Lawrenceville Plasma Physics, Inc

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

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Summary:

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Tungsten passes erosion, first thermal shock tests

New laboratory tests on the existing tungsten plate in FF-1's cathode (outer electrode) have increased LPP researchers' confidence that the planned all-tungsten electrodes will both cure the impurity problem and survive many shots. In the first test, the LPP team measured how much erosion had occurred on the tips of the tungsten teeth where the current starts to flow. These tips suffer from the highest erosion of any parts of the cathode, because of the high concentration of current to which they are exposed. The team compared enlargements of photographs of the tip of the teeth taken when the plate was first installed in November, 2012, with photographs taken this month, after some 340 shots had been fired.

As seen in Figure 1, the tip started out with a 400-micron radius curve. After the 340 shots, the curve remained the same, within the estimated 15-micron accuracy of our measurements. Since any erosion would have flattened the curve, the same way wear blunts a knife-edge, the erosion

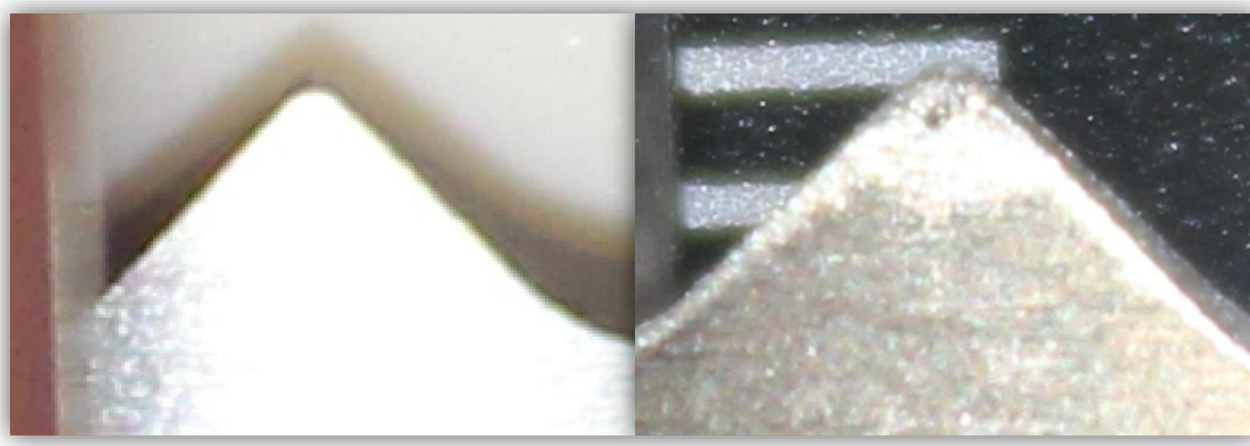

Figure 1: At left, a tungsten tooth in November, 2012; at right, a tooth in October 2013

is estimated at 15 microns or less. Photos of several different teeth failed to show any measurable erosion. If erosion from the anode is approximately as great, an upper limit on total impurity from the tungsten amounts to only about one tungsten ion for every 8,000 deuterium ions, well within the limits that LPP has calculated will be acceptable and have no significant effect on the plasma's properties. By contrast, the present silver-plated copper electrodes erode so rapidly that there is about one impurity ion for every 50-70 deuterium ions. So the tungsten electrode is expected to lead to a 100-fold drop in impurity levels.

A second test was to see if the tungsten plate suffered small-scale microcracks due to the thermal shock of being heated suddenly by the plasma. To increase the total energy that the tungsten was exposed to, the LPP team attached four more capacitors to the FF-1 circuit, bringing it back up to the maximum of 12 capacitors. We fired four shots at 35 kV and then disassembled the electrodes. We observed no microcracking. Others' research with tungsten has shown that microcracking either starts in the first few shots, or is postponed for several hundred shots. So this test is also encouraging. However, we will soon do another round of tests at 40 kV, close to the 45 kV maximum power of FF-1.

We have now received a bid on the manufacture of our tungsten electrodes, so we expect to have them in hand by February, 2014, assuming adequate finances.

Pinch timing measures impurities and sparks international project

Recent research at LPP has shown the great importance of eliminating impurities in the plasma in order to obtain higher densities and fusion yields. These impurities, created by vaporization of the electrode materials, add enough mass to the sheath of plasma that carries the current that it slows its travel down the electrodes and delays the time of the pinch. This pinch is where the current merges together to form the plasmoid. Recent calculations by LPP Chief Scientist Eric Lerner showed that this delay in pinch time, which is very easy to measure, could provide a simple estimate of the amount of impurities. Simply put, the more impurities present, the longer the time to the pinch for a given current and fill-gas pressure.

A computer simulation of the run-down time using the model of Dr. Sing Lee, one of the pioneers of plasma focus research, is a good way to predict what the time to the pinch will be for a given mass of plasma. By adjusting the "fill pressure" in the model so that the predicted run-down time matches the observed time, we can determine the total mass in the plasma. If we then subtract the actual fill pressure of deuterium from the pressure in the model, we get a measure of the mass of impurities.

For FF-1, this exercise indicates impurity mass that is 50-70% of the mass of the deuterium, comparable with estimates made from spectroscopy and other methods. Significantly, the difference between predicted and observed time-to-pinch started to occur back in March 2010, when the first evidence of the "early beam" phenomenon showed up. This early beam was later identified as the signal that part of the current was not merging into the plasmoid, greatly reducing density and fusion yield. In fact the "short pulses", which we now understand were those without large impurities, had ten times the fusion yields of the "long pulses" which did have impurities.

