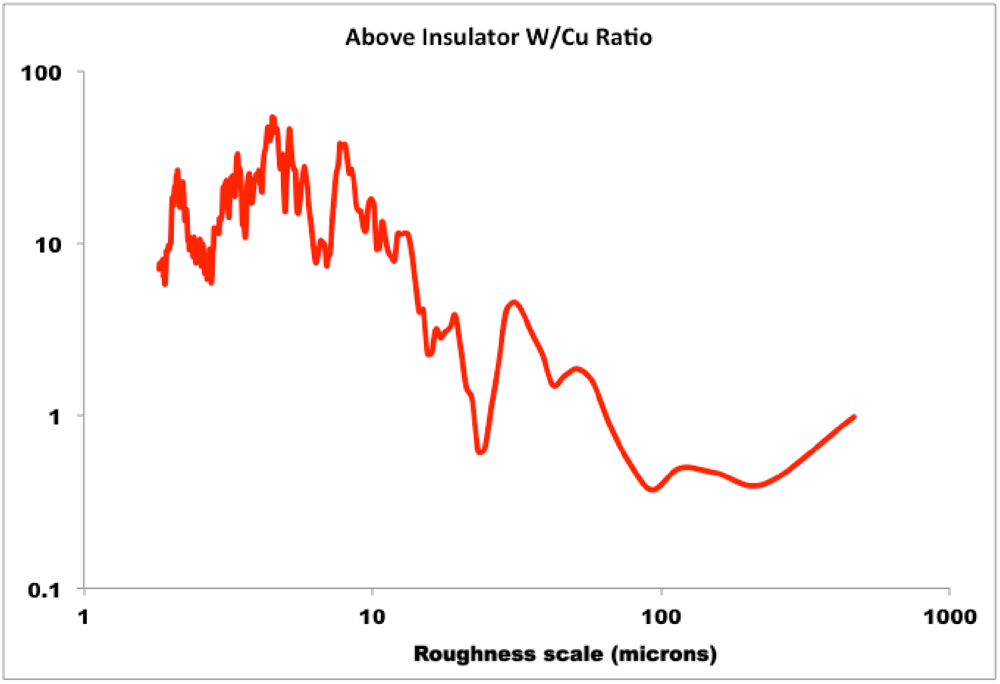
The new data confirmed that most of the deposits coming from the upper erosion region, near the insulator, were indeed tungsten oxide, as Lerner had hypothesized. This is good news, as the oxygen needed to make tungsten oxide can be excluded in the next experiment. Tungsten itself is much harder to melt and vaporize than tungsten oxide. Interestingly, most of the dust deposited on the bottom window was also tungsten oxide, with the rest tungsten metal. This dust came from the lower erosion region, within the hole at the end of the anode, and consisted of dust particles 10-20 microns in diameter (see fig. 1). This indicated that the tungsten oxide layer on the surface of the anode must have been around 10 microns or more in thickness to form similarly-sized droplets.

Even the much larger loose debris from the lower erosion region, blobs of metal 100 microns across, were still about 28% oxides, again evidence of a 10- or 20-micron-deep oxide layer, at least in this region.

The depth of the deposits is important in understanding why the oxides were not cleaned off the anode during the hundred-odd shots of the last experiment. The new measurements indicate that about 60 mg of oxygen was in the oxides near the anode tip. This is the majority of the total oxygen that we estimated was accidentally in the chamber at the start of the experiment. If this depth of oxide was also present in the upper erosion region, then it would be able to provide enough oxides, and thus explain all the impurities, in the shots in that experiment. There was a deep reservoir of oxide available for hundreds of shots.

Why was the oxygen concentrated in just the regions that were being eroded? It was no coincidence. After the initial shot of the experiment, these erosion regions were the hottest, and the rate of oxidation of tungsten in the presence of steam is sharply dependent on temperature. (Steam formed after the shot from the reaction of oxygen with the deuterium fill gas.) The hot upper and lower erosion regions had oxidation rates hundreds of thousands times higher than the rest of the electrode or vacuum chamber walls, which were much cooler. So in a few tenths of a second, nearly all the oxygen was converted into tungsten oxide in these regions. This confirms Lerner’s concern that oxygen must be absolutely minimized **before** the first shot is taken.

Other observations allowed the team to compare the erosion of the tungsten anodes with the erosion of the previous silver-coated copper anode. Using a simple technique first published 20 years ago, Lerner recorded the hissing sounds made when running a finger over the roughened surfaces of the eroded regions of both copper and tungsten anodes. The recording was then analyzed using standard audio software that plots the intensity of the sound vs the frequency. Since higher-pitched sounds are made by roughness at a finer scale, the plots can be transformed into graphs of how rough the surfaces are at a given scale.



