Compact Laser Ignition for Vacuum Arc Thrusters

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1 Motivation and Method

Why?

Vacuum Arc Thrusters (VATs) are currently lifetime limited by the ignition system. The presently used ignition system creates a high voltage pulse to vaporize a small surface layer between the electrodes to initiate the discharge. This classical ignition system either degrades and fails due to a growing conducting surface layer, or an increased gap distance of the electrodes.

If this ignition limitation could be removed, VAT lifetimes could be completely redefined.

How?

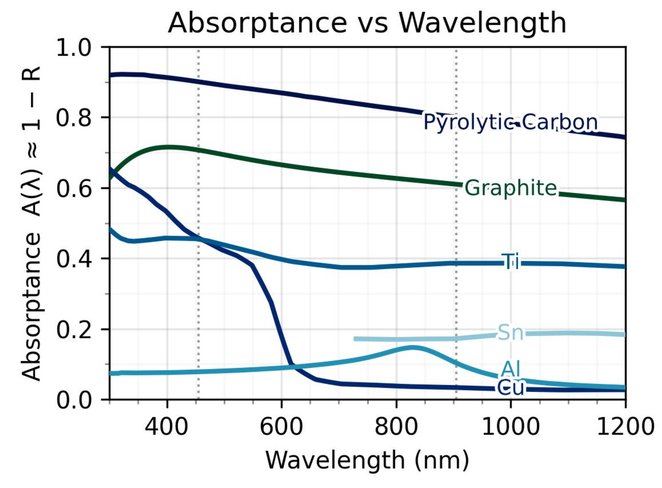
In this research a laser ignition system, based on laser diodes, is explored. Laser diodes feature ultra-compact form factors and low costs, which suit the application niche of VATs. The ignition system consists of a pulsed laser driver that creates an adjustable laser pulse, which is focused on a material sample, where the laser ablation initiates the vacuum arc.

2 Laser Diodes

455 nm

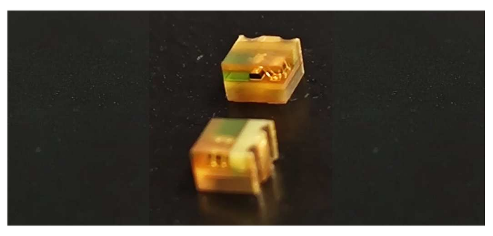
Manufacturer	Nichia
Model	NUBB33
Pulse Width	Infinite / CW
Output Power	23 W
Current	3 A
Inductance	> 8 nH

suitable for long pulses



The coupling is increased at short wavelengths.

905 nm

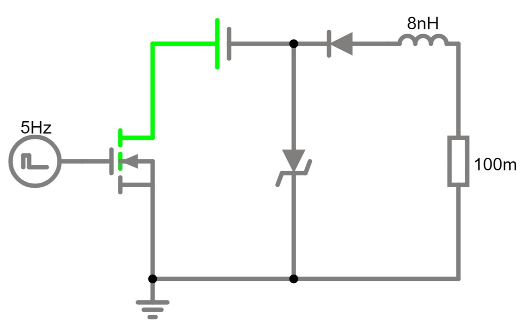


Manufacturer	Laser Components
Model	905D1S3JT09SMD
Pulse Width	100 ns
Output Power	105 W
Peak Current	40 A
Inductance	1 nH

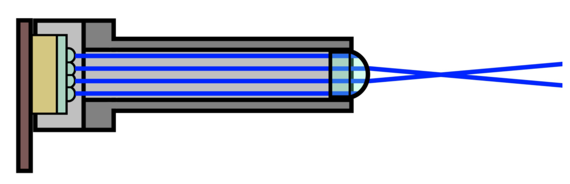
suitable for short pulses

4 Long Laser Pulses

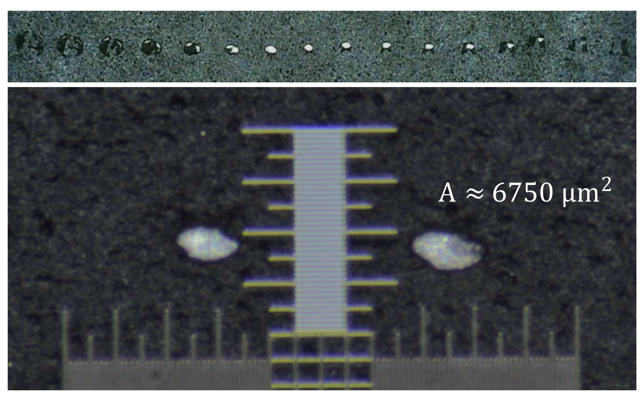
The pulse driver was modified to run the 455nm laser diode from a power supply for increased pulse durations.



