*LPPFusion Report*
*May 13, 2020*

**Summary:**

- **Anode Cracks, New Designs on The Way**
- **Beryllium Decreases Electrode Erosion**
- **LPPFusion is Hiring!**
- **Laser PB11 Show Big Advance**
- **Fusion Documentary "Let There Be Light" Airs in France, Germany, Japan**
- **Lerner to Speak on Energy, Finance and Coronavirus—Online May 17**

# Anode Cracks; New Designs on The Way

Just as the LPPFusion research team was about to resume firing in March, we discovered that FF-2B's anode was cracked. We've used the shutdown time, necessitated by both the crack and the coronavirus, to complete the design of our new switches, and to redesign the anode. We're aiming to resume firing with these crucial new upgrades in the fall. This will allow us to keep to our plan of initiating experiments with hydrogen-boron fuel in 2020.

We discovered the cracks on March 23, when we imaged the anode from a protected window at the bottom of the vacuum chamber. It was clear that we would have to replace the anode but we did not want to open the chamber and completely re-assemble the electrodes. Since we would have to be extremely careful to ensure that no beryllium dust escaped to contaminate the experimental room, we had not planned to do any complete disassembly this year. However, the team came up with a plan to remove just the anode from above, while maintaining a reduced pressure in the chamber, guaranteeing that air would be flowing inwards into the chamber and no dust could escape.

The tricky part was to lift the anode vertically so it would not hit the surrounding ceramic insulator and crack that, too. There is only a 1 mm gap between the two parts. But Research Scientist Dr. Syed Hassan worked out a way to lift the anode with lab jacks and a level to guide a supporting rod. During the delicate operation on March 30, which we recorded, one jack collapsed. Fortunately, Dr. Hassan's many lab skills include a quick reaction time, so he seized the supporting rod in time to prevent any damage to the insulator. (Fig.1) With Chief Scientist Eric Lerner assisting, Dr. Hassan successfully removed the anode and substituted an older steel plate with an O-ring as a temporary seal.

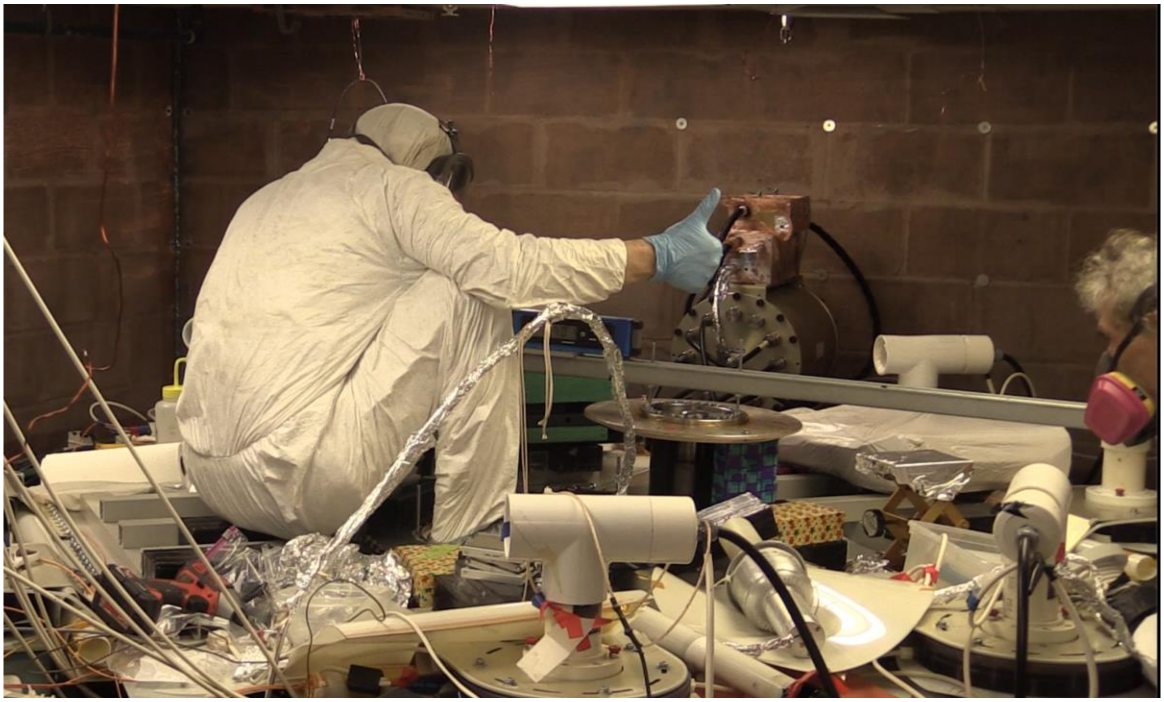


*Fig. 1 LPPFusion Research Scientist Dr. Syed Hassan, fully protected against any release of beryllium dust, signals to Chief Scientist Eric Lerner the successful removal of the cracked anode (dimly visible under steel plate attached to steel beam).*

