Study of low pressure gas discharge plasma by using nonlocal approximation

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Since the realization of gas discharge plasma in the laboratory at the beginning of the last century, the theory of gas discharge plasma and its applications have been fully developed. Gas discharge plasma has realized important applications in daily life. It has made significant contributions to science and technology, and has created great social wealth. With the development of these technologies, the control requirements of gas discharge plasma has become more and more demanding and needs more sophisticated theories and methods. Currently, kinetic theory is a commonly used tool to describe gas discharge plasma. Many applicable theories based on the Boltzmann equation have been developed, among which the local approximation theory has been widely used. However, the local approximation theory ignores the spatial gradient term when describing the gas discharge plasma, which is difficult to apply under conditions such as low pressure. Therefore, the non-local approximation theory has been developed to solve the problems related to the spatial gradient, especially the influence of the spatial gradient on the plasma characteristics at low pressure.

Here we present the local approximation and nonlocal approximation kinetic theory model of gas discharge low-temperature plasma. Firstly, based on the kinetic theory of gas discharge plasma, using the local approximation of the Boltzmann equation, a two-dimensional fluid model is developed to study the effect of pressure on the discharge characteristics of gas discharge plasma. The distributions of the electron density, electron temperature, electric field and mean free path, etc., are obtained and used to discuss the discharge characteristics and physical connotation of hollow cathode discharge in the coaxial grid under different pressure. It is found that, under low pressure conditions, a high-density negative glow plasma is formed inside the hollow cathode due to the hollow cathode effect. The discharge exhibits an obvious layered structure of the cathode sheath-negative glow region. With the gradual increase of pressure, it is observed that both the cathode sheath region and the negative glow region are contracting and eventually the negative glow region no longer overlaps. The Faraday dark region is formed after the negative glow region, in which the electron density and the excited argon atoms density decrease significantly. Additionally, the electron energy mean free path is further investigated to obtain the applicability of local approximation and nonlocal approximation at different pressures (figure 1).

Then the spatially averaged Holstein-Tsendin nonlocal approximation of the Boltzmann equation is used to study the effects of the metastable atoms in gas discharge plasma on the plasma electron distribution function and plasma-related reaction characteristics. The superelastic collision between electrons and metastable atoms will strongly affect the shape of the electron distribution function and the reactions rate constant. The duplication of the electron distribution function will appear with the excitation threshold period.

References
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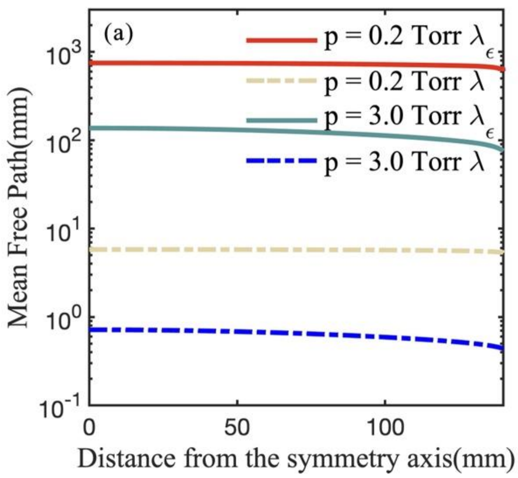

Figure 1. Mean free path of electron and electron energy at low pressure (0.2 Torr) and high pressure (3.0 Torr).