

Cathode configuration influence on low-inductance vacuum spark plasma dynamics

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Abstract. The results of studies of cathode configuration influence on high current low-inductance vacuum spark (HLVS) plasma dynamics are presented in this work. The research was carried out on “PION” installation using shadowgraphy method. Molecular nitrogen laser ($\lambda=337$ nm) was used as a radiation source. It was determined that the HLVS behavior changes with the increase of number of discharges. In a fresh electrode system (less than 200 discharges) the dependence of constriction position on the discharge trigger position is observed during HLVS development. Also, high gradients of plasma density and secondary constrictions are observed. In a previously exploited electrode system (more than 300 discharges) HLVS behavior changes: plasma density gradients become less expressed, secondary constrictions disappear. In electrode systems with highly developed cathode surface plasma density gradient distribution pattern only slightly changes from discharge to discharge, e.g. the discharge becomes more stable.

1. Introduction

Installations based on HLVS discharge plasma source draw researchers' attention for more than 50 years. Such qualities as high plasma parameters (density more than 10^{20} cm⁻³, temperature ~ several keV), simple design, low cost and relatively small dimensions make these installations potentially perspective for wide range of technological purposes. One of the possible purposes is its use in controlled fusion problems solving, for example: modelling of current disruption in tokamaks, as a dense, pulsed, high temperature plasma source for various diagnostic techniques testing and development. For purposes of technological application HLVS-based plasma generators can be of interest as point source of soft and hard X-ray and EUV radiation [1-4]. Also there is a possibility to use pulsed plasma of HLVS discharge for irradiation of metal surfaces in order to develop layers with modified structural-phasic states with altered physical, chemical and mechanical properties [5-6], but this area needs more detailed research.

One of the key goals of HLVS studies is development of stable source of electromagnetic radiation, because of that complete understanding of all factors that influence plasma parameters stability is needed. Such instability is a significant aspect that limits HLVS discharge utilization in technological tasks, because providing plasma parameters stability from discharge to discharge is rather difficult problem.

The results of studies of cathode configuration influence on high current low-inductance vacuum spark plasma dynamics are presented in this work. Shadowgraphy technique was used for plasma

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dynamics research. Spatial distribution of X-ray radiation was registered by four-channel pinhole camera (hole diameter $\sim 50 \mu\text{m}$). Temporal dispersion of X-ray emission was determined by use of X-ray pin-diode.

2. Experimental setup and experiment description

Experiments were carried out on PION installation [5] on Plasma Physics Department NRNU MEPhI. Electrode system of the installation is made as pointy anode 3 mm in diameter, and plane cylindrical cathode 22 mm in diameter with 3 mm hole in the center. Electrodes were made from iron Fe (steel 45). Interelectrode gap was 5 mm wide. The discharge was triggered by erosional-type plasma source. Operating voltage was 15 kV, discharge period 5,5 μs , stored electrical energy – 1350 J, maximum of discharge current – 180 kA.

It is important to utilize short-wave lasers, because HLVS discharge plasma shows high parameters (plasma density in peripheral area of discharge is $\geq 10^{17} \text{ cm}^{-3}$, density in pinch $\sim 10^{21} \text{ cm}^{-3}$, temperature $\geq 1 \text{ keV}$). In the considered research molecular nitrogen laser LGI-21 was used, its wavelength is $\lambda=337 \text{ nm}$. Laser radiation power is 12 μJ .

Studied discharge is powerful source of electromagnetic radiation in wide spectral range – from SHF to hard X-ray radiation. Significant portion of this radiation energy falls at visible and UV light ranges. In such case, during shadowgram registration it is important to deal with high level of backlight noise from the discharge area. This greatly complicates shadowgram obtaining process. Backlight noise falling at spectral range close to laser wavelength appears to be comparable to illumination of the laser itself. Therefore in order to minimize backlight noise in the registration technique diaphragm was used, CCD-camera was allocated 6 m away from the plasma source, and image registration was carried through narrow-range (6 nm) interference filter. Experimental setup is presented on Figure 1.