Simplified schematic for square pulses



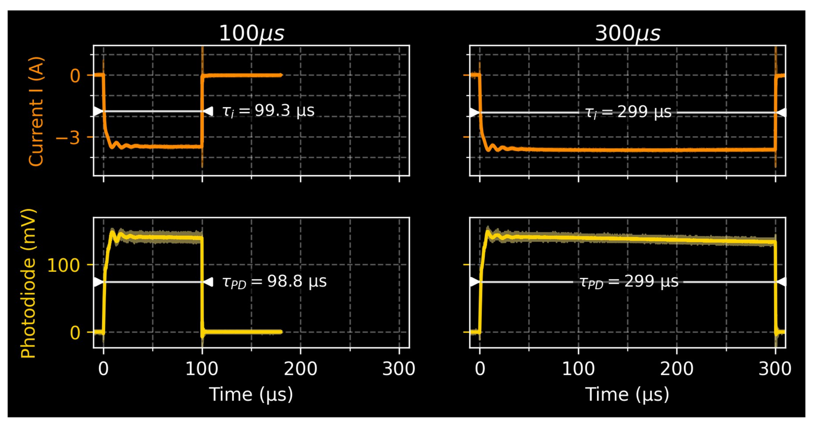
Optical setup schematic focusing 2 emitters

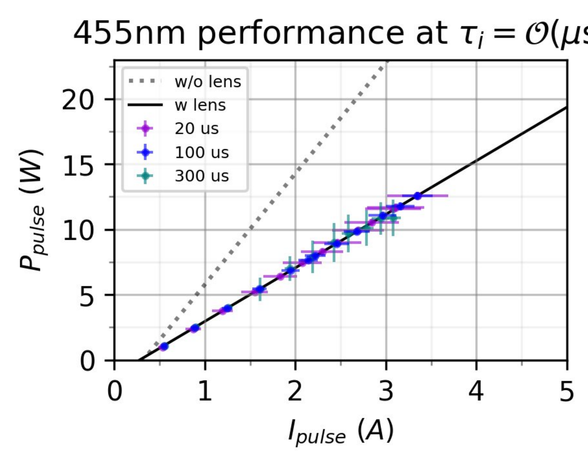


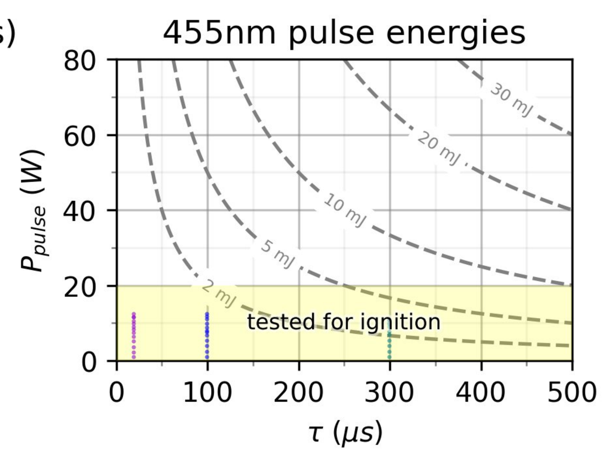
Measurement of the focal spot size

CW-like behavior is present in square pulses.

Pulse energies of ~10 mJ and densities of ~147 J/cm² are reached.