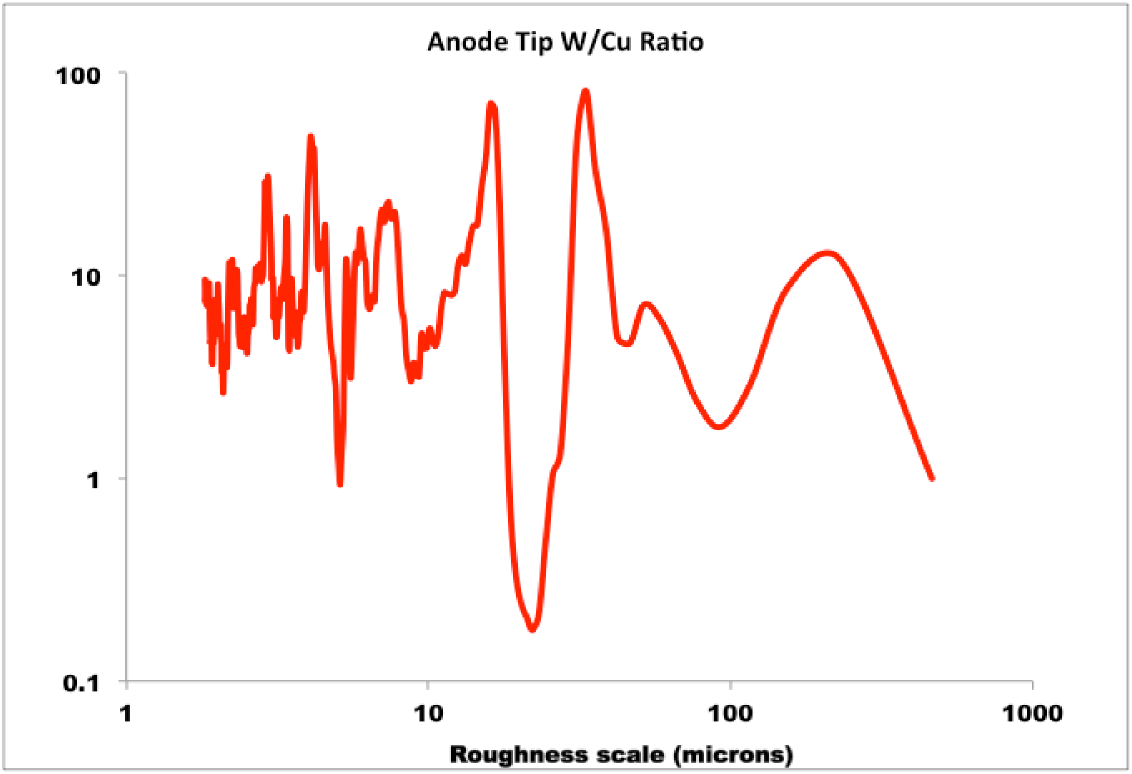


Fig. 2 Audio frequency measurements have been converted into relative measures of roughness, comparing the ratio of roughness at various scales between the tungsten and silver-coated copper anodes. The graphs show the ratio of tungsten/copper roughness for the upper erosion region near the insulator (top graph) and the lower erosion region at the tip of the anode (bottom graph). The top graph shows a considerable reduction of large-scale roughness for the tungsten electrode. The bottom graph shows increased roughness at all scales of the tungsten electrode, especially at around 20 microns. The big dip between the two central peaks is an artifact of the audio technique, produced because the anode has natural resonances at nearby frequencies. This is similar to the way a trombonist excites the natural resonances of the trombone by the vibration of his lips.

The measurements showed that erosion was substantially reduced in the upper region near the insulator, compared to the silver-coated copper, despite the fact that tungsten oxide is far easier to vaporize than silver (see Fig.2). This is again good news and indicated that the energy available in this region is too small to melt pure tungsten, so erosion can be greatly reduced or stopped if the oxygen is eliminated. The pre-ionization that reduced the energy available for erosion thus seems to be working. The much finer-scale erosion from this region is probably due to the low-temperature vaporization of the tungsten oxide, heated by its own resistance to the electric current.

At the same time, the erosion was much **greater**, producing larger-scale roughness, in the lower erosion region at the anode tip, confirming the 10-20-micron-scale erosion observed in the droplet sizes shown in Fig.1. This observation is evidence for the hypothesis that the anode tip erosion is due to recombination radiation from the hot plasma before the pinch. The energy, and thus the penetrating power, of the x-ray photons produced by this radiation is higher for tungsten than for silver. The tungsten-produced radiation penetrates about 6 microns, a reasonable depth for producing erosion pits that are 20 microns wide. The silver-produced radiation penetrates only 2 microns, creating erosion pits that are only about 4 microns wide. While recombination radiation will still be a problem in the next experiment, it will be eliminated as a concern in the following experiments with beryllium electrodes. The large scale of the erosion also rules out an earlier hypothesis that erosion was mainly due to particles from the plasmoid. These penetrate only 0.5 microns, so could not produce the large erosion pits and particles observed.

