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The nonlinear dynamic behaviors in an undriven direct current glow discharge: bifurcation-remerging process, intermittency and hysteresis

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It is widely believed that a nonlinear physical system which far from thermodynamic equilibrium state can exhibit complex dynamic behaviors with regular or irregular structures in time and/or space domains. As a typically complex nonlinear medium, deterministic chaos in laboratory plasmas has been extensively demonstrated both experimentally and numerically over the last decades[1-3].

Due to the existence of the negative differential conductivity (NDC), discharge plasmas operating in the subnormal glow discharge regime can exhibit self-sustained oscillations regardless of the presence of the external driving forces, which can be observed by recording the macroscopic electrical signals[4,5]. The charge-breakdown-discharge process is repeated within the system during the self-sustained oscillation. Meanwhile, it has been suggested that a variety of complex bifurcations can be observed as the discharge parameter changes. Several transition routes to chaos have been reported, such as the period-doubling bifurcation sequence, the quasi-periodicity route, and the intermittent chaos route. Although outstanding achievements in the study of the complexities of gas discharge plasma have been made, most previous studies only go as far as describing experimental phenomena. Due to the limitation of measurement accuracy and the inevitable influence of noise, some discharge phenomena have not been consistently and reasonably explained, and the variation of discharge modes with external control parameters is not entirely clear. The study of nonlinear phenomena in gas discharge plasma contributes to our understanding of the plasma discharge process with the aim of eventually controlling chaos in low-temperature plasma. In addition, it is also important for research on relaxation oscillators in the fields of electronic circuits and neurodynamic.

In this study, a two-dimensional plasma fluid model is established coupled with a circuit model as a boundary condition. Using the applied voltage U_0 as the first control parameter in the simulation, the complete period-doubling bifurcation and the inverse period-doubling bifurcation processes in the oscillatory region are found (as shown in Fig.1(a)-(c)). A series of periodic windows are present in the chaotic region and the type-I intermittent chaos appears near the periodic window. Then the pressure is chosen as the second control parameter, and the influence of pressure on the dynamic behavior is investigated. A two-parameter map of the dynamic behavior is obtained by introducing the pressure as the second parameter and the influence of the pressure on the dynamic behavior is studied. The results show that increasing the pressure can have a similar effect on the discharge mode transition processes as increasing the applied voltage U_0 and the chaotic oscillations exist only under certain parameter range. In addition, it was found that the dynamic behavior of the system also depends on the initial condition and there is a hysteresis between the oscillatory regime and the stationary regime.

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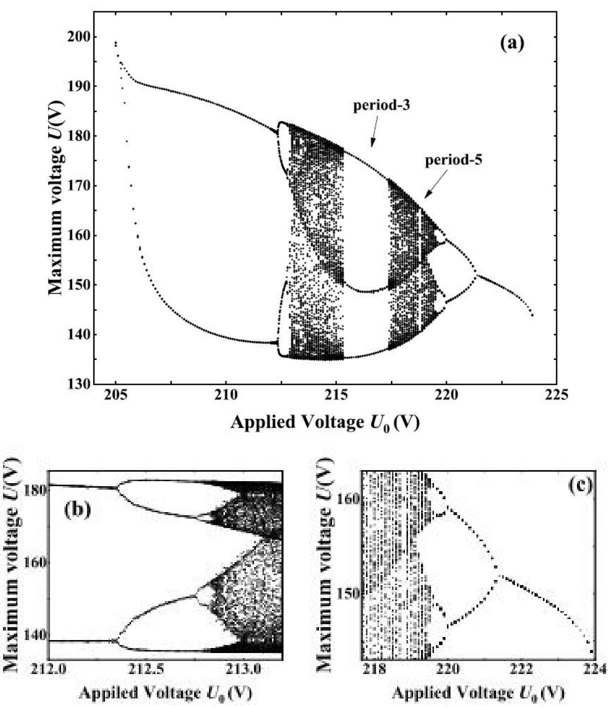

Figure 1. (a) Amplitude bifurcation diagram (b) Period-doubling bifurcation process. (c) Inverse period-doubling bifurcation process.