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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
June 29, 2016

Summary:

- **LPPF Reports New Record Temperatures To Int'l Conference**
- **Hydrogen-Boron Groups Announce Advances, Plan Closer Collaboration**
- **Z-pinch Device Gets 6 J Fusion with Deuterium**

LPP Fusion Reports Ion Energy Records, Other Progress to International Plasma Symposium

LPP Fusion's President and Chief Scientist Eric Lerner reported on June 21 new record ion energies of over 260 keV (equivalent to a temperature of over 2.8 billion degrees K) to 150 plasma scientists assembled in Prague, Czech Republic for the 27th International Symposium on Plasma Physics and Technology. The new results, obtained with the FF-1 plasma focus experimental device in Middlesex, NJ were a 50% advance over the previous record for a single shot, 170 keV, also achieved at FF-1 in 2011. Equally significantly, the mean ion energy for 10 shots at the same conditions also increased by 50% to 124 keV. Combined with other advances reported at the same conference (see next section) these results mean that FF-1 now has achieved the ion energy needed to ignite hydrogen-boron fuel in an average shot, not just in the best shots.

In addition, Lerner reported that in the same 10 shots, the variability in fusion yield from shot to shot was only about 14%, a factor of four reduction over previous results with FF-1. Researchers were impressed with this result, as the plasma focus device has consistently been hindered by large shot-to shot variability, especially at high peak currents. Mean yields were also 50% higher than in the best 10 shots with copper electrodes.

Lerner emphasized that these new results were possible only with the glow-discharge preionization used in the May-June experiments. This preionization, caused by a tiny, several-microampere current flowing in advance of each shot, smoothes the path for the main current, making breakdowns more symmetric and reducing or eliminating the vaporization of the anode material. "We see evidence of the reduction of vaporization from the reduction in the oscillations of the current," Lerner explained (see Fig. 1). "This indicates that less energy is being drawn from the circuit to vaporize and then to ionize tungsten atoms."

The more symmetric current sheath in turn leads to the elimination of the "early beam" phenomenon, when the current sheath splits in two during the compression of the plasma, robbing energy from the plasmoid (Fig. 2). Just moving to the monolithic tungsten electrode alone considerably reduced the early beam, which LPP Fusion researchers first identified as a problem back in 2010. This is likely due to the elimination of arcing between parts of the electrodes, since there are no such parts in the single-piece tungsten electrodes. But preionization completely eliminated the early beam.

