Localized detached glow above a titanium hollow cathode

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Abstract - An argon hollow cathode was investigated as plasma source and sputtering source. The hollow cathode consists of a Ti-cylinder embedded in ceramic. There are various modes of operation: we have observed a corona discharge in argon and the typical hollow cathode discharge mode with strong titanium sputtering. In the latter case a sharply bounded intensive yellow-reddish glowing zone was observed at the "muzzle" of the Ti cathode. Under certain conditions this zone was observed to float freely between cathode and anode ring.

1. Introduction

Hollow cathodes (HC) are used as intensive light sources [1], spectroscopic light sources [2], cluster sources [3], electron beam sources [4,5], ion thrusters [6] and sputtering sources [7,8,9,10]. The annular cathode fall within the hollow cathode cylinder forms a deep potential well in which electrons can perform pendulum motion. This strongly enhances electron density, ionization and sputtering rate. Recently HCs have become important for thin film deposition of ferromagnetic materials [11,12] since they do not need a magnetic field, which makes them a useful alternative compared to other sputtering devices such as magnetrons.

In our case the hollow cathode has various regimes of operation: for low voltages a dark discharge can be produced; for higher voltages a corona discharge was observed, for further increase of the discharge voltage the actual HC mode appears with a strong localized glow. We report also on the effect that the localized brightly glowing zone (GZ) detaches from the "muzzle" of the HC to freely float above it. Highly localized glowing structures are known from beam-plasma-discharges [13] or as results of space charge double layers, also known as "fireballs" [14].

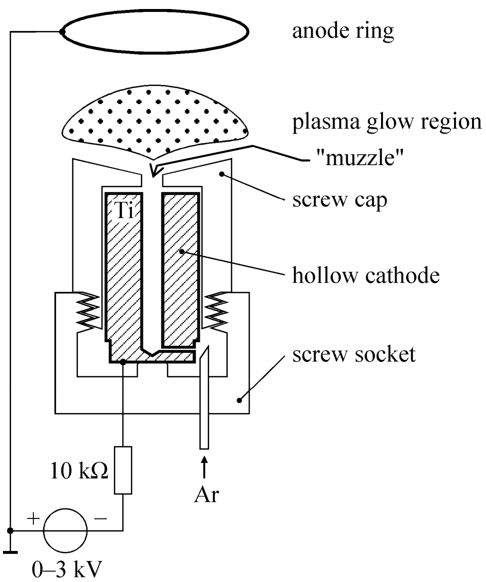


Fig. 1. Schematic of the set-up with gas feed, electric circuit and detached glow above the "muzzle".

2. Experimental set-up and results

The hollow cathode (HC) system consists of an annular titanium cylinder with a length of 40 mm, an outer diameter of 22 mm and a concentric cylindrical bore of 5 mm diameter and 37 mm length. The Ti-cylinder

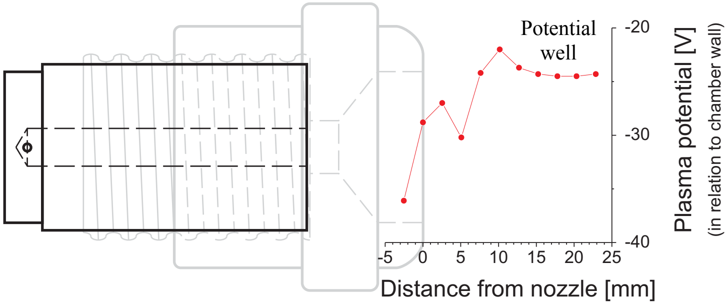


Fig. 2. Schematic of the hollow cathode with plasma potential profile above the "muzzle" in the HC regime.

is embedded into the ceramic screw cap of a conventional fuse, screwed into a standardized Edison E27 screw socket. A small bore of 1 mm diameter serves for the employment of the working gas (argon) from the screw socket into the HC. Into the socket the working gas enters through a PTFE-tube with an inner diameter of 3 mm. Above the ceramic screw cap (the "muzzle" – see Fig. 1) in a distance of 55 mm a copper ring is mounted, which acts as grounded anode for the HC and as substrate holder. The electrical connection for the cathode is made through the bottom of the socket. Thereby the Ti-cylinder is negatively biased in a range of V_0 = 0-3 kV through a load resistor of 10 kΩ. Obviously the voltage V_c on the cathode thus depends also on the discharge current I_{dis}. Fig. 1 shows a schematic of the experimental setup. Fig. 2 shows also the profile of the plasma potential on the axis above the muzzle. The plasma potential indicates the formation of a potential well starting at a distance of about 10 mm above the muzzle, which traps the ions in that region. This we presume is the region where the GZ is observed in the HC regime.

