LPPFusion Report
August 1, 2019

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LPPFusion Reports Highest Plasma Purity at PLASMA 2019 Conference

At the PLASMA 2019 conference in Opole, Poland July 15-19, LPPFusion Chief Scientist Eric Lerner presented experimental evidence that our fusion device, FF-2B, has met our initial goal of achieving low-impurity plasma. In other presentations at the conference, and in discussions, it emerged that the purity level achieved by FF-2B is well beyond that reached by the large tokamak experiment JET, which like the LPPFusion device, uses beryllium in its structure. In fact, LPPFusion's purity results have **exceeded those of any major fusion experiment's published results**, including those of the large Chinese tokamak EAST and the new European stellarator, W7-X.

Achieving a high degree of purity in the plasma is key to any approach to fusion energy generation. Impurities, particularly those of heavy elements with many protons in their nuclei (high-z impurities) can greatly increase the resistivity of plasma, and the X-ray radiation from the plasma, thus preventing the confinement of the hot plasma needed for high fusion energy yield. Since the effect of impurities depends on their abundance in the plasma and on the square of the atomic charge, z, (the number of protons in the nucleus), the parameter fz^2 is a simple way of measuring the amount of impurities, where f is the fraction of impurity ions in the plasma. Adding up the fz^2 contribution of all impurity elements gives the overall measure of impurity.[1]

By this measure, Lerner reported that FF-2B experimental device has reached an fz^2 of only 0.08, meaning that impurities change the characteristics of the plasma by only 8%. This is **more than five times better** than the best reported measure from JET of an fz^2 of 0.44. The Chinese tokamak EAST had recently reported a much higher fz^2 of around 6, while at the conference the W7-X researchers reported that high impurity levels had limited their machine to only 1.9 keV ion energies (equivalent to a temperature of 20 million degrees K, but a factor of 20 short of the minimum needed to rapidly burn fusion fuel.)

The spectra Lerner presented to the conference (Fig. 1), representative of many taken in the new experiment, showed that only deuterium (the fill gas), beryllium and oxygen are present in the plasma in measurable quantities. The

[1] *Another common way of measuring impurity is with Zeff, which equals* $(1+fz^2)^{1/2}$

amount of beryllium present was calculated by measuring the rate of beryllium deposition on the vacuum chamber windows. By comparing spectra taken through the clean windows with spectra taken after different numbers of shots, the thickness of the deposits could be measured, giving the total beryllium in the plasma at each shot (Fig. 2). Since only 0.35 nm (about three atomic layers) was deposited in each shot, there was only 70 micrograms of beryllium in the plasma, only 2% of the plasma by mass or less than 0.5% by number of ions. Taking into account beryllium's atomic charge of 4, this leads to the calculated fz^2 of 0.08.