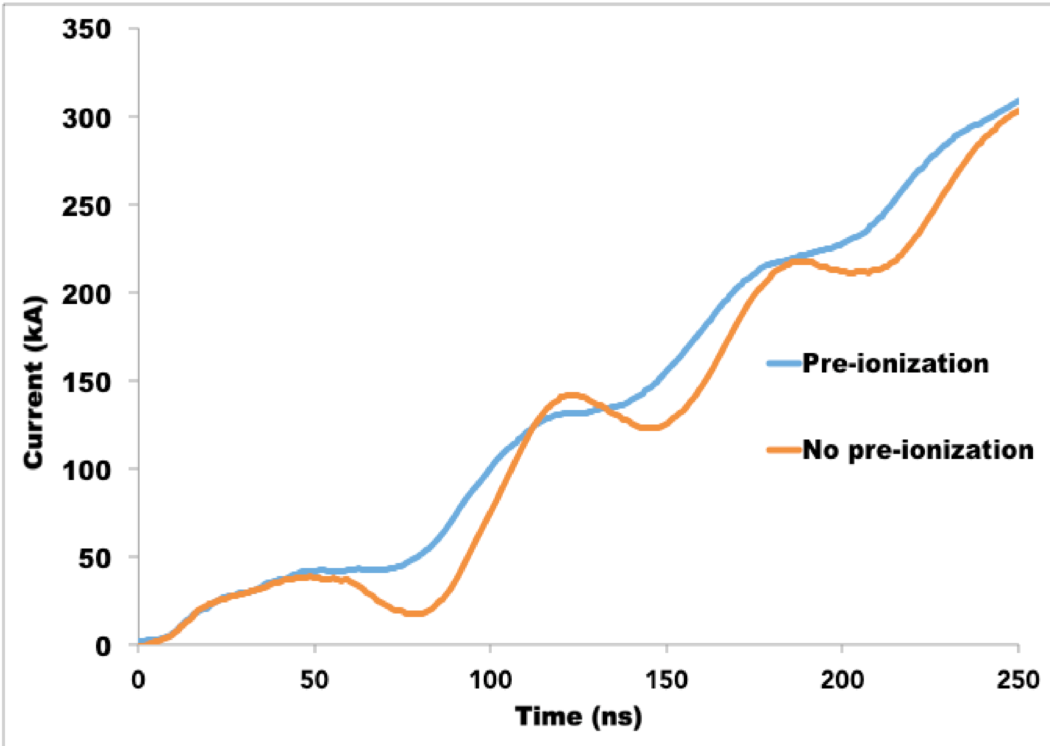

Fig. 1 The dip in current at around 70 ns, showing energy withdrawn to vaporize and ionize anode tungsten, is significantly smaller with pre-ionization (blue) than without (orange), showing a reduction in vaporization of impurities into the plasma.

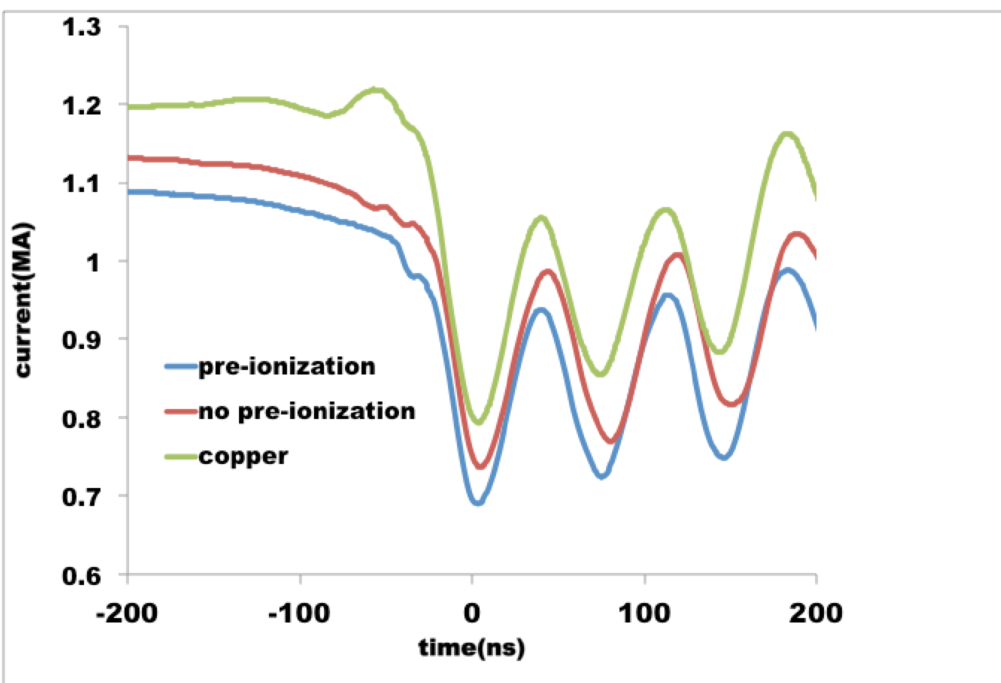

Fig. 2 The early beam (bump in current 60 ns before the pinch) was prominent in shots with copper electrodes (green line) and robbed energy from the plasmoid, but shrank with tungsten electrodes (red) and disappeared with pre-ionization (blue).

This then leads to more energy in the plasmoid, as measured by a higher peak in the voltage at the time of the pinch—the formation of the plasmoid (Fig. 3). Higher plasmoid energy finally results in higher ion energies. As well, reduction of the asymmetries due to vaporization leads to reduced variability in yield.