What caused the impurities to suddenly turn up? At that time, improvements in switch functioning were increasing FF-1's current. When current density (current per unit area) passed a critical threshold, around 2 MA/cm^2, electrode evaporation started to occur, releasing the impurities.

These measurements are so easy to do and to analyze that they can be done on any plasma focus device. Last month, Lerner circulated the proposal that other groups duplicate these measurements to the members of the International Center for Dense Magnetized Plasmas, an international group of plasma focus researchers. Initial reaction was very favorable, and new results should be emerging in the coming months. It will be very interesting to see if there is the same critical current density separating the machines with impurities from those without and if there is the same large difference in fusion yield.

Laser experiment gives new visibility to pB11 fusion

While FF-1 is still some steps away from switching to pB11 fuel, other approaches are proving the reality of hydrogen-boron fusion, which produces no neutrons in the main reaction and no radioactive waste. In a report published in *Nature Communications* and summarized in an October news item, a French and American team of researchers announced that they had succeed in increasing the fusion yield in a laser-driven pB11 experiment about 100,000-fold from earlier experiments in 2009. While the yield of about 0.3 millijoules was small compared with the 400 J of laser energy delivered and even smaller compared with the energy needed to drive the lasers, it was a step towards demonstrating the potential for pB11 fusion energy, and the publication in *Nature Communications* gave some needed visibility to aneutronic fuels.

In the experiment at the École Polytechnique in France, a laser pulse of a few nanoseconds first created a plasma from a solid chunk of boron. Then a much shorter and more intense laser pulse of just a picosecond hit a thin foil sandwich of plastic, aluminum and gold. The interaction of the short laser pulse with the sandwich generated a huge electric field that accelerated a beam of protons from the hydrogen in the plastic toward the boron plasma. When the protons and the boron-11 nuclei (80% of the nuclei in the boron target) collided, fusion reactions occurred. Instruments then observed the alpha particles (helium nuclei) produced by the reactions.

The density of the plasma in these experiments, at 10^{22} ions/cm^3, was higher than plasma densities yet achieved in FF-1 using deuterium, but the duration of the reactions of one trillionth of a second (10^{-12} s) was much shorter than the lifetime of FF-1 plasmoids, some 10 ns (10^{-8} s) or so. The 100,000-fold leap in fusion yield, however, is not atypical of the jumps in output that can occur in fusion research.

Italian physicist analyses Focus Fusion, sees promise

In a third independent analysis of the prospects for pB11 fusion with the plasma focus device, University of Genoa researcher Andrea Di Vita reports in the European Journal of Physics that ignition of the fuel should be possible, if there is substantial reflection of x-ray energy back into the plasmoid. Earlier, separate analyses by LPP researchers and Iranian researchers in the Journal of Fusion Energy had concluded that ignition and net energy production would be possible even with no reflection of x-rays. Also, in agreement with LPP work, Di Vita concluded that the injection of angular momentum into the plasma (for example by an externally-applied axial magnetic field, as in FF-1) should aid in achieving ignition.

Di Vita's report makes clear the reason for the somewhat differing conclusions, although all three analyses agree that pB11 with a plasma focus (what LPP has termed "Focus Fusion") is a promising line of approach to fusion energy. As Di Vita emphasizes, his analysis is based on certain "empirical scaling laws" that he has derived from the literature. As Di Vita writes, "Admittedly, the relevan[ce] of available scaling laws to our problem is questionable, to say the least. First of all, they are just rule-of thumb descriptions..." These rules-of-thumb scaling laws differ significantly from the theoretically-derived scaling laws used by LPP, laws which have been significantly confirmed by experiment. For example, Di Vita's scaling laws do not predict the observed I^5 scaling of fusion yield, where I is peak current, while the LPP scaling laws do. Similarly, Di Vita's calculations predict a constant current in the plasmoid or hot spots of about 0.4 MA, while the LPP believes its calculations and theory more accurately predict increasing plasmoid current with increasing peak current.

Following a friendly exchange on different models with LPP's Lerner, Di Vita offered to predict the results of FF-1's upcoming experiments with tungsten electrodes. Stay tuned for the exciting outcome!

Motherboard features LPP's role in fusion race

LPP's Focus Fusion research has been featured in an article by Sam Roudman for Motherboard, which declares that "The Nuclear Fusion Arms Race is Underway." Time's Newsfeed noted the story as some of the day's most fascinating news. The article also featured input from NextBigFuture's Brian Wang, who has been consistently covering Focus Fusion and other innovative fusion approaches for many years:

> *Despite scant funds, the potential economics of LPP reactors make them more appealing than other approaches.*
>
> *"If you have another clean way to produce [energy] at 2 to 10 cents per kW-hr, the world does not change," says Brian Wang. In that range, the fusion energy would be cost competitive with other renewables, as [well] as fossil fuels. But it would not be cheap enough to prevent investment in new capacity for dirty energy. New coal plants and oil refineries would continue to be built. "Only [with] LPP, if they can get it down to .1 cent per kW-hr does the world change."*

Check out the Media section of the LPP website for other news coverage of Focus Fusion.