SPECTRUM SHOWS LOWEST IMPURITIES

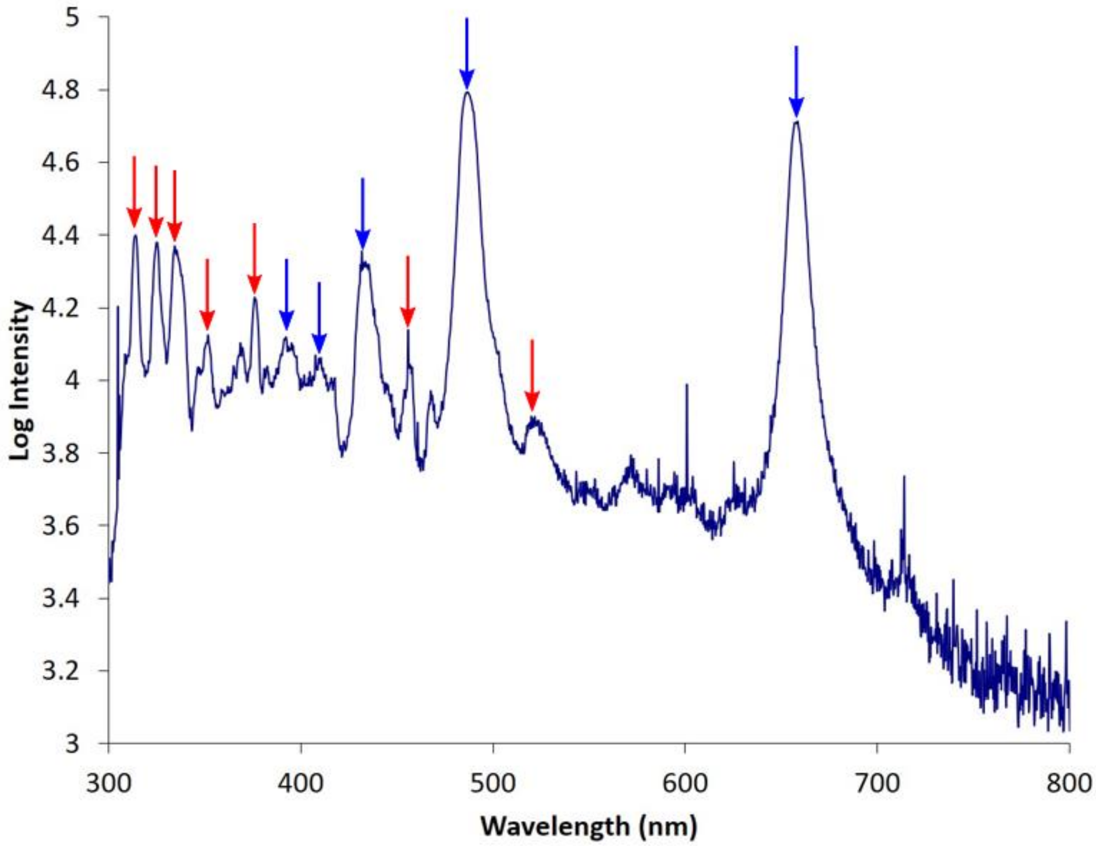

Figure 1. The spectra obtained from FF-2B shots show that only beryllium is the only major impurity in the deuterium plasma. Red arrows indicate the peaks of beryllium and blue arrows the peaks of deuterium. No high-z elements are present.

This is a huge improvement compared to the impurity levels obtained with tungsten electrodes—total erosion has been reduced by a factor of 4 by volume, by a factor of 40 by mass and by a factor of hundreds by fz^2. The absolute purity level in the plasma before the fusion reactions take place is probably even better than the one we calculated, because much of the erosion comes from the tip of the anode after the plasmoid, where the fusion reactions occur, dissipates.

