Dynamics of high power impulse hollow cathode discharge

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Abstract - Fast imaging technique was used for the investigation of the plasma dynamics of a high power impulse hollow cathode discharge. The high repetition frequency provides an overlap of the plasma species ejected in subsequent pulses with those produced by the previous pulses. The plasma in front of the hollow cathode changes from a hemispherical shape during the pulse-on time, to a drop-like shape during the pulse-off time.

1. Introduction

Hollow cathode (HC) discharges are rather simple plasma systems used as sources for spectroscopic light, electron beams, and clusters or as ion thrusters. In this kind of discharge a high density flux of energetic working gas ions is produced by the electron pendulum effect inside the hollow cylinder cathode [1,2]. Nowadays, high power pulse supplies are used to produce highly ionized plasma in HC discharges [3]. The high degree of ionization is beneficial for the growth of nanoparticles because the ejected metal ion cloud overlaps with nanoparticles already formed by previous pulses. The main purpose is to optimize the pulse parameters, i.e., pulse duration, frequency and peak current, in order to control the size of the nanoparticles [3]. Recently, ionization rates, extraction efficiency of the sputtered materials and spatio-temporal evolution of the plasma species outside the HC have been simulated by Hasan *et al*. [4].

2. Experimental set-up and results

In this contribution we report experimental results concerning the dynamics of a **hi**gh **p**ower **i**mpulse **h**ollow **c**athode **s**puttering (HiPIHCS) discharge by means of time-resolved discharge imaging. The experimental results were obtained using an iron hollow cathode with 3 cm length and 0,5 cm inner diameter. The working gas (Ar) was employed at a flow rate of 50 sccm through the HC and the pressure in the expansion volume was kept constant at 1 mbar. The HiPIHCS discharge was operated at very short discharge pulses (10 μs), with a pulse repetition frequency of 20 kHz, attaining a peak cathode current of 1,7 A for an applied

voltage of 600 V (Fig. 1a). Plasma potential and ion saturation current were recorded at 3 cm in front of the HC nozzle using both emissive and electrostatic probes (biased at –100 V).

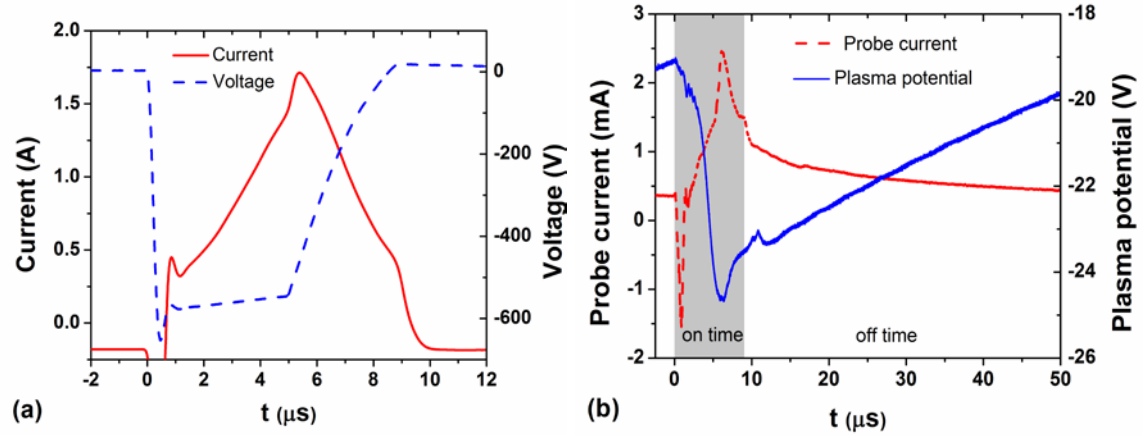

Fig. *1. (a) time evolution of the discharge current and voltage; (b) electrostatic probe current (probe bias –100 V) and plasma potential measured as floating potential of the emissive probe.*

During the pulse-on time the plasma potential drops from –19 V to –25 V and the ion saturation current of the probe increases from 0,3 mA to 2,5 mA, mainly due to the fast electron injection and consequent increase of the ionization rate (Fig. 1b). Moreover, the optical emission spectrum of the pulsed HC discharge, in the visible spectral range, is dominated by ionic species emphasizing the highly ionized plasma (Fig. 2).

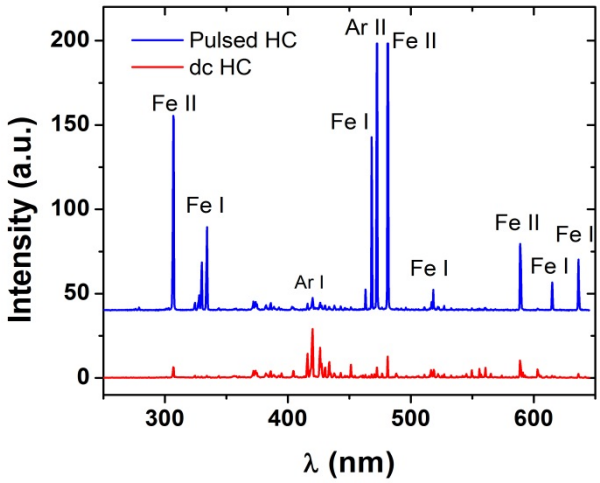

Fig. 2. Global optical emission spectra of hollow cathode plasma in dc and pulsed mode, respectively, for the same average discharge power of 70 W.

The temporal evolution of both ion saturation current and plasma potential during the pulse-off time indicate the presence of afterglow plasma caused by the loss of charged particles through ambipolar diffusion processes.