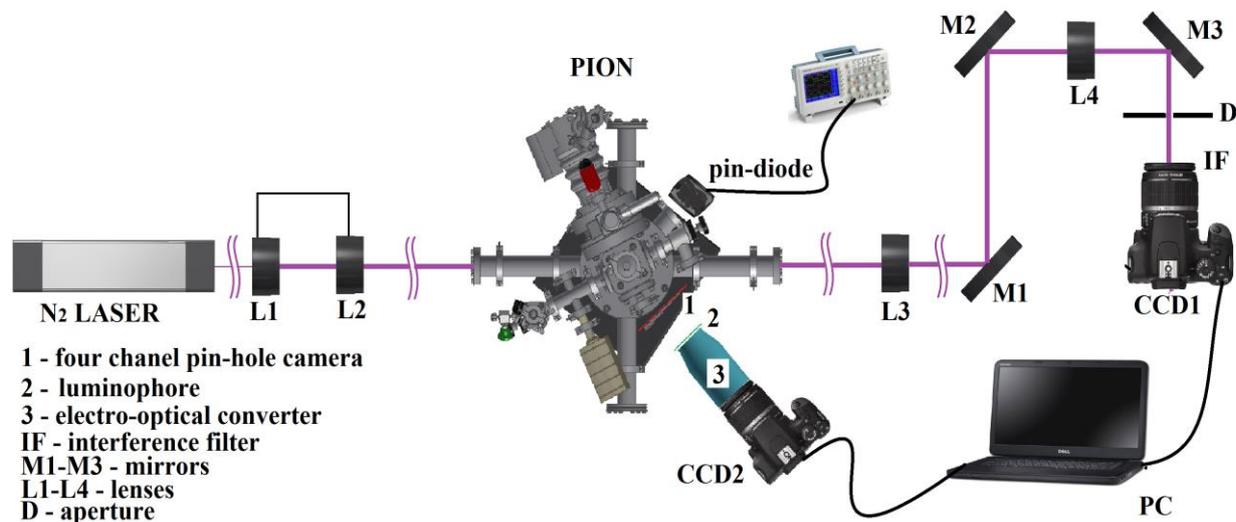


Figure1. Experimental setup.

With the rising of number of discharges electrode system suffers significant changes. The hole in the center of cathode becomes welded, cathode surface itself exposed to interaction with plasma flows transforms, sharp brim and weld bed are formed [5]. Such cathode configuration development leads to changes in discharge behavior and has an impact on its stability (repeatability of emission characteristics from discharge to discharge). The goal of the research was to determine how cathode surface development with the growth of number of discharges influences on HLVS discharge plasma dynamics.

As it was mentioned above, temporal dispersion of X-ray emission was determined by use of X-ray silicon-based pin-diode, and spatial distribution was registered by four-channel pinhole camera. Pinhole channels were covered by aluminum filters of different thickness: 60 μm thick – which allowed registration of >6 keV photons, 120 μm thick (>8 keV), 240 μm thick (>10 keV) and 480 μm thick (>13 keV).

Two similar electrode systems were used in the experiments, each was exposed to the same number of discharges (600). Shadowgrams, pinhole images, pin-diode and Rogovsky coil signals were registered in the process. Simultaneous registration of pin-diode and Rogovsky coil signals allowed to determine the precise moment of micropinch formation, this moment was taken as zero-point on the sequences of shadowgrams. The second electrode system was used for the validation of the results of preceding research.

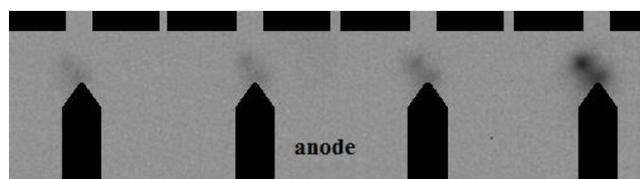


Figure 2. Pinhole images of the discharge. (The thinnest filter is on the right) Discharge trigger is on the left side of the anode.

