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ON A SELF-SUSTAINED OSCILLATING MODE FOR OPERATION OF A GLOW DISCHARGE

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Abstract. A self-sustained oscillating mode for operation of a hollow cathode discharge (HCD) is analyzed based on a equivalent glow discharge RCL scheme. The oscillation takes place under i-V operating point of positive differential resistance and its frequency ($\approx$ kHz) depends on the discharge current value. The oscillation arising is found to require reasonable date values characterizing glow discharge plasma in general.

1. INTRODUCTION

Numerous glow discharge (GD) applications are based on its stable mode for operation. From another point of view, the gaseous plasma in a GD is known as a typical nonlinear dynamical "open system" with a large number of degrees of freedom. Within these frames a GD modification, i.e. hollow cathode discharge (HCD) should possess one more additional degree of freedom due to the specific Penning ionization (Dimova et al. 2004) of sputtered atoms. There are very little accessible data on this process. To date the instabilities observed are closely related to the i-V- region of negative differential resistance $(\partial U/\partial i)<0$ and a qualitative analysis is done in ref. (Zhechev et. al. 1998). In some experiments (Jung et. al. 1999) self-sustained instabilities in a HCD are observed under operating point of $(\partial U/\partial i)>0$.

In this work the origins of the self-sustained oscillating mode for operation under operating point of $(\partial U/\partial i)>0$ is studied within the frames of both space structure of a HCD and equivalent GD scheme.

2. EXPERIMENTAL

The stability of a HCD dc operation is studied at absence of any external perturbation. A standard HCD experimental set-up is used. Time-dependent change in the impedance of the discharge is detected by measuring the voltage $\Delta U(t)$ across the 50 Ω resistor R_m. The R_mC constant is low enough to allow one to resolve the shape structure of $\Delta U(t)$. The signal was sampled by the oscilloscopes LP142 and C-108. A home made HCD modification where the cathode consists of two parallel nets (20 x 20 x 20 mm) (Figure 1) is used. Here the space structure of HCD is related to various i-V operating points.

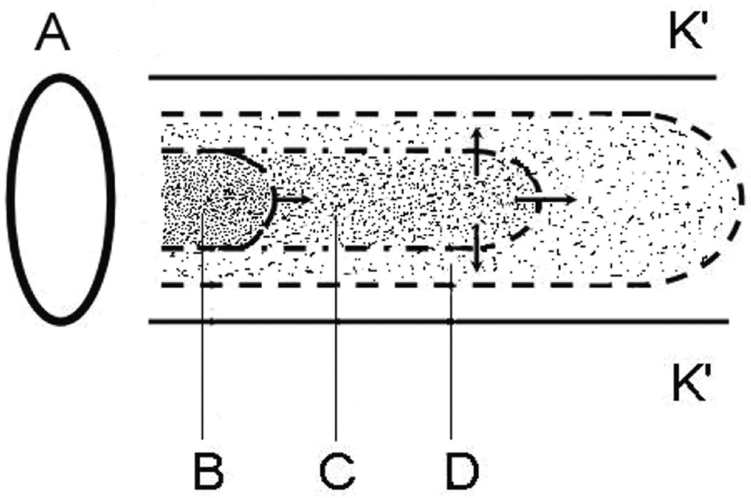

Figure 1: Macro-structure of HCD plasma bulk under p_{Ar}=0.15 Torr. **B** - initial NG under [253÷ 267] V; **C** - development of NG along the axis under [267÷ 305] V; **D** - enlargement of **C** - structure. (The conditional board lines are given by dotted ones).

3. RESULTS AND DISCUSSION

3.1. Some periodic self-sustained instabilities of various character were observed on i-V branches of both negative and positive dynamic resistance. Self-sustained oscillating mode for operation was observed under the initial i-V region of the i-V curve, where $(\partial U/\partial i) > 0$. The oscillations were localized to arise in the plasma layer **B** near the anode (Figure 1). Here a discontinuous transition of the operating voltage, i.e. 255 V - 263 V - 267 V takes place. The frequency of the oscillation is of the order of a few tens kHz and varies under these voltages. Further, the oscillating mode disappears under the voltage region 267 V - 300 V - **C** - mode. Here plasma fills up the HC cavity fractionally.

3.2. Obviously, under above points of $(\partial U/\partial i) > 0$ the discharge transforms the energy of the feed continuous discharge current into oscillating one. The transformation occurs in the anode plasma layer (APL) **B** of the NG (Figure 1). This process may be ascribed on both external inductance L (due to cables and ballast resistor, e.g. $\approx 10^{-4} \div 10^{-5}$ H) and HCD capacitance. The transformation may be analyzed qualitatively within the frames of the glow discharge equivalent electrical scheme (Figure 2)(Miniature Lamp Department, 1966).

