Chaotic-to-ordered state transition of cathode-sheath instabilities in DC glow discharge plasmas

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Abstract. Transition from chaotic to ordered state has been observed during the initial stage of a discharge in a cylindrical DC glow discharge plasma. Initially it shows a chaotic behavior but increasing the discharge voltage changes the characteristics of the discharge glow and shows a period subtraction of order 7 period → 5 period → 3 period → 1 period, i.e. the system goes to single mode through odd cycle subtraction. On further increasing the discharge voltage, the system goes through period doubling, like 1 period → 2 period → 4 period. On further increasing the voltage, the system goes to stable state through two period subtraction, like 4 period → 2 period → stable.

Keywords. Cathode-sheath; instabilities; chaos; period subtraction; bifurcation; DC discharge.

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1. Introduction

Nonlinear phenomena are abundant in nature and laboratory plasma. Plasma is a typical nonlinear dynamical system with a large number of degrees of freedom, and a medium for testing a wide variety of nonlinear phenomena such as self-oscillation, period doubling, bifurcation, period subtracting, period adding, chaos, intermittency etc. [1,2]. Characteristics of chaos have been observed in externally driven and self-driven plasma systems. In externally driven systems, chaotic behavior can be seen in pulsed plasma discharge and period doubling cascade to chaos in thermionic plasma discharge [3], and in self-driven case, i.e using no external perturbation in the system, periodic to chaotic transition has been observed [4,5]. Experiments on plasma that exhibits period doubling and chaos using external driver (oscillator) in a double plasma device has been done by Ohno et al [6]. The period subtracting phenomena, have been observed in externally driven ion-beam plasma systems [7]. In this experiment oscillation periods decrease in the sequence 6 period → 5 period → 4 period and so on. Another phenomenon in the driven
plasma system is period adding opposite to the period subtracting. Here periods successively increase with control parameters.

In all the above-mentioned experiments, the fluctuations are observed in the bulk region of the plasma, whereas in the present experiment we are reporting the chaotic oscillation, period subtraction and period doubling phenomena that are observed in the sheath region. The plasma sheath is a region with large electric fields where charged particles can encounter acceleration to high energies. This can give rise to various types of fluctuations through wave particle interaction. These reasons motivated us to investigate the fluctuations in the sheath region of a cylindrical DC glow discharge plasma. Moreover, the sheath region is important from the application point of view like material processing, dust levitation etc. Chaotic oscillations were observed during the initial phase of high pressure discharges. With increase in the discharge voltage it goes to an ordered state through period subtraction and finally the modes vanish and the plasma becomes stable via period doubling and period subtraction.

2. Experimental set-up

The experiment was carried out in a coaxial cylindrical DC glow discharge system with argon as shown in figure 1. The hollow stainless steel (SS) outer cylinder of 45 mm diameter is the cathode and the SS rod of 1 mm diameter inside the cathode is the anode, which is grounded. The whole system has been placed in a vacuum chamber and evacuated to a base pressure of 0.001 mbar by means of a rotary pump. Argon gas is introduced into the chamber using precision needle valve. Neutral gas pressure has been maintained at a particular pressure and discharge voltage to initiate a glow discharge plasma. A Langmuir probe made of tungsten has been used to measure floating potential fluctuations. It is of diameter 0.2 mm and length 4 mm, and movable along the plasma column. The probe holder is also very thin with a diameter of 2.5 mm and made of glass. The probe was kept at one location and the experiment was carried out, instead of inserting the probe after plasma was formed, and hence the disturbance to the plasma conditions were much less. It is connected to the digital tektronix oscilloscope. The probe was placed in the sheath region, i.e. about 0.5 cm from the cathode wall. Data have been transferred to the computer through the USB port.

3. Results and discussions

Though plasma could be formed at low pressures, the chaotic oscillations in the floating potential were observed only above 0.4 mbar. The present experiments were carried out at a neutral gas pressure of 0.95 mbar of argon. At this particular pressure the discharge voltage between the anode and the cathode was increased slowly till the discharge was obtained at 283 V. The DC floating potential is about $-21$ V. AC fluctuations are recorded through oscilloscope. The plasma density in the bulk region was about $3 \times 10^7$ cm$^{-3}$, and temperature $T_e$ $\approx$ 2–8 eV. At this voltage the fluctuating signal and its power spectrum are shown in figure 2a (raw data), figure 2b (corresponding power spectrum), and figure 2c (phase-space plot).