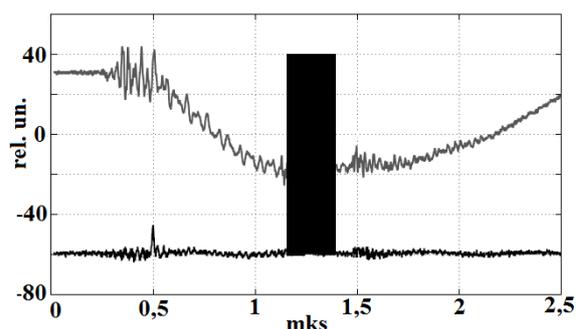


Figure 3. Temporal dispersion of X-ray emission in the first 200 discharges (average for two sequences).

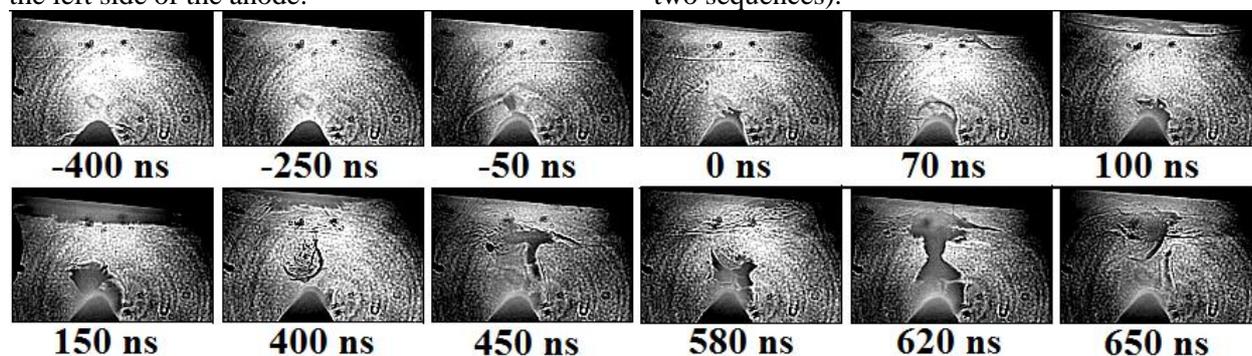


Figure 4. Sequence of shadowgrams for a fresh electrode system. Zero point corresponds to micropinch formation moment.

It was determined that when electrode system is still fresh (less than 200 discharges) the discharge is rather unstable – significant temporal (~ 200 ns) and spatial (~ 800 μm) dispersion is observed on pinhole images and pin-diode signals. As it appears from shadowgrams in this case HLVS discharge development is followed by rather high plasma density gradients, secondary constrictions are formed, which do not lead to X-ray emission, and primary constriction is shifted closer to the trigger. Distinctive pinhole images, temporal X-ray dispersion and shadowgrams sequence are presented on figures 2,3 and 4 respectively. On figure 3 width of the black rectangle shows temporal dispersion of X-ray pulse and height shows the disperse of pulse amplitude. In this case X-ray radiation was registered during $\sim 75\%$ of discharges.

As the electrode system becomes more exploited the discharge becomes more stable. Temporal dispersion decreases to ~ 80 ns (figure 6). Micropinch appears later in time, closer to discharge current maximum, which leads to optimization of energy input in plasma point. According to pinhole images (figure 5) and shadowgrams (figure 7) there is no such significant shift of constriction to the trigger

side. X-ray radiation is more intense and is concentrated in anode area (see pinhole images on figure 5). It is seen from the sequence of shadowgramms on figure 7 that density gradients are not so defined in this case, and there are no secondary constrictions. Micropinch formation and development is more “laminar”, and repeatability of discharge development is higher. In this case X-ray radiation was registered during ~ 90% of discharges.

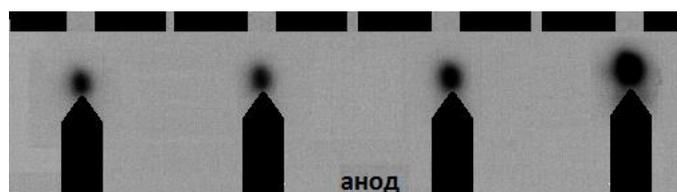


Figure 5. Pinhole images of the discharge for previously exploited electrode system. (The thinnest filter is on the right) Discharge trigger is on the left side of the anode.

