36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-5.202 (2009)

LIF CHARACTERIZATION OF THE HOLLOW ANODE PLASMA IONS

V. Vekselman, D. Yarmolich, J. Z. Gleizer, J. Felsteiner, and Ya. E. Krasik

Physics Department, Technion, Haifa 32000, Israel

Hollow anode (HA) discharge with ferroelectric plasma sources (FPS) can be considered as a novel type of active plasma cathode which is successfully used for generation of electron beam with amplitude of 1-4kA, cross-sectional area of 100cm^2. It was shown that the HA discharge (1kA, 20μs) can be ignited and sustained by FPS which requires a nanosecond time scale driving pulse for surface generation plasma. Recent experiments have shown that FPS-assisted HA discharge provides a uniform electron beam extraction and characterized by self-sustaining operation mode [1]. It was found that the electron energy distribution (EED) of the HA discharge is non-Maxwellian and consists of 6-8eV and ~50eV electrons; FPS surface plasma has density of 10^{14}-10^{16}cm^{-1} and expands from the FPS surface with velocity ~1cm/μs. However the plasma density distribution inside the HA is not known yet. In addition, it was found that plasma potential is slightly (20-30V) positive relative to the HA walls during HA discharge and it increases sharply up to several kV during accelerating high-voltage (HV) pulse application. Thus, plasma electrons with energies less than few keV cannot pass the potential wall formed between the plasma boundary and the HA output grid. The possible mechanism of electrons extraction suggested in Ref. [2], is based on the formation of ion screening layer in the vicinity of the HA output grid wires. In the present paper we characterize the operation of HA plasma cathode with and without application of HV pulse using laser induced fluorescence (LIF) diagnostics – an un-perturbing, time- and space-resolved spectroscopic technique.

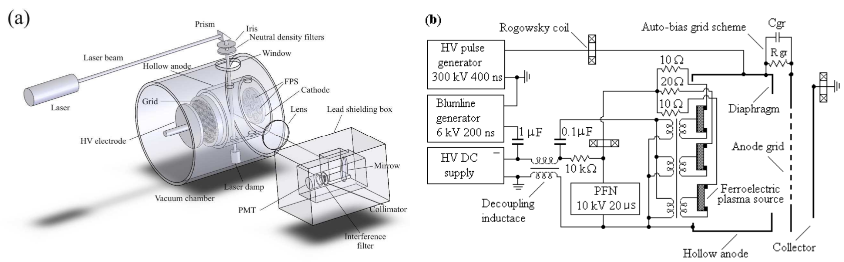

Fig. 1. (a) Experimental setup and (b) its electrical scheme.

The experimental setup was similar to the one described in Ref [3]. Namely, a HA (ø15cm hollow cylinder) consists of seven identical FPSs (Fig. 1a). The application of a driving pulse (~2kV, ~200ns) caused plasma formation at each FPS front surface (Fig. 1b). This plasma initiates the HA discharge supplied by PFN generator (~5kV, 20μs). During the HA discharge, the FPS plasma is self-consistently formed at the front surfaces of the FPSs by plasma ions which are accelerated towards the FPS from the HA plasma. An accelerating pulse (~250kV, ~400ns) delivered by the nanosecond HV generator is applied with a time delay τ_d=20μs with respect to the beginning of the FPS driving pulse. This accelerating HV pulse leads to extraction of electrons from the HA plasma through the HA output grid. The tunable dye laser Continuum ND6000 (0.05cm^{-1} @560nm) was pumped by pulsed Nd:YAG SureLite laser (λ=532nm, 0.2J, and 8ns) forming ⌀6mm laser beam at desired wavelength. The iris diaphragm and a set of neutral density filters (NDF) were used for attenuation of the laser beam intensity and its spatial transformation. The laser beam crossed the HA at different distances (5mm–20cm) with respect to the central FPS front surface (see Fig. 1a) and it was absorbed by a graphite damper. The photomultiplier tube (PMT) was used to collect the light emitted from the intersection volume of the laser beam and plasma using an achromatic lens, an interference filter (5nm @460nm) and a set of collimators. The lead shielding was used to prevent the PMT from X-ray radiation.

The LIF measurements were carried out using the three level Ar II scheme, namely, the Ar II ions with 3d $^2G_{9/2}$ metastable level (τ>100μs) undergo excitation to 4p $^2F_{7/2}$ level under irradiation by a laser at 611.492nm. This upper level then spontaneously decays to 4s $^2D_{5/2}$ level by radiating a fluorescence photons at 460.957nm. By detuning the laser from the resonance wavelength (transition 3d $^2G_{9/2} \rightarrow$ 4p $^2F_{7/2}$) the Ar II ions still undergo excitation to upper level by having appropriate velocity in direction of laser beam. If a bandwidth of laser is less than absorption bandwidth of Ar ions (defined by the velocity distribution/temperature of Ar ions) the number of observed fluorescence photons versus laser wavelength reveals the Ar ion velocity distribution function. Assuming Maxwellian distribution one can calculate the ion temperature.

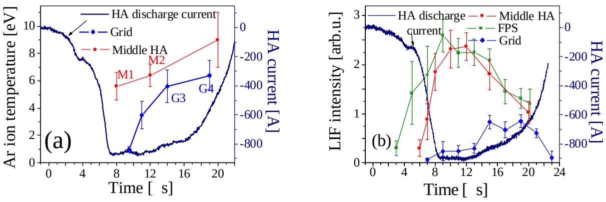

Fig. 2. (a) Ar ion temperature and (b) intensity of LIF signal during HA discharge.