*Fig. 2 Side view of anode shows one of two cracks extending down the sides. Top view shows two cracks, top and bottom extending out of the damage area on the inner lip of the anode.*

## Finding the Cause

Inspection showed two cracks running the entire length of the anode shaft (Fig.2). Initially, we suspected this might be due to mechanical stresses caused by the attachment of the upper vacuum chamber. But we saw no cracks on the base of the anode, where the upper chamber is attached. In addition, CAD simulations performed by LPPFusion Mechanical Engineer Rudy Fritsch showed that the stresses we had created were small on the base of the anode and negligible on the shaft. But if mechanical stress was not a problem, what could have concentrated stress to create these two cracks? The damage seemed to have originated from 100-micron wide cuts in the inner lip of the anode.

At this point, LPPFusion CIO Ivy Karamitsos pointed out that, since we had been so concerned for a long time about asymmetries in the current sheath, why couldn't these same asymmetries have led to the cracks? This seemed a good idea to look at. Lerner's calculations showed that a plasma filament with 100-micron diameter could vaporize the beryllium if it carried a current of more than 60 kA. A symmetric set of filaments would carry only 20 kA apiece, so would not cause the observed damage. But in a very asymmetric set of filaments, one filament could easily carry three times the average current.

This hypothesis explained how the cracks originated in small areas at the hollow end, or mouth, of the anode, where the current is at its most concentrated, and then propagated mechanically toward the anode base. The mild melting on the rest of the inner anode lip was consistent with what would be expected from an un-filamented sheath. There was also independent evidence for an asymmetric discharge. The deposits of beryllium on our two opposing windows were very different in shape and amount.

But what caused such asymmetric filaments and when did they occur? Since we don't have any images of the anode taken from the bottom window during last fall's firing, we don't know for certain when the cracks occurred. We will in the future have a procedure for taking images after each day's firing. The deposits on the windows did give us a clue. The thickness can be measured from the spectrum, which was taken with nearly every shot. This data implied that erosion increased between the end of October and mid-December, a period with 30 shots.

During this period, there were three likely causes, which probably had to occur in some combination to cause the damage. First there were several prefires, in which one switch alone fired, causing major asymmetries in current. Second, we had deliberately turned off the pre-ionization as a test. Pre-ionization smoothes the initiation of the current, and turning it off could have increased asymmetry. Finally, several of the shots were at low pressure, which also can lead to an uneven breakdown. In a couple of shots on October 29 all three conditions occurred simultaneously.

## Prevention and Beyond—New Switches

Fortunately, we are in a good position to prevent such cracks going forward. We have made major design changes to our new switches that will likely eliminate prefires. We will avoid in future shots turning off the preionization and firing at low pressures. In addition, the new anode we will be getting can be strengthened with design changes and annealing, a process of controlled heating to release strains caused during the machining of a part.

We expect that it will take about three to four months to replace the beryllium anode and we've already contacted potential suppliers. To avoid a major delay in our work, we will simultaneously be getting our new switches made and installed. We are already soliciting bids on their manufacture. The new switches will not only eliminate prefires, they will also allow us to have much less down time for maintenance. Even more important they will increase the amount of current the device produces which will increase fusion yield. When we resume firing in the early fall, we believe we will have a device that can overcome the remaining hurdles to high fusion yield. We'll have more details on our plans in the next report (coming soon).

# Beryllium Decreases Electrode Erosion

While the cracks were bad news, our inspection of the beryllium anode also brought good news. The erosion of the electrode near the insulator has markedly decreased with the beryllium electrode as compared with our previous tungsten electrode. This erosion and roughening, seen clearly in Figure 3a of our last tungsten anode caused an asymmetric formation of the current sheath at the very start of the pulse. This, in turn, was a big contribution to an asymmetric compression, and much less density and fusion yield than our goals. The roughened surface acted like thousands of tiny lightning rods, making breakdown easier and faster in some spots and slower in others.