HOW THE IMPURITY DEPOSITS WERE MEASURED

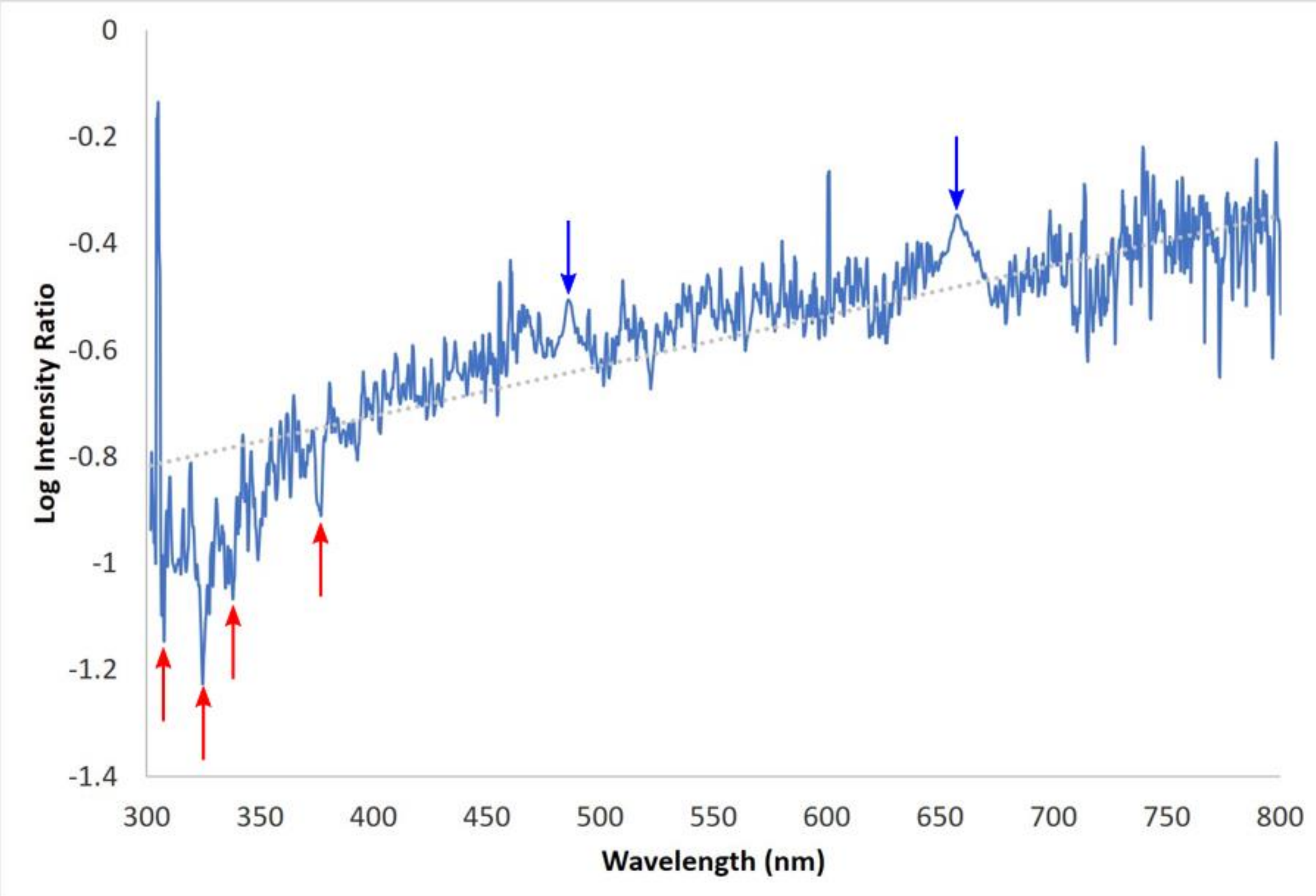

Figure 2. This graph shows the way we measured the thickness of the beryllium deposits on our vacuum chamber windows. We took the spectrum from one shot (in this case shot 9, July 12) and divided the intensity values by those of the spectrum for an earlier shot (shot 4, June 10). Then we took the logarithm of the ratio—what is shown here. The thickness of the layer is proportional, by a known formula, to the slope of the dotted line fitted to the data. By dividing by the number of shots, we can get the thickness deposited per shot—only 0.35 nm. In addition, the comparison shows that the deuterium lines (blue arrows) have gotten stronger and the beryllium lines (red) arrows have gotten weaker, showing that erosion has slowed over the month.

The key point is that LPPFusion's goal of reducing the impurities to insignificance, defined by a less than 10% effect on plasma parameters, has been achieved. **We had set ourselves the goal of demonstrating low impurities in the first 100 shots of the new experiment, and have achieved it in only 75 shots.**

Annual Fusion Conference in Poland Helps LPPFusion Plan Next Steps

Science is a collective effort and at this conference, as others, LPPFusion received valuable information from our colleagues. While many devices are used in fusion energy research, the plasma is the same everywhere, so results with one device can be used in experiments with others. In particular Lerner got vital clues to the next steps in optimizing FF-2B function and curing its early "teething" problems.

The biggest of these problems is an uneven start of the discharge, indicated by big, rapid oscillations in current (Fig. 3). With an uneven start, different parts of the current sheath arrive at the pinch, where the plasmoid forms, at different times. This means that the region that contains all the current never gets very small, preventing high compression, high density and thus high fusion yield. Only if the compression is symmetrical do we expect to see the gains in fusion yield that low impurity will bring.