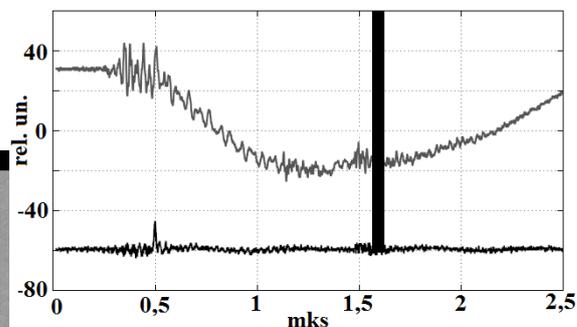


Figure 6. Temporal dispersion of X-ray emission from 300 to 600 discharge (average for two sequences).

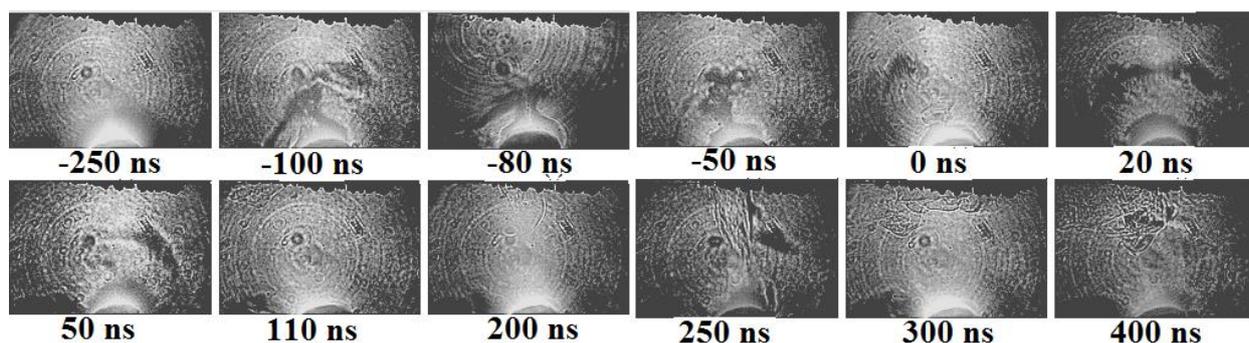


Figure 7. Sequence of shadowgramms for previously exploited electrode system. Zero point corresponds to micropinch formation moment.

3. Conclusions

Shadow photographing and pinhole imaging methods revealed number of patterns and features of high-current low-inductance vacuum spark development on “PION” installation during electrode system modification with increasing number of discharges. It was found that with increase of discharge numbers the behavior of HLVS is changed. There is a strong dependence of the constriction position from trigger position (it can be seen on pinhole pictures) during the development of HLVS in fresh electrode system (until 200 discharges), there are significant gradients of plasma density and secondary constrictions. The behavior of HLVS changes in previously exploited electrode system (more than 300 discharges), gradients of plasma density become less pronounced and secondary constrictions disappear. Pattern of plasma density gradients distribution in the electrode gap was slightly different from discharge to discharge in the electrode system with highly developed surface structure, constriction (plasma point) almost not moving toward the trigger, x-ray observed in ~90% discharge (versus ~ 75%) and intensity of x-ray was higher (emission area in pinhole pictures became higher), that indicates more stable discharge flowing.

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References

- [1] Dodulad E I, Kostyushin V A and Bashutin O A 2016 *J. of Phys.: Conf. Series* **666** 012013
- [2] Kirko D, Dodulad E and Savjolov A 2016 *J. of Phys.: Conf. Series* **666** 012019
- [3] Pavez C, Pedreros J, Tarifeno-Saldivia A and Soto L 2015 *Physics of Plasmas* **22** 040705
- [4] Dodulad E I, Kostyushin V A and Savjolov A S 2015 *Phys. Procedia* **71** 155-159
- [5] Sarantsev S A, Dvoyeglazov Ya M and Raevskiy I F 2015 *Phys. Procedia* **71** 160-164
- [6] Sarantsev S A 2015 *Phys. Procedia* **71** 165-170