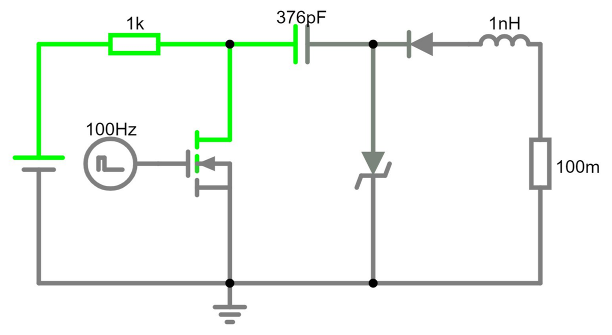




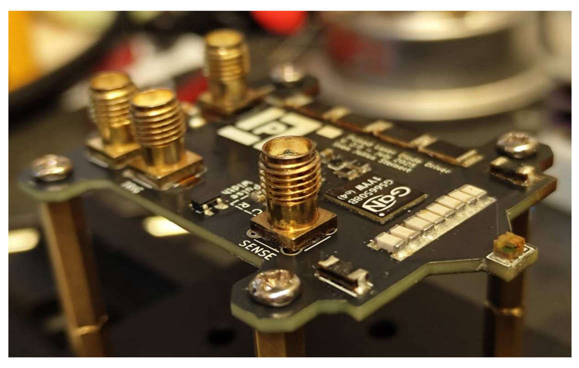


3 Short Laser Pulses

A nanosecond capable driver was developed to supply short laser pulses.

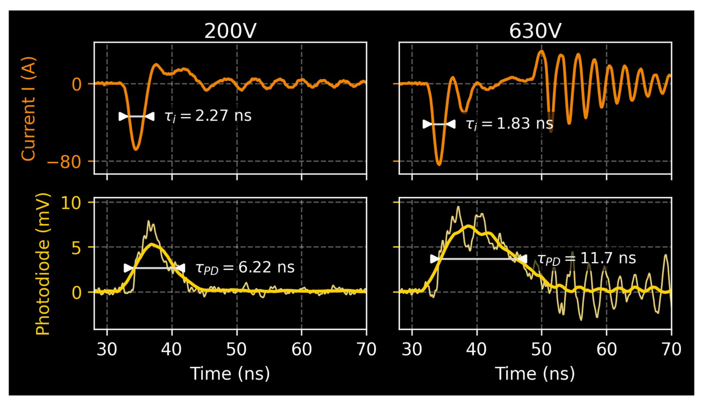


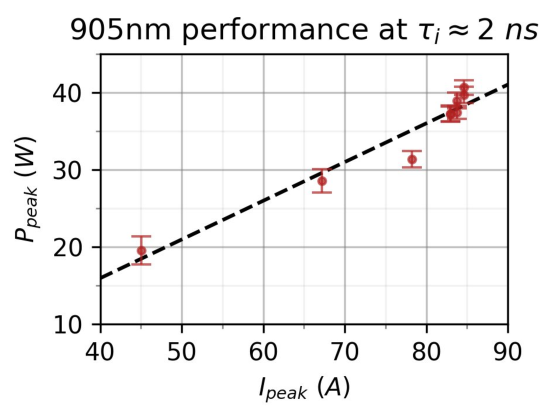
Simplified schematic for gaussian pulses



Assembled PCB of the pulsed laser driver

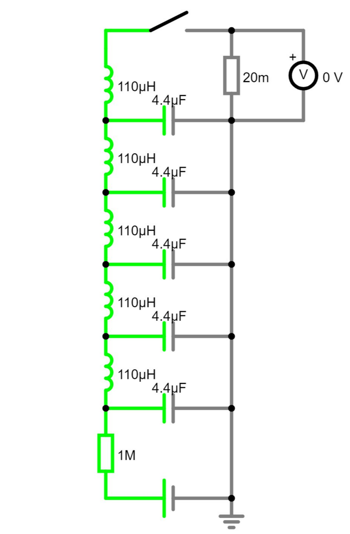
GaNFET architecture can deliver 1.8 ns current pulses driven up to 650V.