Lerner pointed out that although a record yield of 0.25 J was possible just with the new monolithic electrodes (as reported in the May LPPFusion report), it took preionization to get the reduced variability and the record ion energy. The preionization success was truly a team effort. Research Physicist Dr. Syed Hassan suggested switching to the more even glow discharge. The team found that stabilizing the glow discharge was not possible using a current coming from a shunt resistor tied to the charging of the main capacitors. Chief Information Officer Ivy Karamitsos had earlier suggested separating the preionization and charging processes. When a separate high voltage power supply was used for the preionization, Electrical Engineer Fred van Roessel devised the circuit needed to protect the power supply from the current spike when the device fires.

Despite the progress reported, Lerner emphasized that much remains to be done. Oxides are still present in the device due to the introduction of water by a leaky valve and, unlike in the first 30 shots, are now declining very slowly, preventing further gains in yield. Impurities overall have only been reduced by about one third compared with last year's experiments, so yield is still far below where it would be theoretically, with no impurities. In addition, there is no evidence yet of increases in the density of the plasmoids, nor of improved fusion performance with the deuterium-nitrogen mix (although 5% nitrogen is needed to stabilize the preionization discharge.)

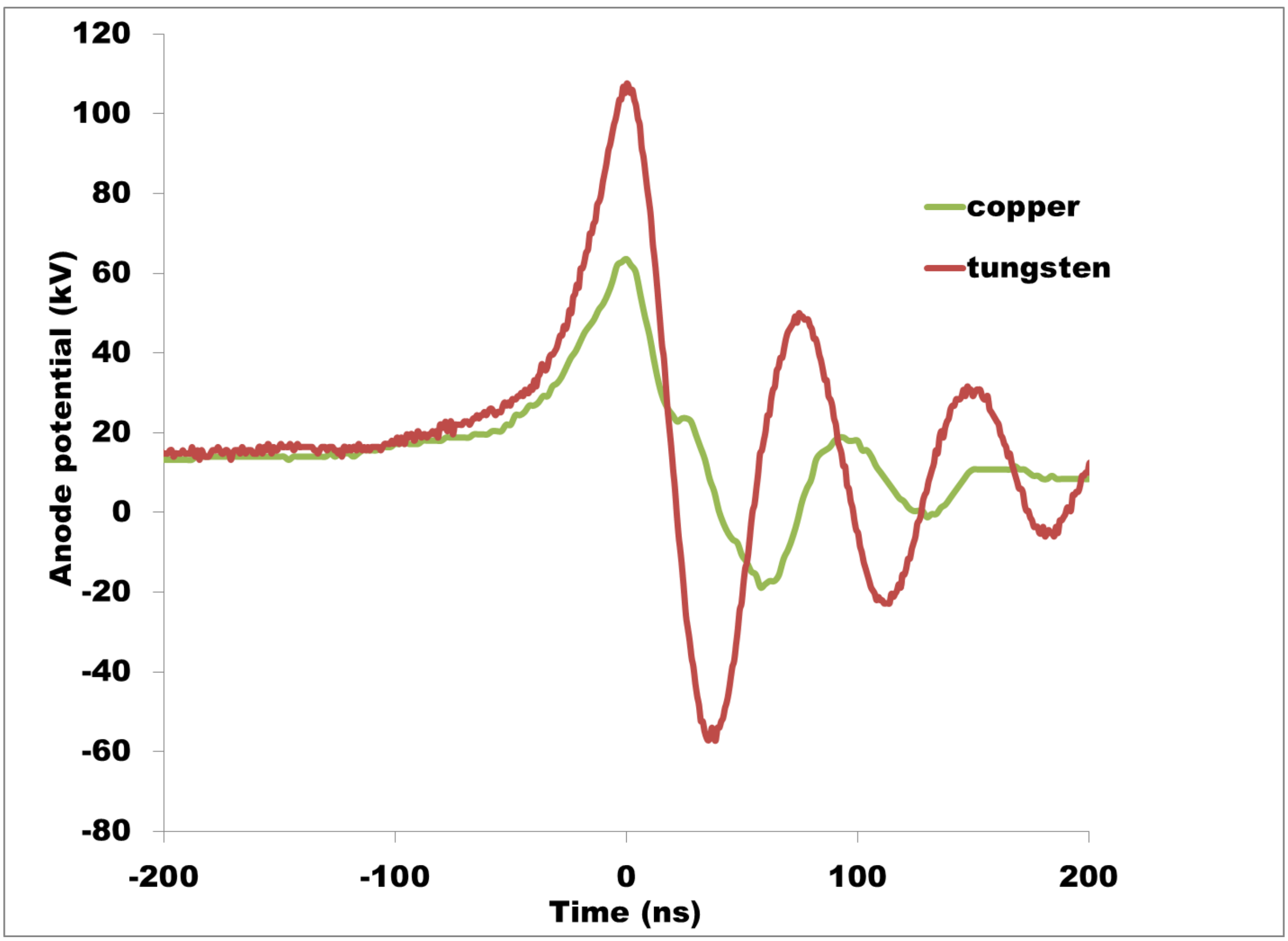

Fig.3 The energy transferred to the plasmoid, measured by the peak in the voltage on the anode is much higher with tungsten electrodes (red) than with copper (green).

The next step is to use an ultrafast ICCD camera to get images of the area near the insulator where erosion has occurred, to see if vaporization has been eliminated or merely reduced, and to see the details of the process. A new reassembly of the device will almost certainly be needed to really eliminate oxides. Silver plating can be used to avoid tungsten's affinity for oxygen (oxygen is bound very weakly to silver). In addition, by September, new beryllium anodes will be delivered. While beryllium lacks