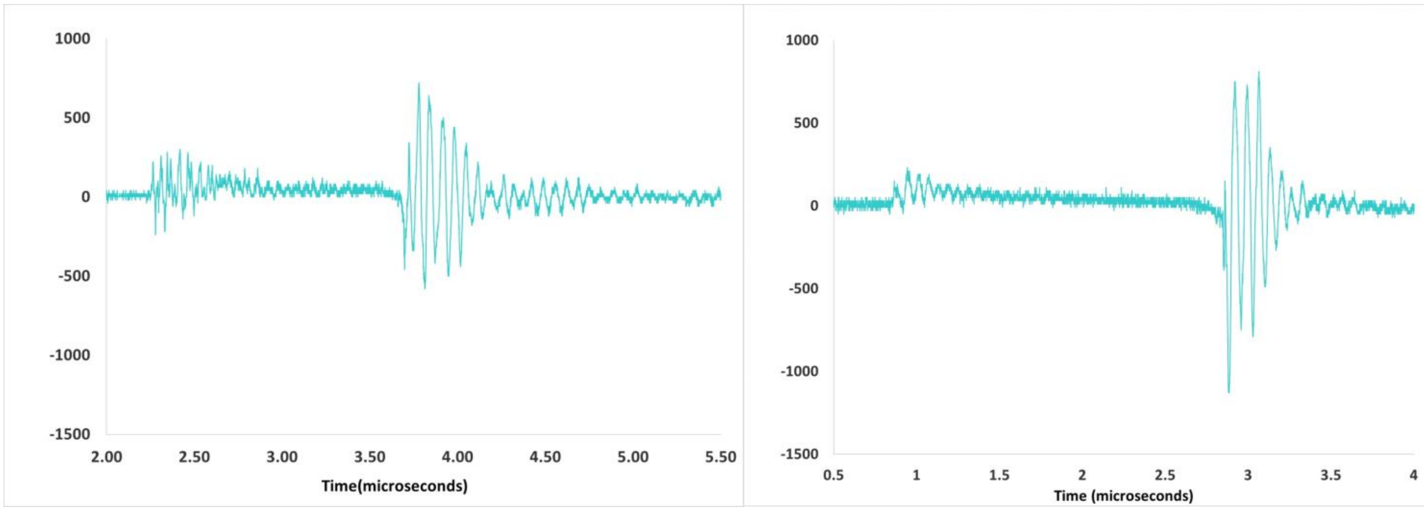

Figure 3. (a) The large, rapid early oscillations (around 2.2-2.6 microseconds) in shot 6, July 8, 2019 with FF-2B indicates an uneven breakdown. The rate of change of the current is recorded here in units of 10 A/ns. Uneven breakdown leads to poor compression, indicated by the slow drop in current at the pinch (at 3.6 microseconds) (b) Using a nitrogen-deuterium mix with preionization in FF-1 led to small, slow oscillations in shot 6, June 7, 2016 with FF-1, leading to a more even breakdown and better compression, indicated by fast drop in current (at 2.9 microseconds).

With FF-1 and its tungsten electrodes, the LPPFusion team was able to minimize the early oscillations and get more even "breakdown" (when the resistance of the neutral gas "breaks down" as it turns into an electrically conducting plasma) by using a combination of nitrogen and a preionization current. The aim of the tiny preionization current that turn on minutes before each shot is to "smooth the path" for the main current by producing small numbers of electrons between each cathode vane and the anode. The idea is to make it so easy for each part of the current to start flowing from each of the 16 vanes that they all start at once. The role of the nitrogen in this process is to stabilize the preionization, as nitrogen is an insulating gas. This allows a higher steady preionization current, making the preionization more effective.

But at high temperatures, nitrogen reacts with beryllium to form the insulating solid beryllium nitride. So initially LPPFusion researchers did not use nitrogen out of concern that an insulating layer would erode quickly, the way the initial beryllium oxide layer did, producing lots of dust and, again, an uneven initial breakdown. Instead, we chose neon as the mixing gas as neon, a "noble gas", does not react chemically at all.

At the conference, Lerner spoke with JET researchers Dr. Ewa Pewlec and Dr. Alice Widdowson, who told him that JET had also experimented with both neon and nitrogen, using them to cool the outer regions of the plasma that touches the beryllium walls. They found much better results with nitrogen and did not observe any detrimental reactions with beryllium. After the conference, literature searches confirmed that nitrogen—which is far less reactive than oxygen—has no known detrimental effects on beryllium and even appears to slow its erosion. Neon, while non-reactive, is not a good substitute for nitrogen, as it does not "attach", or grab onto, electrons, slowing them down and thus stabilizing the current. (Lerner also had a number of good discussions with fellow plasma focus researcher Dr. Marek Sadowski, who works with the large PF-1000U device in Warsaw.)

Based on this new information, LPPFusion intends to use nitrogen to duplicate with beryllium the even breakdown achieved in the FF-1 device. For safety's sake, we will spend a day introducing small amounts of nitrogen and testing its effect during shots. Then we'll move on to the 4-5% mixes that worked well with FF-1. We'll be observing the effects on the initial stages of breakdown with a new set-up of our ICCD camera, which we will say more about in our next report.

