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Lawrenceville Plasma Physics, Inc

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

LPPF Focus Fusion Report
September 11, 2017

Summary:

- **Beryllium Cathode Arrives**
- **Student Intern Helps Measure the Beams**
- **Microwave Power is Up**

Beryllium Cathode Arrives

The long-awaited beryllium cathode arrived at LPPFusion's Middlesex lab on August 18. Since the beryllium anodes have been in hand for some months, this completes the delivery of the electrodes that are needed for the next crucial step in the Focus Fusion experimental program. This will be the first time beryllium electrodes are used in a dense plasma focus device.

Beryllium, a very light metal, has long been planned for the next set of electrodes and has strong advantages over other materials. "We expect that beryllium electrodes will solve the impurity problem that has been limiting fusion energy yields for years," says LPPF Chief Scientist Eric J. Lerner. The key reason is that the effect of impurity ions on the plasma is proportional to the square of the ion's electric charge. Since beryllium has only 4 electric charges (four protons in the nucleus) each beryllium ion has an effect of 16. That is 300 times less than one tungsten ion (used in the current FF-1 electrodes) and 50 times less than one copper ion (used in the earlier electrodes).

This great reduction in impact on the plasma is expected to greatly lift fusion yield. In addition, the plasma will radiate far less energy, reducing x-ray damage to the anode tip. Finally, beryllium is nearly transparent to most x-rays, further reducing the damage to the anode. This will allow anodes in a future fusion generator to withstand hundreds of millions of fusion pulses before needing replacement.

Beryllium, however, does have two drawbacks that have prevented their use in plasma focus devices thus far. For one thing, beryllium is expensive. The electrode set cost LPPFusion over $120,000. This expenditure was only made possible by the money raised in LPPF's 2014 Indiegogo crowdfunding campaign. Second, although beryllium in bulk metal form is harmless, beryllium dust that is fine enough to be breathed is toxic. In susceptible people, tiny amounts of dust set off auto-immune responses that generate serious disease.

Figure 1. The new beryllium cathode (25 cm or 10 inches in diameter) sits at LPPFusion's lab in its sealed bag. The protection is needed because exposure to atmospheric humidity for too long can damage the part's surface.

To ensure the safety of our researchers, LPPFusion will be buying the needed safety equipment, including a glove box that allows objects to be manipulated in a sealed environment. We've also designed modifications to the vacuum system of FF-1 so that any dust created during shots will be trapped in a safe manner and not exhausted to the environment.

Once the present series of experiments with the tungsten electrodes is completed, probably during September, FF-1's vacuum chamber will be disassembled and shipped for a recoating with titanium nitride. This stable material will cover up any tungsten that has been plated onto the chamber. This and other upgrades to FF-1 will take a few months, leading to the start of new experiments with the beryllium electrodes around year-end.

Student Intern Helps to Unravel Ion Beams

The ion beams that FF-1 produces during a shot are an important feature of its operation. In the present experimental phase of our work, the energy of the ion beams give one measurement of the energy transferred into the tiny plasmoid that produces the fusion reactions. The current of the ion beams is also a measure of how many particles are confined in the plasmoid. In the longer term, the ion beam will be one of two ways to derive energy from a Focus Fusion generator, with direct conversion of the beam energy into electricity in a circuit.

However, there are a number of puzzles we need to solve about our measurements of the ion beams. We measure the energy of the beams by measuring the velocity of the ions—the greater the velocity, the greater the energy. We do this by using two coils, called "Rogowski coils" or RC for short. When the beam passes through a coil, it induces a current in the coil that we can measure—a current proportional to the rate of change in the ion beam current. By measuring the time that the beam passes the upper RC or URC and then the lower RC or LRC we can calculate the velocity.

The puzzle arises because, for some shots, the energy we measure seems too high—more than 5 MeV. Such high-energy deuterons (deuterium nuclei) can undergo reactions with the steel at the end of the drift tube that create short-lived radioactive elements. However, we have observed only a very tiny increase in radiation—far less than we expect if the ions were really 5 MeV energy. (Induced radioactivity would not occur in a fusion generator, since the energy of the ions would be extracted by a different sort of coil before they could hit anything.) In addition, our JavaFusion program for automatically finding and measuring the peaks in the output of the RC and other instruments was missing many of the peaks.