But after nearly 200 shots, almost exactly as many shots as the tungsten anode underwent, the beryllium anode remains smooth and almost mirror-like near the insulator. A small amount of melting has clearly rippled the surface somewhat, as indicated by the broadening of the light reflection as compared to the untouched metal that was protected by the insulator. But the heavy roughening and erosion so evident with the tungsten has disappeared.

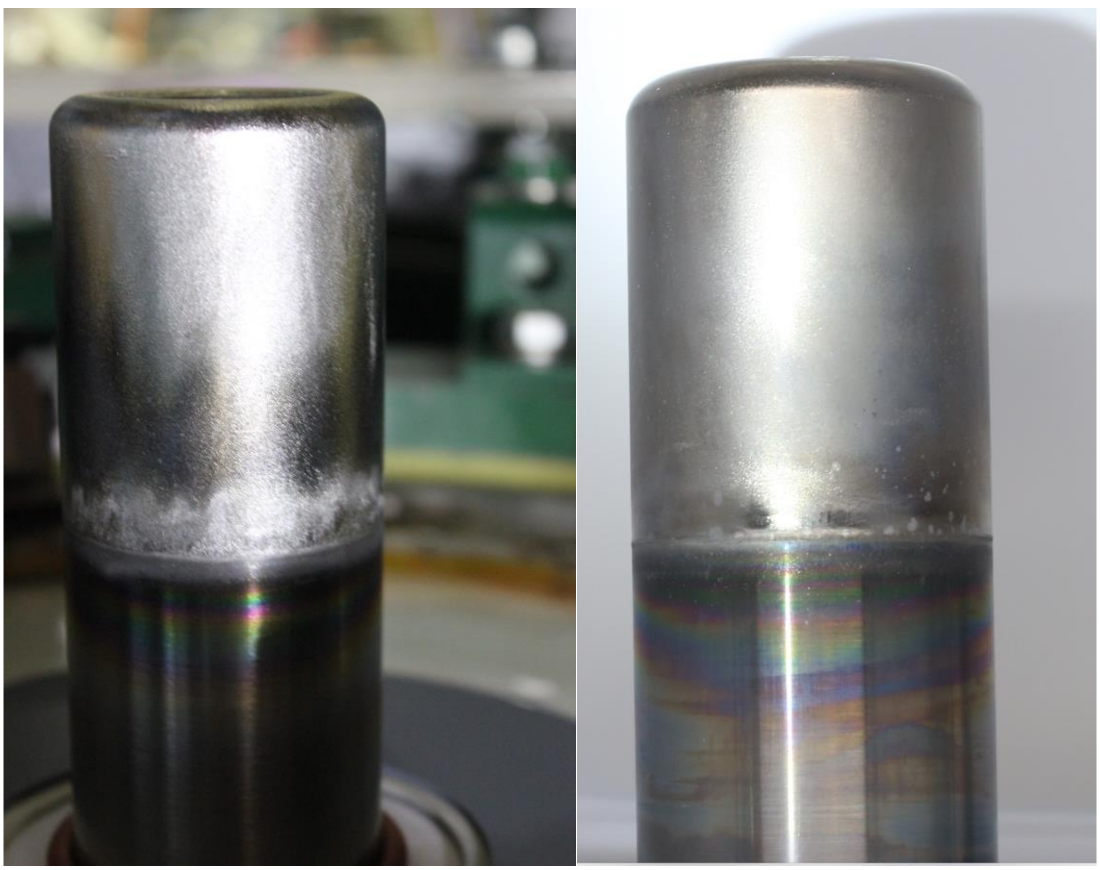


*Figure 3. The tungsten anode (a) shows heavy erosion and roughening near the insulator, while the beryllium anode (b) shows a much smoother surface. The lower half of each anode was covered by the insulator and so was not eroded at all. The rainbow-like colors are created by thin layers of metal deposited on them.*

Why would beryllium, with a boiling point of 2470 ℃, resist erosion better than tungsten, with a boiling point of 5550 ℃? We're sure the answer is that the tungsten anode had a deep layer of tungsten oxide which we were never able to remove. The tungsten oxide was very fragile and easy to vaporize, disintegrating at 500 ℃, but the layer kept re-forming after each shot. In contrast, beryllium forms a very thin oxide layer, which was vaporized with our first shot, back in June of last year. After that, the bare beryllium metal was able to conduct the heat generated in the initial "breakdown" that forms the plasma without vaporizing.