tungsten's high melting and boiling points, for a given amount of energy, 15 times less beryllium than tungsten will be evaporated and each microgram of beryllium will have 17 times less effect on the plasma, due to beryllium's far lower atomic charge. So, one way or the other, the impurity problem will be overcome. (Lerner's full presentation is available here.)

"This was an extremely productive conference," commented Lerner, "and I learned a lot from my colleagues. A plasma chemist offered to help interpret our optical spectra. Presentations explained how evaporation of electrodes, a widespread problem, is affected by surface acoustic waves—intense heat making the electrodes bounce—and by very thin plasma sheath layers that can re-accelerate even slow electrons. The problem of defeating erosion is complex—but it can be done. Another researcher explained how, in automotive tungsten arc lamps, lifetimes of 10,000 hours were achieved with current densities of 10 GA/cm^2. That's at least ten times the minimum lifetime and 10 times the current density that focus fusion electrodes will require for a working generator. But it may take the engineering phase of our project to get there."

Hydrogen-Boron Groups Announce Advances, Plan Closer Collaboration

Hydrogen-boron (pB11) fuel has long been the ideal fusion fuel, offering the potential for cheap energy through direct conversion with no radioactive waste, as LPPFusion has often pointed out. But until recently only one or two researchers reported on results at any conference, while most focused on the far more common deuterium-tritium or pure deuterium fuels. The Prague symposium was something of a coming-out party for pB11, with several groups reporting new advances and hydrogen–boron research featured in invited presentations. The researchers present planned closer collaboration, including an international workshop and joint experiments.

Fig. 4. The Prague Asterix Laser System, where researchers obtained a billion reactions from hydrogen-boron fuel. Asterix is a popular cartoon character in France, so the name is a bit like calling something in the US the "Mickey Mouse Laser Facility". However, with a power output of 3 TW (3 trillion watts) PALS is anything but "mickey-mouse."