The measured Ar ion temperature during HA discharge at different distances are presented in Fig. 2a. Let us note that almost the same temperatures of ions were obtained at different distances (8cm and 14cm) from the FPS (pairs of points M1-G3 and M2-G4) but at different time delays with respect to the HA discharge beginning. In the vicinity of the HA output grid the rapid increase of ion temperature (from 1 to 6eV) during 10μs is possible for 5-8eV plasma electrons at density more than ~$1.7\cdot10^{15}$cm^{-3} only [4]. The latter contradicts to previous experimental estimations of HA bulk plasma density as ~10^{12}cm^{-3}. To exclude a possibility for additional broadening mechanisms of LIF signal, such as Stark effect and saturation broadening [5], appropriate procedures were performed. Notably, the influence of laser electric field on Ar II metastable level was checked and non-saturated mode of laser operation was found [5]. So, only incomprehensible flows of Ar ions with velocities up to ~$5\cdot10^{5}$cm/s along laser beam direction can explain obtained "temperature". Obviously, that amount of LIF photons is proportional to the population of Ar II metastable level and to the plasma Ar ion density. Thus, the plot of LIF intensity versus the HA discharge's time and space (Fig. 2b) represents the plasma density evolution during the HA discharge. One can see a fast rise of plasma density during ~4 μs up to its maximum value and further a decrease in the plasma density during just a bit longer time.

Based on the obtained data we proposed the following scenario of the HA operation. The application of driving pulse to FPS causes formation of dense surface plasma. This plasma expands inside the HA cavity and ignites the HA discharge. Further, formation of secondary plasma on the ferroelectric surface by the HA plasma ions accelerating towards the ferroelectric, allows one to sustain HA discharge. The plasma heating mechanism has non-collisional nature and is not clear yet. One can consider a formation of a collisionless shock wave (CSW) with phase velocity of ~$8\cdot10^{5}$ cm/s (Fig. 2), that corresponds Mach number $\boldsymbol{M} = {}_{ph}\Big/\sqrt{kT_e/m_i}$ =1.5. In case $\boldsymbol{M}$<1.6 also the stationary ionic-sound soliton of CSW is possible [4]. The latter is characterized by symmetrical distribution of the plasma density before and after CSW front that agrees with our observations (Fig. 2b). This CSW may have potential of ~13V that is sufficient for observation of 6eV Ar "ion temperature". Another heating mechanism can be related to an anomalous resistivity of plasma arising due to existing of non-Maxwellian 50eV electrons passing HA plasma. Thus electrons' energy effectively transfers to plasma ions.

In addition, LIF measurements were performed during the accelerating HV pulse. The obtained data were compared with the LIF data obtained during the HA discharge only (see Fig. 3a). One of the characteristic features of HV pulse influence is related to the PMT background signal, which is 3-4 times larger in the vicinity of HA output grid as compared with all other observation positions. Here we must note that the bandwidth of interference filter makes possible the observation of additional spectral lines of O II, Ar II, and N II. In any case, more intense plasma light emission indicates on the growth of electron-ion collisions and/or increase in the plasma density and/or increase in the ion temperature. The latter was measured at different time delays with respect to the beginning of the HV pulse (see Fig. 3b).

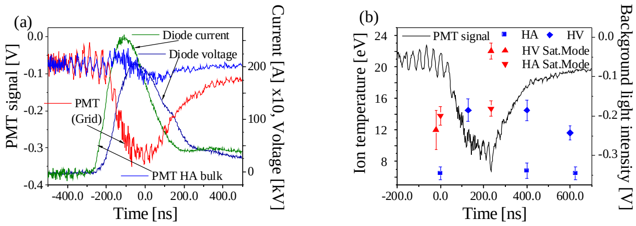

Fig. 3. (a) PMT background signal and (b) ion temperature during HV pulse.

Due to a large background signal of PMT the observation of LIF signal during HV pulse at some time delays were performed in saturated mode of laser operation. This ***a fortiori*** leads to broadening of velocity distribution function; however, by comparing the same data without HV pulse one can obtain the difference in ion temperature due to application of HV pulse. It was found that ion temperature increases up to 15 eV during first 200ns. Such rapid rise of ion temperature cannot be explained by collision processes. The possible explanation may be as follows. Before the application of HV pulse the sheath is formed between HA bulk plasma and HA output grid, where all potential drop is occurred. This region is occupied primary by ions. Application of HV pulse increases plasma potential and sheath width, and forces the ions to oscillate in the potential well formed in the vicinity of HA grid. Inhomogeneity of electric field distribution near output grid leads to randomization of ion velocities so that ionic space charge screens the negative grid potential from plasma and allows electron beam extraction.

To summarize, experimental results showed that the HA plasma ions acquires 6eV energy and the extraction of electron beam from the surface HA plasma is possible due to ion oscillation near HA output grid.

References

[1] J. Z. Gleizer, D. Yarmolich, J. Felsteiner, and Ya. E. Krasik, Plasma Devices and Operations 14, 223 (2006)

[2] V. Tz. Gurovich, J. Z. Gleizer, Yu. Bliokh, and Ya. E. Krasik**,** Phys. Plasmas 13, 073506 (2006)

[3] D. Yarmolich, V. Vekselman, J. Z. Gleizer, Y. Hadas, J. Felsteiner, and Ya. E. Krasik, Appl. Phys. Lett 90, 011502 (2007)

[4] L. A. Arcimovich, R. Z. Sagdeev, Fizika plazmy dlja fizikov (1979)

[5] M. J. Goeckner and J. Goree, J. Vac. Sci. Technol. A 7, 977 (1989)