Eliminating the roughness is a big step forward towards our goal of symmetric plasma breakdown and compression. But we can improve further. We suspect that the small light grey patches on the beryllium anode were formed during that first "blow-off "shot which covered the chamber with a layer of beryllium oxide. The patches may still contribute somewhat to an irregular breakdown. In preparing the next anode, we will be working with the manufacturer to see if we can prevent the formation of even a thin layer of oxides, so that the first shot of the new series can't create any asymmetries.

# LPPFusion is Hiring!

For the first time in years, we are expanding our staff by seeking to hire another researcher to accelerate our fusion effort. This will be a full-time permanent position in one of the most exciting fusion energy research efforts in the world. We seek a research electrical engineer who will assist in all aspects of our experiments including carrying out experiments, data analysis, equipment maintenance and repair and the design of new parts. We provide competitive pay, full health insurance, and a stock option plan. Requirements: the type of degree is not important but we need someone with **solid experience** in an experimental lab and with HV equipment. Programming ability with Java is a plus as is experience with SolidWorks. Applicants must be able to start work in NJ by September 1. We very much regret that due to the awful immigration policies in the US we can't consider applications from those who lack US working papers. We are an Equal Opportunity Employer. We encourage qualified women and men of all backgrounds to apply. Please send resumes to fusionfan@lppfusion.com.