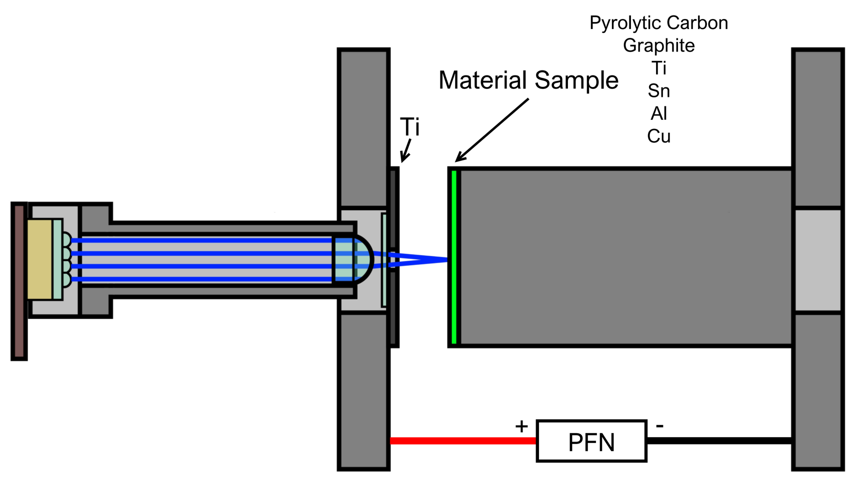


Pulse energies of ~500 nJ constrain reaching the ablation threshold.