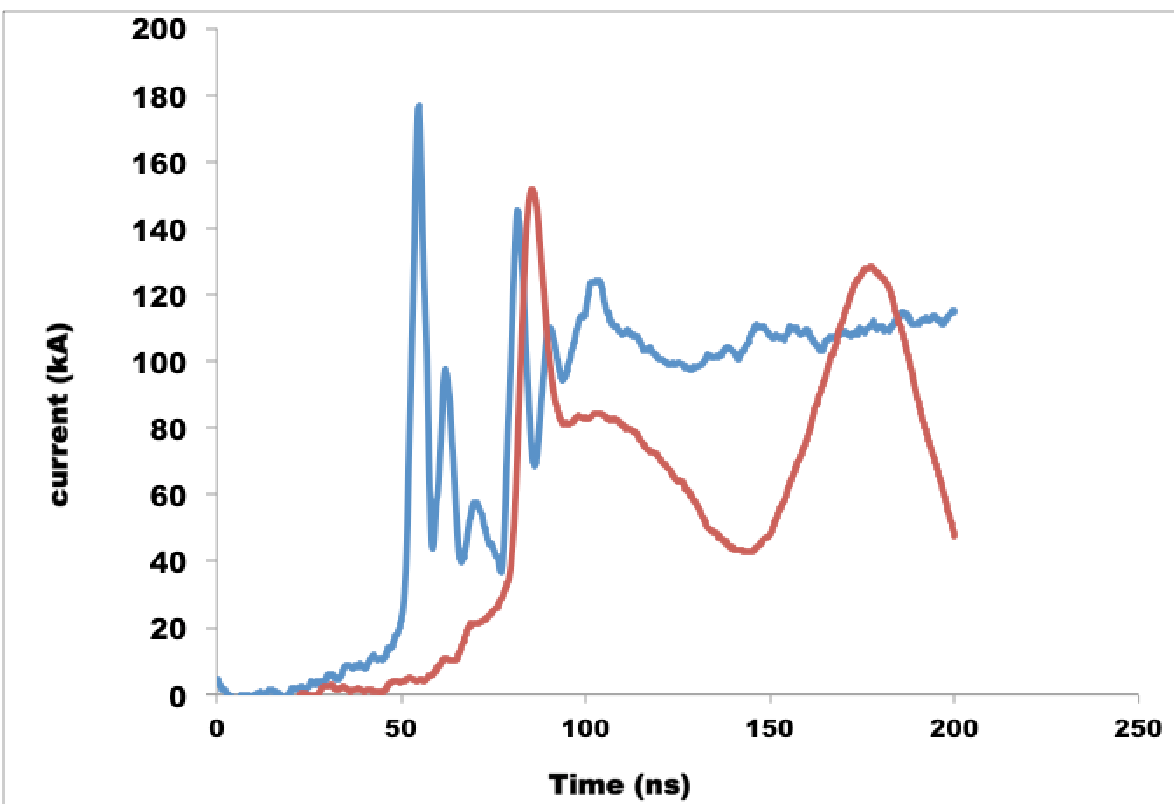

Figure 2. A typical ion beam (from May 12, shot 3) as recoded by the URC (blue line) and the LRC (red line). The LRC current is enlarged by 5 to compensate for the greater distance from the source. The time between the first blue and red peaks indicates a puzzling high energy of 10 Mev, while the longer time between the second blue and red peaks show a more-easily-understood 1 Mev.

So Chief Scientist Eric Lerner worked with Student Intern Justin Cohen (a junior nuclear engineering major at North Carolina State) this summer to start to unravel the puzzles. Cohen looked at the outputs of the RCs for the shots FF-1 fired in May of this year. He measured and analyzed the currents and timings observed, comparing the results that he obtained by hand with those of the JavaFusion program. Based on his analysis, he and Lerner arrived at new criteria for JavaFusion to distinguish the real signals (sharp peaks as in Figure 2), from the electromagnetic noise that the RCs pick up.