At a pressure of around 0,5 mbar a dc-discharge is produced. Fig. 3a,b shows the complex voltage-current (V_c-I_{dis}) characteristic of the discharge. The black symbols show the regime of a dark discharge not emitting visible light. For $V_c \cong$ 540 V a corona discharge with

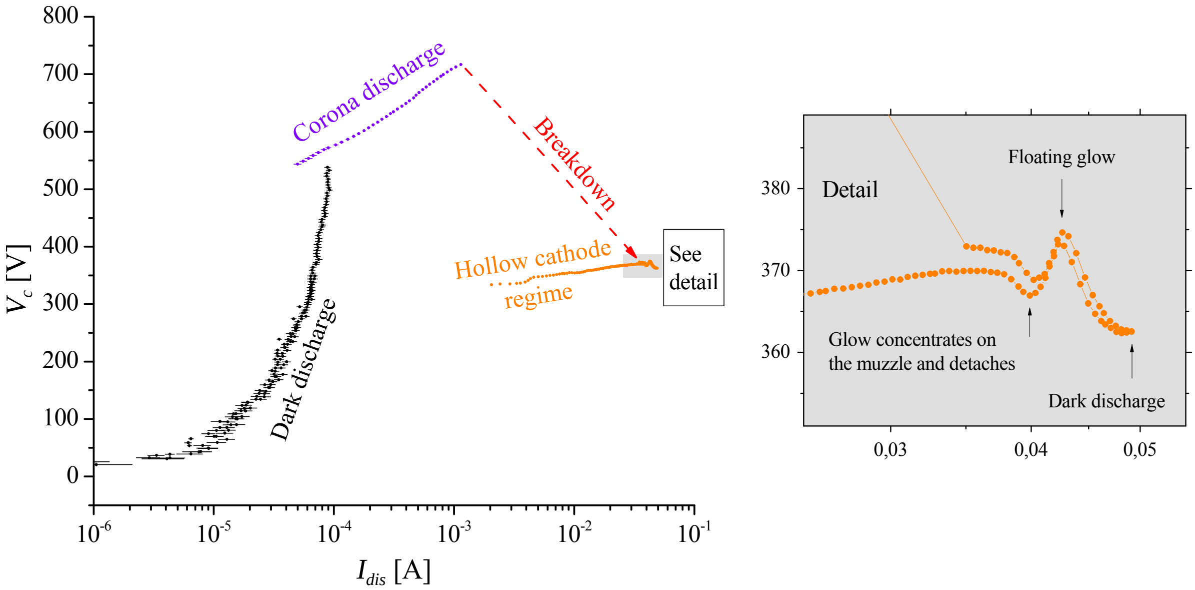


Fig. 3. (a) Voltage-current characteristic of discharge: dark discharge regime (black symbols), corona discharge (blue symbols), hollow cathode regime (orange symbols), the small grey rectangle is shown in detail in (b).

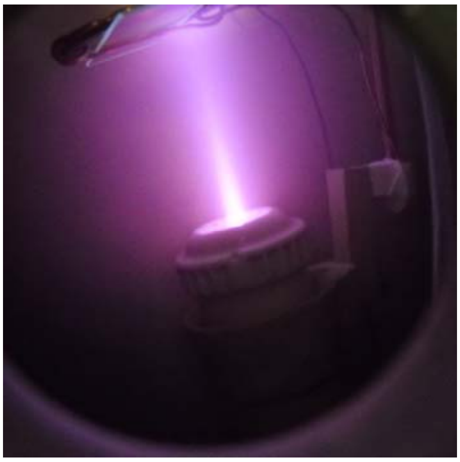
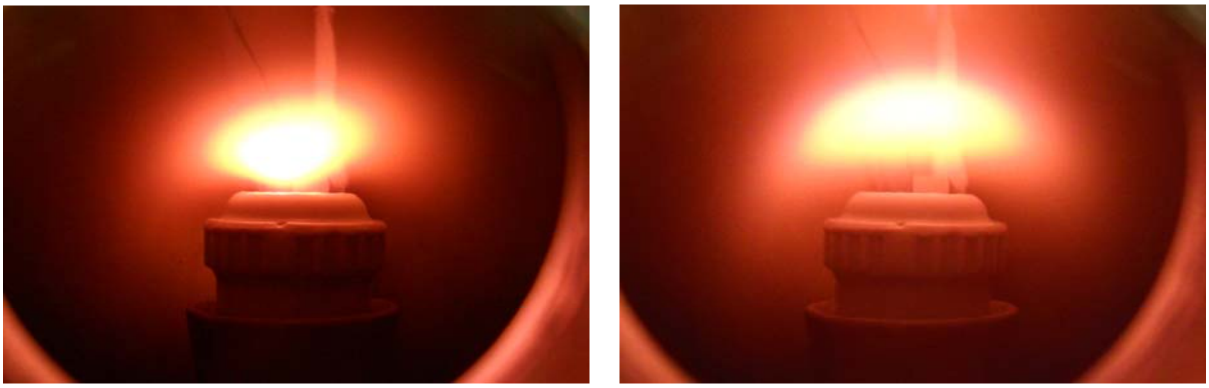