Dr. Heinrich Hora, University of New South Wales, Australia, one of the invited speakers, tied together several of the advances in his review presentation to the conference. After pointing to the well-known advantages of hydrogen-boron as the route to cheap, clean, safe and unlimited energy, he turned to recent experimental results with hydrogen-boron fusion initiated by lasers. Experiments occurred in Russia in 2005, in France in 2013, and at the host city of Prague in 2015, and each time the number of fusion reactions rose a thousand-fold, now to a billion reactions at the Prague Asterix Laser System (shown in Fig. 4)

The relatively high yield in the most recent experiment, Hora continued, is best explained by a recently published theory that shows, in some circumstances, hydrogen boron reactions can occur as avalanches, with each reaction setting off several more. In these new calculations, the three alpha particles (helium nuclei) produced by a single pB11 reaction undergo a kind of three-cushion pool shot, in which a series of collisions with protons gives the last proton just the right 600 keV energy for a fusion reaction with boron. This effect is most important at relatively low average ion energies, and thus makes hydrogen-boron reactions easier to ignite. (This is the second result in recent months pointing to easier ignition—see May 28 LPP Fusion report.) Another researcher, V. Belayeav, Central Research Institute of Machine Building in Korolev, Russia also reported on encouraging research on hydrogen-boron reaction rates.

LPP Fusion's report at the Symposium of mean ion energy in a series of 10 shots of over 120 keV, combined with these new results, indicates that hydrogen boron ignition is within reach of plasma focus devices, once the highest densities achieved of more than 10^{23} ions/cm^3 can be combined with these high ion energies. At the conference, researchers discussed new collaborations involving additional plasma focus groups, as well as ideas for combining focus fusion and laser approaches. Participants plan to organize a hydrogen-boron fusion workshop back in Prague with the coming year.

GIT-12 Z-Pinch Achieves 6 Joule Fusion Output with Deuterium Fuel

Z-pinch devices are closely related to plasma focus devices in that they also use the currents through the plasma itself, not external magnets, to produce the strong magnetic forces that confine hot plasma. In a z-pinch, however, the current flows between two electrodes in a line, rather than the plasma focus's concentric electrodes. At the Prague conference, Russian and Eastern European physicists announced new experiments with the powerful GIT-12 z-pinch. They used a configuration in which the plasma was arranged in two concentric rings, puffed into the gap between the electrodes right before the discharge. Nearly 6 J of fusion energy (producing $6x10^{12}$ neutrons) were released with a 3 MA current and 3 MJ of input energy to the device. Since only 500 kJ of energy was released from the capacitor bank prior to the pinch, the ratio of 1.2 J of fusion per 100 kJ of input rivaled or slightly surpassed the best results obtained in either plasma focus devices or tokamaks, both of which are close to 1 J per 100 KJ input.

In addition, compared with similar results with the smaller Angara z-pinch, the researchers claimed scaling of fusion yield with current of $1^{4.5}$, comparable with scaling laws obtained with smaller plasma focus devices, but not yet matched with larger ones. This indicates that there is no unavoidable limit to fast scaling in mega-ampere pinch devices. Indeed, while more analysis is required, these new higher yields may in part be due to the lack of impurities in the pinch plasma, as LPPFusion researchers have hypothesized will occur in the plasma focus.

Images of the pinching plasmas, (fig.2 of this reference) show clear evidence of the formation of plasmoid (bright blob moving upward in the images) showing the z-pinch's close comparability to plasma focus performance. Earlier reports of these experiments, published in 2015, emphasized clear evidence that the deuterons producing the neutrons were trapped, not just passing through.

GIT-12 produces extremely high energy ion beams, up to 20-30 Mev. These impressive beams are not necessarily desirable however, as they also produce high energy neutrons which create radioactive materials in the device walls. No such activation has been observed in FF-1's operation.

In the GIT-12 experiments the electrodes were steel mesh and were destroyed after each shot, so the present configuration is not suitable for high-repetition-rate applications such as fusion. One disadvantage of the z-pinch compared with the similar plasma focus device is that the intense axial current is highly concentrated on the z-pinch electrodes, while it spreads out on the plasma focus electrodes. This makes the design of long-lasting electrodes more difficult for the z-pinch.