We analyze whether a small deviation vs. the selected working point (i_0, V_0) can rise in amplitude spontaneously. Generally, the discharge current i in APL may be expressed as:

$$i = j_a V_a + C_a[dV_a/dt] + V_a[dC_a/dt) \quad (1)$$

where j_a is the plasma active conductivity, V_a voltage drop in APL. Let η is a small

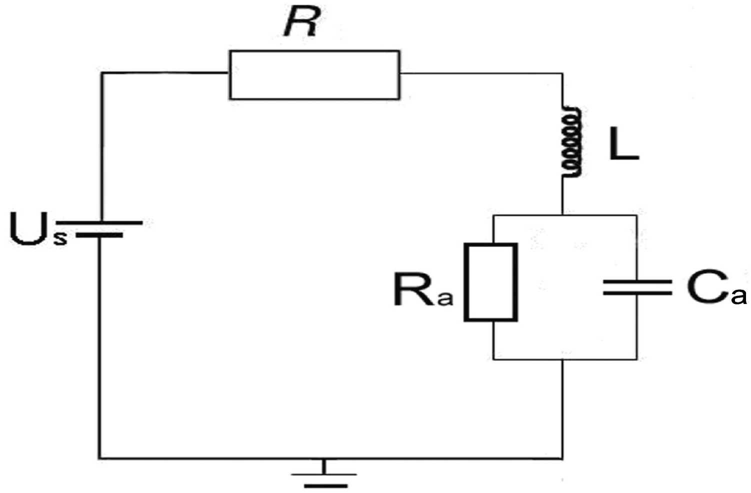

Figure 2: Equivalent scheme of a HCD: U_s - power supply, L - inductance, R - resistance of both ballast resistor and plasma bulk out of APL, R_a - APL active resistance, C_a - capacitance resistance of APL.

deviation of the continuous discharge current i_0 . Then

$$i = i_0 + \eta \tag{2}$$

and

$$V_a = V_0 + [dV_a/di]\eta = V_0 + r_{din}\eta \tag{3}$$

where r_{din} is the slope of the dynamical resistance in vicinity of (i_0, V_0). Two more equations are valid:

$$L[di/dt] + Ri + V_a = U_s \tag{4}$$

$$L[d\eta/dt] + R\eta + r_{dyn}\eta = 0 \tag{5}$$

On the other hand (Ginzburg et. al. 1967) the conductivity j_a may be taken as

$$j_a = K\omega_0\nu_{eff}[4\pi[(\omega_i\omega_e/\omega)^2 + \nu_{eff}{}^2]]^{-1} = A[B(i_0^4 + C)]^{-1}$$

where

$$A = K{\omega_0}^2\nu_{eff}$$

$$C = \nu_{eff}^2 B^{-1}$$

$$B = 64\pi^4 e^4 (c^8 r^4 M^2 m^2 \omega^2)^{-1}$$

and $\omega_{i,e}$ is Larmor's frequency of either ions (*i)* or electrons, ν_{eff} - frequency of pulse transferring collisions *electron* (mass *m*) → *heavy particle* (mass *M*), K - coefficient related to the discharge geometry.

The substitution of Eqs (2) and Eqs (3) in Eqs (1) and Eqs (4) and the relation $i_0(A,\ B,\ C)$ give the standard equation of the type

$$a(\partial\eta/\partial t)^2 + b(\partial\eta/\partial t) + d = 0$$

where the coefficients a, b and d represent functions of the above signification A, B, C, L, R, V_0, η, i_0 and of value D, characterizing the plasma dielectric property. In particular, $d = B\eta\ i_0(C\ \text{-}\ Di_0^2)$. The positive solution of the interest $\partial\eta/\partial$t$>$ 0 takes place at $d < 0$. It means $i_0 > (C/D)^{1/2}$. Reasonable values of both circuit and HCD plasma answer the requirements of this inequality. A rod - like anode used in some commercially available HCD lamps has been taken in this consideration.

4. CONCLUSIONS

Self-sustained oscillating instabilities are found to arise under i-V region of both negative resistance $(\partial U/\partial i) < 0$ (frequency of Hz) and positive resistance $(\partial U/\partial i) >$ 0. At $(\partial U/\partial i) > 0$ the instability takes place in two cases: under i-V point close to the critical low one (kHz) and under i-V point close enough to the inflection point. Here period-doubling is observed as a transition to chaos-like state. The self-sustained instabilities correlate with the plasma structure development. The oscillating mode for operation at $(\partial U/\partial i) > 0$ is found to arise under combination of reasonable parameters of a HCD plasma.

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