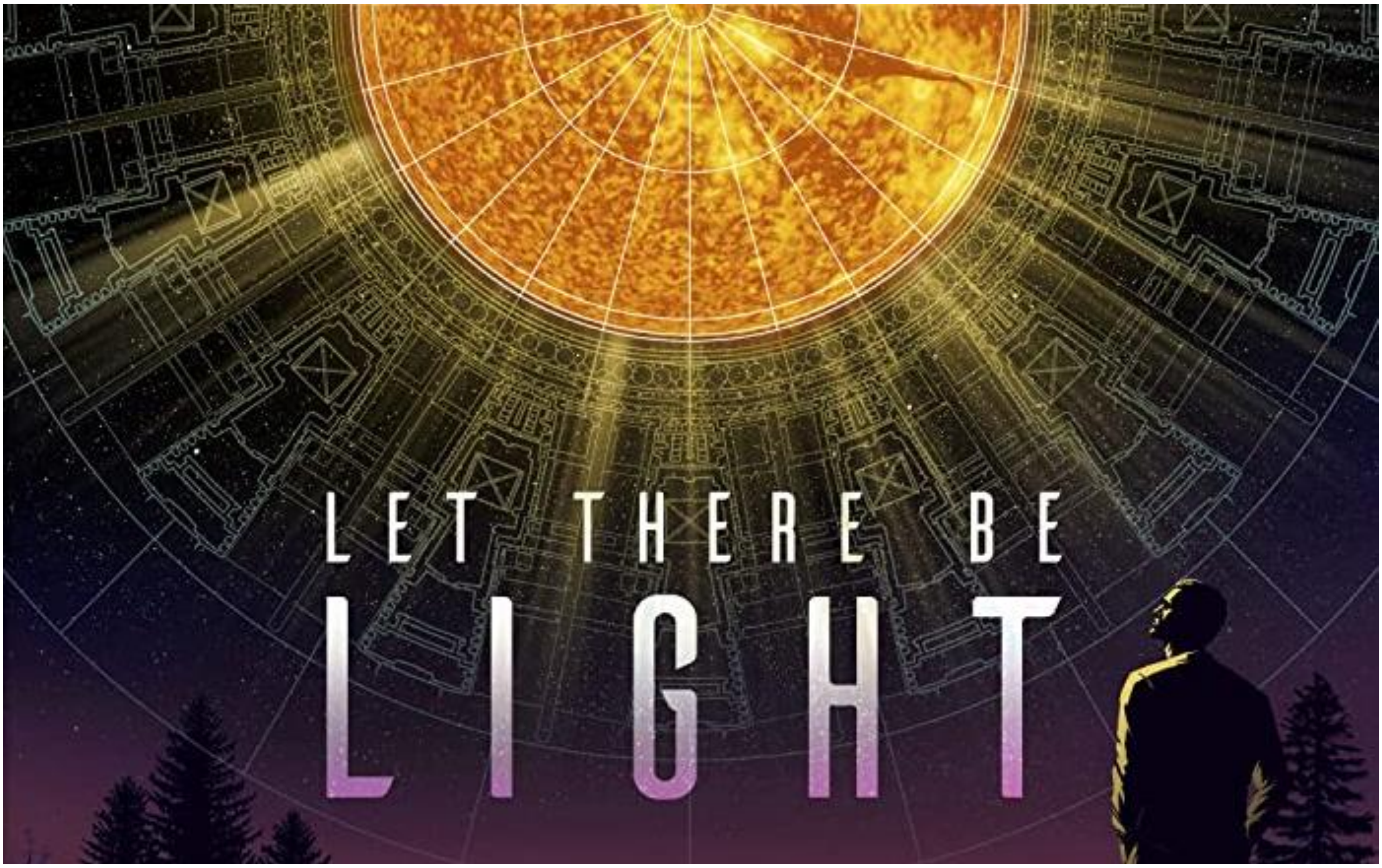
# Laser PB11 Shows Big Advance

An international scientific collaboration using the PALS laser facility in Prague has reported a major advance in hydrogen-boron (pB11) fusion. The report, published in January in Physical Review E, demonstrated a **40-fold increase in fusion yield** over previous experiments at the same facility in 2014. Researchers hit a target of boron nitride with some embedded hydrogen with a 2 TW burst of infrared laser radiation, focused down to an 80-micron spot. The research team explained that they achieved the 40-fold increase in fusion yield simply by making the target thicker. The advance is both a step forward for hydrogen-boron fusion, which has the potential to provide cheap, totally clean energy, and an example of the sort of leaps that can occur in fusion research.

The laser approach to pB11 fusion is being promoted by Australian company HB11 Energy, although that company was not involved in the PALS experiment. The main disadvantage of this approach relative to Focus Fusion using the plasma focus device is the very low efficiency of the laser needed to initiate the fusion. The iodine laser at PALS, for example, needs 1.2 MJ input to produce a 600 J laser pulse. The fusion output from the latest experiment was 0.06 J, so the critical ratio of output energy to input energy is still about 80 times less than that achieved by LPPFusion's FF-1, using a much less reactive fuel, deuterium. To reach net energy, HB11 Energy envisions fusion generators that would be much larger and more costly than will be needed for Focus Fusion.

Despite these drawbacks to the approach, the data obtained in the PALS laser experiments is extremely encouraging to all those, including LPPFusion, working toward pB11-based energy generation.

# Fusion Documentary "Let There Be Light" Airs in France, Germany, Japan




The documentary film "Let There be Light", which features our work at LPPFusion, has recently been broadcast in translated version on French, German and Japanese TV. The French version is also available now here: https://youtu.be/xd5MlhysI_U.

The film, made by EyesteelFilm of Canada in 2017, tells the story of fusion energy research by concentrating on two large government projects, ITER and Wendelstein-7X, and two privately-funded projects, LPPFusion and General Fusion. On just one site, the French version of the film has had over 200,000 views and we estimate that world-wide viewership may be over a million. The new publicity has already sparked some investment interest.

# Lerner to Speak on Energy, Finance and Coronavirus—Online May 17

Eric Lerner will be speaking Sunday, May 17 at an online **Teach-in on the Coronavirus: Causes, Impact and Our Response**. He will be speaking on **"Energy, Finance and the Coronavirus"**. The presentation will explain how fossil fuel use contributed to the pandemic. It will also show how the collapse of oil prices in March motivated a bail-out that is funneling trillions of dollars of public money to billionaires, creating a system of state-financed capitalism. Lerner will lay out some urgent steps to get out of the crisis, including a crash program to develop fusion energy as a total replacement for fossil fuels.

Lerner will be speaking at 2:30 PM. In the first presentation of the teach-in Environmental biologist Rob Wallace will explain how Big Agriculture also prepared the conditions for the pandemic. Avram Rips and Jay Arena will discuss the impact on public education and education workers' response. The event is hosted by the Organizing Committee for a Popular Assembly.

This event is not sponsored by LPPFusion, but we thought it will be of interest to the readers of this report.

The teach-in, with time for Q and A and discussion, will be via **Zoom at 2:00 PM EDT Sunday May 17**. Send an e-mail to contact@jaera.org if you'd like to participate.