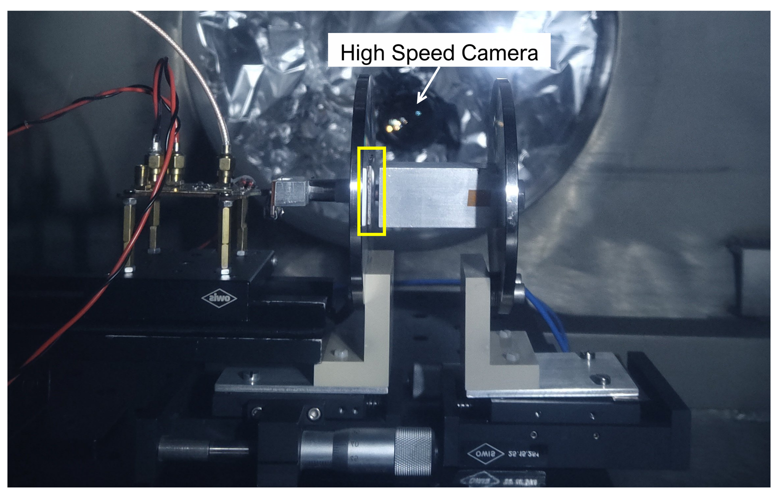
5 Ignition Experiment



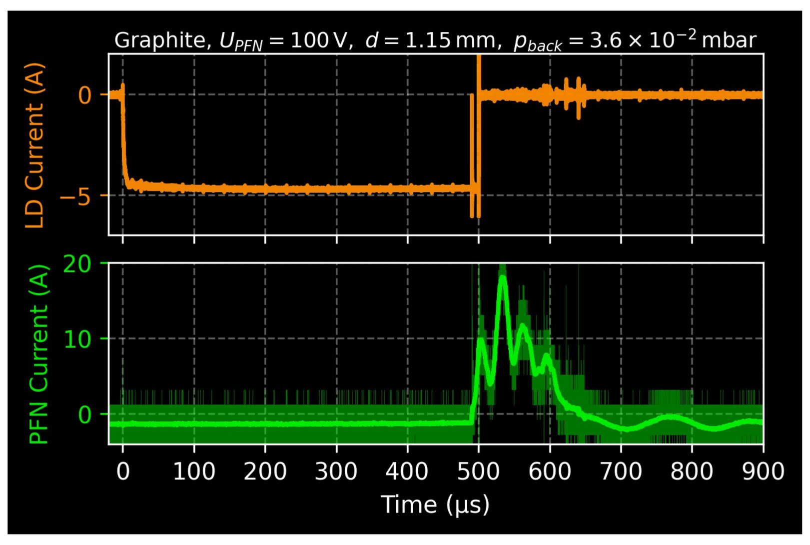
PFN to drive the vacuum arc

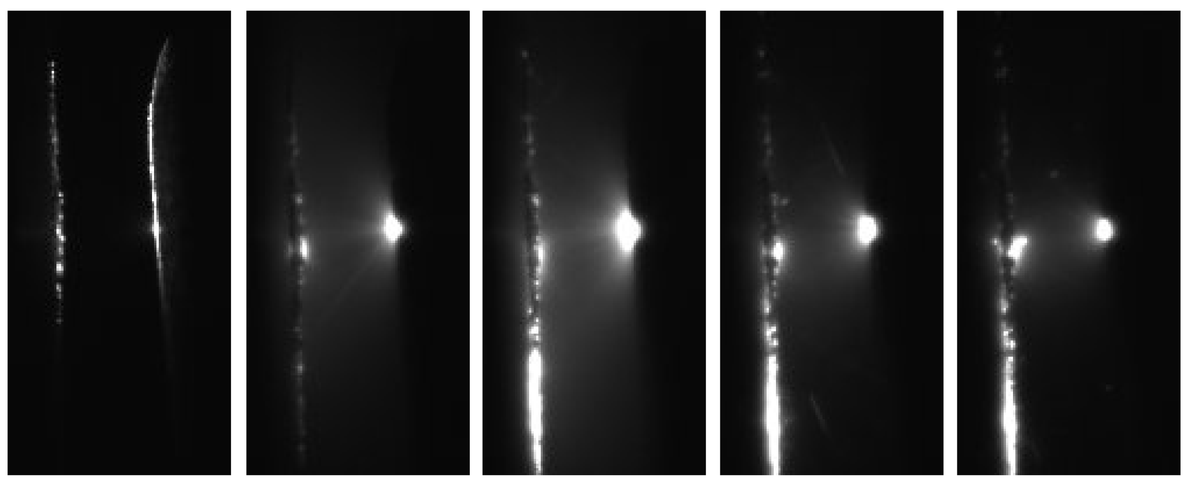


Schematic of the test setup with multiple material samples

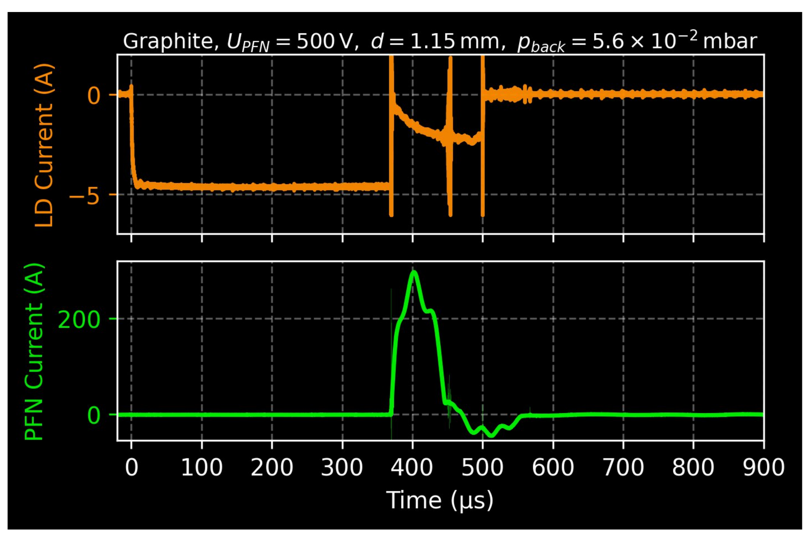


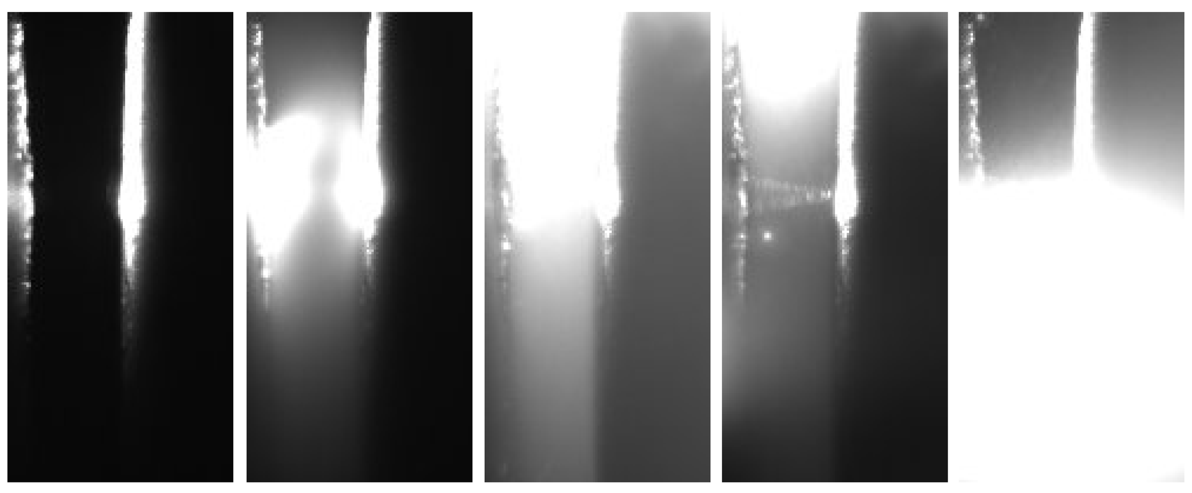
Vacuum setup with a camera focused on the gap (yellow)