Calculations Explain Destruction of Filaments

It’s clear that the existence or non-existence of filaments—dense vortices of current and plasma—in the current sheet has a huge impact on the functioning of FF-1, because the filaments are the first stage of compressing the plasma. The disruption of the filaments is a key reason for lower-than-expected fusion yields in past experiments. Yet, while many researchers have studied filamentation, it has been difficult to get a clear understanding of when they form and how they are destroyed. New calculations by Lerner have used the concept of minimum dissipation of energy to figure out this problem. In general, processes will minimize the amount of energy they dissipate or turn into heat—Mother Nature is not lazy, but she is efficient. If hydrodynamic friction dominates this energy dissipation, the Rayleigh-Taylor instability will conserve or produce filaments because filaments dissipate less energy moving through the background gas than does a solid sheet. But if electrical resistance dissipates more energy, then the electric current tends to spread out to minimize this resistance. This spreading can disrupt filaments, or prevent their generation.

Impurities, such as tungsten, can greatly increase electrical resistance, because when such heavy ions lose several electrons, their greater charge makes collisions with electrons in the current much more likely. The new calculations show that filaments with large radii tend to be more stable than those with small ones. But with tungsten impurities of even 4% by mass, filaments would have to be so large they would merge with their neighbors, and so be disrupted. Since in the last experiment, we had about 20% tungsten impurities by mass, that indicates that we can avoid disruption of the filament only if we can reduce the impurities by ten-fold or so. This gives us a good quantitative goal to aim for in the elimination of oxygen. To achieve this level of impurity, initial oxygen in the chamber has to be less than about 10 micrograms, an achievable level.

Lerner also made more detailed calculation of the damage that can be expected from the recombination radiation for both filaments and a non-filamented current sheet. Further research showed that the most damaging form of radiation is “dielectronic recombination radiation,” which occurs when a free electron recombines with an ion, and the energy is absorbed by a second, bound electron, which jumps to a higher energy level. The second electron then radiates the energy when it jumps back down to lower energy. The calculation showed that with even small tungsten impurities, some 30 MW/cm^2 of radiation will hit the end of the anode, enough to melt tungsten and cause heavy erosion. So Lerner does not expect this source of erosion to improve greatly in the next experiment. However, these impurities will enter the plasma too late to affect the fusion yield. In addition, once the experiments switch to beryllium as the electrode material, recombination radiation will be practically eliminated. The beryllium ions, with only 4 electrons, will be completely stripped. In this case, the calculation indicates a 40-fold decrease in radiation, falling below that needed to melt beryllium.

Meetings Help Spread Word on Focus Fusion

Starting October 5, LPPFusion and the Focus Fusion Society have been organizing educational meetings on the “New Fusion Race.” The aim of the meetings is to give an objective picture of where the race to practical fusion power stands and where our Focus Fusion efforts are within that race. In a nutshell, as previously reported on our website and in these monthly reports, FF-1 results are right now far ahead of those of any other privately-funded fusion effort and are nipping at the heels of the giant government-backed projects that have spent thousands of times more money.

The first such meeting, on Oct. 5, was attended by about 30 people in New York City, and the second, on Nov. 11 was in Framingham, Mass. Chief Information Officer Ivy Karamitsos is now editing the Oct.5 presentation by Lerner into an interactive video with greatly improved graphics and explanations. We hope that this video will be available in December and can be used to set up more meetings around the world. We also expect to provide subtitled versions of at least some sections of the video in Spanish, Chinese and possibly other languages. We expect that out of the meetings will come organized Focus Fusion groups that can spread the word about our project to broader layers.

Focus Fusion Song and Poetry Contest

In another effort to get the word out more broadly, LPPFusion is announcing the first **Focus Fusion Song and Poetry** contest. We're inviting all of you to submit songs, raps, or poems that are relevant to our efforts to get cheap, clean, safe and unlimited energy. You can submit them as videos, audio files, or just text. The ones we like (or our panel of judges likes) will get posted on our website and, hopefully, will go viral. To get the ball rolling, Chief Scientist Lerner has submitted Fusion Rap #1. If you like it, make a video of it. If you think it's awfully silly or just simply awful, send us something much better. And remember, Fusion Can Be Funny! Send submissions, with the subject "contest", to fusionfan@lppfusion.com. The deadline is Jan.15, 2017.

Fusion Rap #1

I was working on my calculation
I found the key to the whole situation
It was a new revelation
Dielectronic **re**combination **ra**diation
Dielectronic **re**combination **ra**diation
I saw a path to its elimination
That's the key to the whole situation
That's the path to our salvation
It's an end to our frustration
And to all our tribulation
Dielectronic **re**combination **ra**diation
Dielectronic **re**combination **ra**diation
You got to say it in syncopation
If you want an explanation
You got to use your concentration
Dielectronic **re**combination **ra**diation
The electron ends its separation
Makes the ion to get excitation
That's when you get **bad** radiation
Dielectronic **re**combination **ra**diation
But we can use purification
That leads to its elimination
I can see it in all my equations
We have the documentation
I will say it across the nation
It's the path to fusion creation
Dielectronic **re**combination **ra**diation
Dielectronic **re**combination **ra**diation
Elimination!