Fig. 4. Corona discharge regime

the typical bluish argon colour sets in, indicated in Fig. 3 by the blue symbols (see Fig. 4). For $V_c \cong 720$ V the voltage breaks down, the current I_{dis} strongly increases and the HC regime commences with a sharply bounded strong yellow-reddish localized glowing zone (GZ) (Fig. 5). At the same time V_c reduces to 380 V. Decreasing V_0 leads to a slow reduction of I_{dis} until the HC disappears and the V_c-I_{dis} characteristic jumps back to the line with the black symbols.

The grey rectangle at the maximum of I_{dis} in Fig. 3a is shown in detail in Fig. 3b. After the onset of the HC discharge ("breakdown") and the appearance of the glowing zone, V_c passes first through a local minimum. There the GZ is still connected to the muzzle. Then a local maximum of V_c follows and the GZ detaches from the muzzle and floats freely between it and the anode ring. Thereafter V_c decreases again and the GZ disappears completely, leaving only a luminous pink sheath around the anode ring. Reducing V_0 will lead to a retraction of the characteristic and a reappearance of the GZ at a local maximum with only a slight hysteresis.



(a) **(b)**

Fig. 5. (a) Glowing zone (GZ) starts to detach from the muzzle; (b) Glowing zone floats freely above the muzzle.

Fig. 5 shows the two stages of the localized brightly glowing zone, which is very sensitive to V_0 and the current drawn. Fig. 5a shows the stage where the GZ starts to detach from the muzzle (see Fig. 3b, "Glow concentrates on the muzzle and detaches"). Fig. 5b shows the stage where the GZ is fully detached from the muzzle (see Fig. 3b, "Floating glow"). The vertical position of the GZ is very sensitive to I_{dis}. The photographs were taken with a 10,34 Megapixel (⅓" CCD) digital camera.

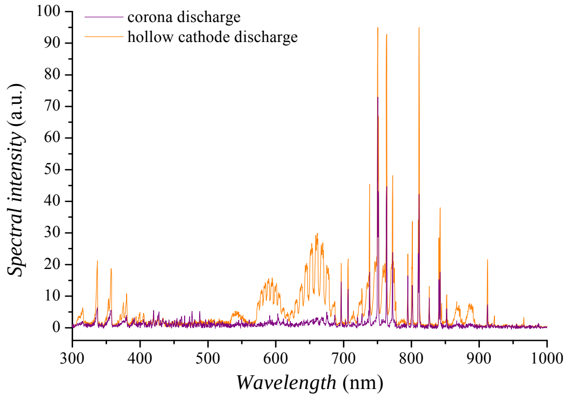


Fig. 6. Optical spectra: blue line – corona discharge regime, orange line – hollow cathode regime.

Optical emission spectroscopy was used to obtain information about the composition of the discharge plasma. A comparison of the spectrum in the corona discharge mode (blue line) and the HC discharge mode (orange line) is presented in Fig. 6, where the latter contains emission lines of argon *and* sputtered titanium. The differences of the spectra in the ranges between 550 and 700 nm and 850 and 900 nm are obvious. Especially the lines in the 550-750 nm range are typical for titanium; see also [12]. Further high resolution investigations of the optical emission spectrum are necessary for an unambiguous identification of the lines.

The HC discharge was further investigated by small Langmuir probes, which were also used as RF-probes. The fluctuation spectrum of the probe shows a sharp line in the range of 100 kHz. No high frequency signal was seen, which rules out a beam plasma discharge [13]. On the other hand, localized space charge structures like fireballs are known to show a wealth of fluctuation and oscillation phenomena [14].

Acknowledgements

The authors would like to thank Jan Kluson for his help with the hollow cathode. This work was supported by grant P19901 of the Austrian Science Funds (FWF).

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