PBS—Public Broadcasting System—TV Reports on LPPFusion

On July 15, Public Broadcasting System station NJTV broadcast a report featuring LPPFusion: "*Could a Jersey lab be the key to unlocking the sun's energy on Earth?*". The report by Leah Mishkin covers fusion efforts at ITER, the huge tokamak under construction in France, at Canadian company General Fusion, as well as at LPPFusion. Describing us—accurately—as a "grass-roots project", the report emphasized the small size of our device, contrasting FF-2B's three-ton mass with ITER's 365,000 tons. The report was also carried on the national website of PBS.

This is the first mass media coverage of LPPFusion in a few years, and it is important that it be circulated widely. So, we ask everyone to widely share the links to this report.

NJ Legislature to Fund Fusion? See LPPFusion Presentation at NJ Fusion Symposium

Following the May 23 Fusion Symposium that his office organized in Trenton, NJ, State Senator Joe Pennachio (R-26) is drafting and introducing into the NJ Senate a series of bills to aid fusion research. At the symposium, LPPFusion's Lerner gave a presentation on a Faster Route to Fusion, advocating a crash program that funds all possible approaches to fusion. Specifically, Lerner proposed that the NJ government match dollar-for-dollar the funds raised by private NJ fusion companies. The proposal was based on an idea circulated by the Fusion Industries Association, which LPPFusion is a member of. The video is available on Vimeo.

Now, Sen. Pennachio has introduced three bills to aid fusion research: S-3946, which includes fusion within the definition of Class I renewable energy, like solar and wind energy; S-4045, which establishes a scholarship program for graduate students and postdoctoral researchers in the field of fusion science and SR-146, which urges Congress to increase funding for fusion energy research. Equally important, the Senator's office is drafting a bill to create an incentive program to attract fusion technology business to NJ. We don't know yet if the draft will include the matching funds idea.

This important initiative could greatly aid LPPFusion's efforts. **We ask everyone to please send emails to Sen. Pennachio at SenPennacchio@njleg.org encouraging his work in supporting fusion and urging him to include dollar-for-dollar matching funds as one of the incentives for fusion technology businesses in NJ.** Of course, if you live in NJ, or especially in the 26th Legislative district, mention that. But emails from all over are helpful.

LPPFusion Launches Short-Term Capital Drive to Raise $250,000; Longer-Term, X-Scan Device Ready for Sale for Engineering and Commercialization Phase

We want to replace our existing 12 switches with 24 smaller switches in order to increase the current delivered by FF-2B, and the speed of the pulse—how fast the current rises. We expect both will considerably increase fusion yield beyond the goal we have for the present set-up. But this will cost tens of thousands of dollars.

To address our short term and medium-term financial needs, LPPFusion is announcing a series of steps. First, we are launching a short-term capital drive to raise $250,000 by October 1 through our existing share offer. This offer is, by SEC rules, only open to accredited investors, both in the United States and around the world. If you are an accredited investor (net worth more than $1 million or annual income of $200,000), please contact us at invest@lppfusion.com. We will send you the PPM that describes the offering in detail.

While large investments are absolutely essential, their timing is unpredictable. We also need a reliable source of predictable income. The Wright Brothers needed neither government grants nor investors to finance the research that led to the invention of the airplane, because they had their bicycle shop. Right now, we need YOU to be our bicycle shop. We want to have 2,500 LPPFusion subscribers to pledge $10 a month or more for the next 12 months. You can do this simply through PayPal. If we reach this goal, we will have $300,000 a year secured, half our minimum budget.

Every subscriber will be able to participate in a quarterly phone conversation with LPPFusion officers Eric Lerner and Ivy Karamitsos about everything from our lab results to the future fusion society to our public communications and finances. You will also have the satisfaction of knowing that you are providing the vital resources we need to get fusion energy working everywhere.

At the same time, we are initiating a new campaign to get our spin-off X-Scan technology to market, to provide another steady source of income for our research. The X-Scan technology, already proven in our laboratory and protected by our overall patents, is a method of cheaply scanning infrastructure such as roads and bridges, potentially saving billions in infrastructure repairs. We need an industrial partner who can buy the rights to this technology and work with us to bring it to market. If you have any contacts with companies who would be interested in taking this device to the manufacturing phase please contact us. We will be releasing a new video on this technology shortly.

We know it will still take some time to get X-Scan commercialized. Until then—we need YOU.