Side-view images of the discharge were recorded with a high-speed ICCD camera, using an exposure gate of 100 ns. Thus, time and space distribution of the light intensity emitted by the plasma volume can be plotted for both pulse-on (Fig. 3) and pulse-off (Fig. 4) phase of the pulsed discharge. We noticed that the discharge is axisymmetric, having the maximum light intensity on the cathode axis. The spatial distribution of the light intensity exhibits strong gradients both in radial (r) and axial (z) directions, as indicated in Fig. 3. During the pulse-on phase, the maximum light intensity is localized at the exit of the hollow cathode and its time evolution follows that of the discharge current (Fig. 3).

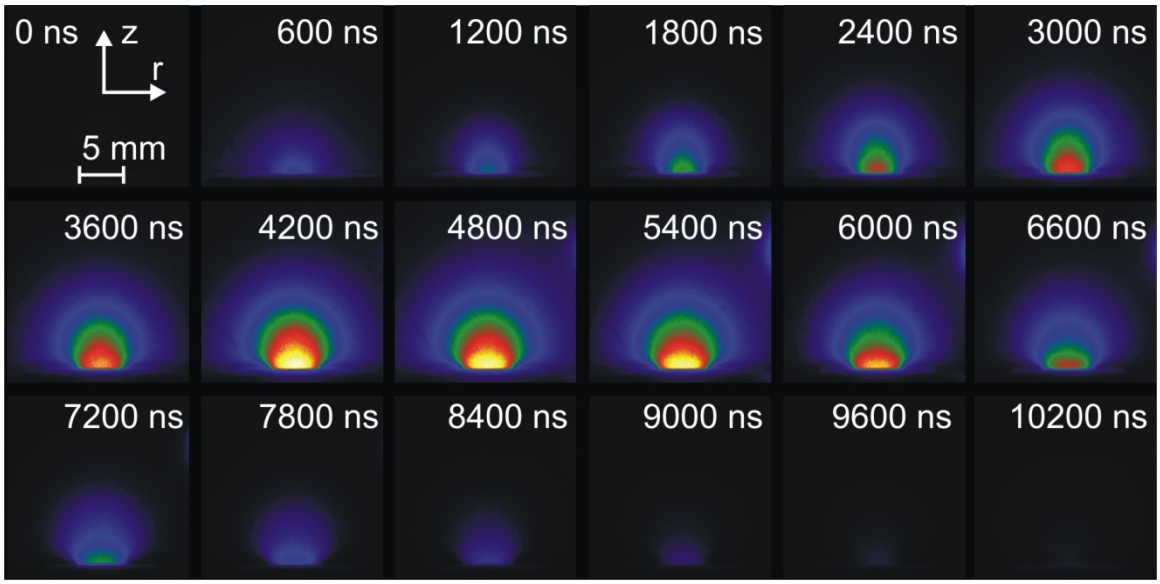

Fig. 3. Fast ICCD images taken during the pulse-on time (t = 0 ÷ 10200 ns). Gain = 600.

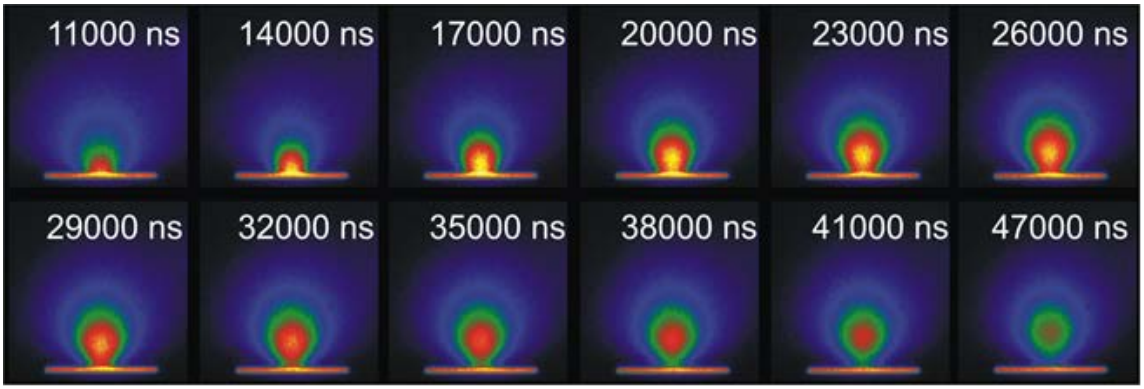

Fig. 4. Fast ICCD images taken during the pulse-off time (t = 11000 ÷ 47000 ns), Gain = 800.

Consequently, the maximum light intensity is reached in about 4,5 μs when the discharge current also attains its maximum, then it monotonically decreases following the discharge current evolution. In the pulse-off regime, the afterglow plasma behaves differently

(Fig. 4). After about 12 μs the discharge voltage becomes zero and the real pulse-off time sets-in. The light emitted by the afterglow plasma becomes very weak and its registration needs increase of the ICCD sensitivity (Fig.4). In this case, in spite of zero discharge current (Fig. 1a), there is still a local monotonic decrease of the plasma density shown by the time evolution of the ion saturation current of the probe (Fig. 1b). The light emission of the afterglow plasma shows a spatial expansion of the plasma volume which tends to detach from the cathode exit, moving towards the anode, as also seen in former DC HC experiments [5].

3. Conclusion

The afterglow plasma acts as an energy reservoir which is beneficial for the fast ignition of the subsequent high power pulses. The high ionization degree of HiPIHCS discharge is a key feature in the growth process of nanoparticles due to high instantaneous sputtering rate and the possibility for the nanoparticles to become negatively charged. Moreover, the nanoparticles size can be easy controlled by pulsed discharge parameters, i.e., peak current, pulse duration and frequency.

Acknowledgement

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