LPPF's Electrical Engineer Fred Van Roessel is now working to implement the new criteria in Java Fusion. Once that is done, hundreds of shots from this year and last year can be analyzed automatically and quickly. We expect this new analysis to give us the clues that we need to resolve the puzzle of the high ion beam energies.

Microwave Power is Up, Testing Still Underway

Based on tests conducted in May, the LPPFusion research team decided that more microwave power was needed to clean the oxides off our tungsten electrodes. The oxides, which break up easily when heated, had been contributing impurities to the plasma and limiting fusion yield. We decided to mount two kW microwave magnetrons on a single large window to double the power. The larger window admitted the 12-cm-long waves far more efficiently than a smaller window used with the second magnetron in May. Combining the two magnetrons proved to be fairly difficult, because the two magnetrons, working independently, could cancel out each other's waves.

First Dr. Hassan made a copper, v-shaped combiner to couple the two magnetrons. Then, based on that experience and papers published by other groups, the team designed an aluminum coupler with a "trombone tuner" that could adjust the coupling of the waves between the two magnetrons. That combiner, fabricated at local shops, worked well and nearly doubled total power output. After some experimentation, the team was able to use the combiner to create more intense plasma heating (Fig.3). The heating was shifted into the space between the electrodes, where it was needed for oxide cleaning. Spectra from the glowing plasma confirmed that the temperature of the plasma was much higher, almost certainly above the target of 20,000 K.

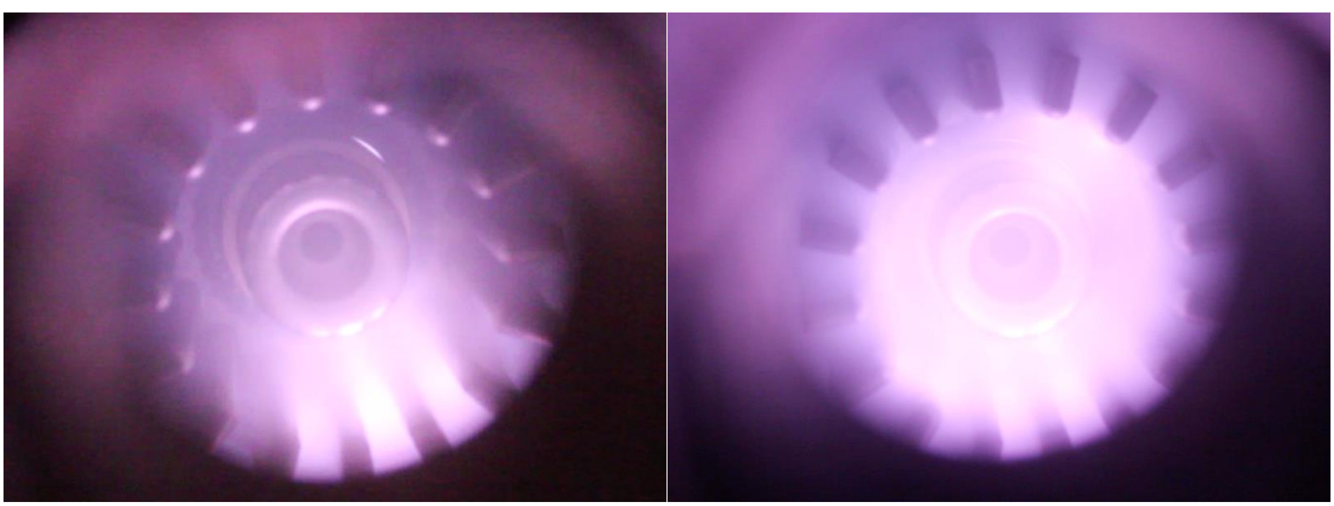

Figure 3. Microwave heating is more intense and centered on the electrodes with two magnetrons on one large window (right) than with two magnetrons on opposite windows (left).

However, so far the most intense plasma heating has proven to be somewhat unstable and hard to replicate exactly. In addition, testing so far has not shown the needed reduction in oxides. The team is continuing testing and intends to wind up these experiments in September, so as to shift focus to the upcoming beryllium experiments. Since beryllium itself will contribute little to harmful impurities, (see Beryllium Cathode Arrives) the oxide problems will not be important with the beryllium electrodes.