Associated high speed camera recording with 33k FPS (30μs apart) at ignition





Associated high speed camera recording with 33k FPS (30μs apart) at ignition

6 Ablation Results

The following table summarises applied ignition values (at Y) or lower boundaries (at N)

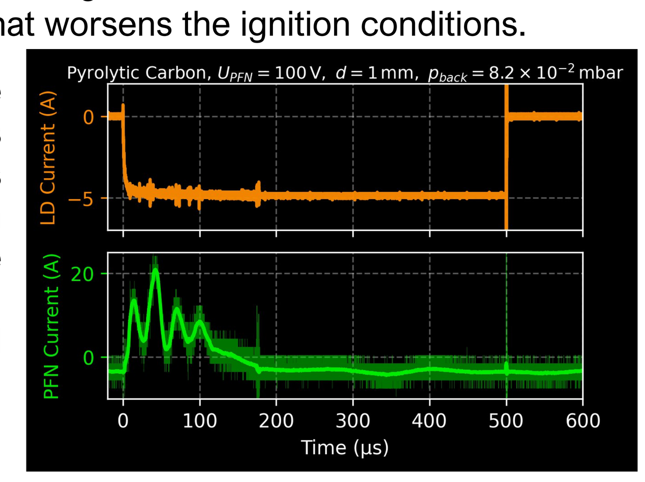
Material	Size [mm]	U_{PFN} [V]	d [mm]	τ_{LD} [μs]	Ignition? [Y/N]	I_{LD} [A]	P_{sample}* [W]	E_{sample}* [mJ]	F_{Sample}* [J/cm²]
Pyrol. C.	25x25x1	100-550	0.50-2.34	500	Y	4.30-5.0	13-15.3	6.5-7.6	96-113
Graphite	Ø8x2	100-550	0.65-1.15	500	Y	2.34-4.7	6.7-14.4	3.3-7.2	49-107
Ti	25x25x1	550	0.49	500	N	> 4.78	> 14.6	> 7.3	> 108
Sn	25x25x1	500	0.49	500	N	> 4.80	> 14.6	> 7.3	> 108
Al	25x25x1	550	0.49	500	N	> 4.86	> 14.8	> 7.4	> 110
Cu	25x25x1	550	0.50	500	N	> 5.06	> 15.5	> 7.7	> 115

*the protective glass sheet dampened ~21% and added an uncertainty due to growing contamination

Pyrolytic Carbon Ignitions

The successful ignitions exclusively occurred on the first shot for pyrolytic carbon, afterwards an ignition was no longer possible, unless the sample was cleaned. The burn marks on the material, particularly the central color change, suggest that the arc discharge has altered the surface material in a way that worsens the ignition conditions.

However, with its original surface intact, the discharge did set off almost instantaneous after the laser light was applied. This suggests a much lower laser ignition threshold, than what was applied during the experiment. This behaviour was solely found on pyrolytic carbon, even under low PFN voltages.



Graphite Ignitions

In contrast to all other material samples, this sample was smaller than the aluminium block mount. As a result, the vacuum arc could be initiated from the sample, but then be taken over by the aluminium block around it. This movement of the vacuum arc can be explained by the different resistivities in the current path, due to the attachment method of the sample. With this effect, larger distances of the electrodes can be bridged by arc elongation. And most favourably, the material consumed by the vacuum arc can be separated from the material that is consumed for laser ablation.

The graphite layout gave the best repeatability and suitability for an ignition system.

6 Result Summary

- A novel ignition method for VATs was successfully demonstrated, which has the potential to redefine VATs lifetime limitations.
- The developed laser system is based on laser diodes, which enable an ultra compact form factor of the ignition system.
- Multiple materials have been tested as ablation source, where ignition was reached with pyrolytic carbon and graphite.
- A preferable arrangement was found to separate the laser ablation material from the vacuum discharge material.

By these outcomes the foundation is laid for the development of a vacuum arc thruster fully reliant on laser ignition.