Filamentation of Capacitive Radio-Frequency Discharge at Low Pressures

S.A. Dvinin and Z.A. Kodirzoda

Lomonosov Moscow State university, Moscow, Russia, [s\_dvinin@mail.ru](mailto:s_dvinin@mail.ru)

Discharge instabilities, resulting in failure of uniform plasma density distribution, may occur [1 – 3]. The model [1] associates these instabilities with the peculiarities of transfer processes in the non-Maxwellian electron energy distribution function. In this paper we consider the stability of capacitive gas discharge between two cylindrical electrodes with height L radii R1 and R2 at low pressure. To construct electrodynamic model the existence of plasma sheathes with thicknesses d1 and d2 are taking into account. d1 and d2 values are calculated as a function of electron density, temperature and electric field strength [4], using matrix sheath model [5]. Assuming that the electrode potential is *U*=*U*S–*Z*S*I*, where *U*S, *Z*S are e.m.f. and internal impedance of RF source, we will find that electron density n evolution is described by equation

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where *F*(*N*)={*F*1(*N*)–1}*N*, *F*1(*N*)=*ξ*{(1–*N*)2+*N*2ν2/ω2}–γ, *N*=*n*(*R*2–*R*1)/*n*C/(*d*1+*d*2), *n*C=*m*ω2/4*πe*2, *ξ*0*=νi*0*Λ2/D*a, *ξ=ξ*0(*U*/*US*)γ. In analytic model we use power approximation for ionization frequency *ν*i*=ν*i0(*E*/*E*0)γ, Da is ambipolar diffusion coefficient and Λ is transversal diffusion length. Value *N*= 1 corresponds to geometric plasma sheath resonance [6].

This resonance leads to a considerable reduction in discharge voltage, when whole discharge chamber is filled by plasma. When plasma occupies only part of discharge chamber, empty region without plasma has capacitive impedance, but its capacitance is small due to large distance between electrodes. It is shown that for large electrodes R2–R1<<R2 the uniform density distribution in the discharge may be unstable if the frequency of supporting HF field will be higher than the frequency of the geometric plasma-sheath resonance, and the output impedance of the RF generator is large enough. When the discharge is powered by a voltage source, electron density occupy whole chamber. If HF source has rather high internal source resistance filamentation of discharge can be observed.

According to simple analytical model, assuming that electromagnetic field distribution in any radial section of discharge is determined by plasma space distribution in same section, the size of filament decreases with increasing internal resistance of the source and increases with a decreasing of gas pressure due to increased intensity of transport processes. Analytical calculation is confirmed by numerical simulation.

References

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