Abstract

It is a fact that an anode introduced in a plasma chamber with adequate potential biasing can trigger the formation of a dim glow in the sheath region. This dim glow of light resulting from the collisional excitation and de-excitation processes is popularly termed as 'plasma fireball'. The strong anodic electric field thereof accelerates charges within the sheath region inducing electron-neutral collisions. These collisions can excite and ionize the neutrals in the experimental plasma chamber. The release of this excited energy occurs through visible light emission forming the plasma fireball glow across the sheath region. Besides, the plasma-electrode interaction can also excite several plasma instabilities during the formation of the plasma fireball glow. These specific possible plasma instabilities are classified herein as plasma fireball instabilities. This thesis is compiled with analyses on a few of such plasma fireball instabilities. The analyses are done using linear, quasilinear, and nonlinear perturbation formalisms on both the regular fireball and inverted fireball cases. These three formalisms individually manifest the behaviour of the plasma fireballs and excited instabilities during various stages of their lifetime. The possible fireball model applications in both applied and pure fields of research are summarily highlighted. This thesis offers a perturbative model study for the different plasma fireball instabilities under different realistic circumstances multi-parametrically. The outcomes of this thesis chapters deepen the basic understanding of diverse plasma fireball instability patterns in an organically well-linked manner.

*In **Chapter-1**, we present a brief overview of the plasma medium and plasma fireball formation. This comprises of the various properties of plasma medium, condition of plasma existence, fluid model approach, and so forth. Besides, the formation mechanism of plasma fireball, different plasma fireball classes, associated instabilities, various possible applications of fireball model are discussed. The motivation and objectives of fireball analysis are also finally outlined. The methodological framework utilized for the respective studies to fulfil the objectives are also briefly discussed.*

*In **Chapter-2**, we analyse the sheath plasma resonance (SPR) in an inverted fireball (IFB) developed inside a spherical hollow anode in a usual laboratory two-component plasma system. The SPR occurs when the fluctuating electric field (at radio frequency) of the anode drives plasma oscillations beside the sheath at a frequency on the order of the ion-plasma oscillation frequency (sheath eigenmode). This frequency matching between the anode electric field fluctuations and ion-plasma oscillations*

triggers the SPR in the plasma system. It is noteworthy here that the SPR analysis inside an IFB is first of its kind known so far in the literature. This builds up the primary novelty and motivation behind this proposed SPR research in IFBs against those previously reported central anode arrangements.

In addition to the above, the obscure influence of various relevant plasma parameters on the SPR formation also motivates plasma scientists for comprehensive multi-parametric SPR research globally. The SPR-driven IFB system is studied using a linear small-scale perturbation formalism (linear normal mode analysis). The quartic (fourth-order) dispersion relation (DR) resulting from the small-scale linear perturbation after a standard method of decoupling is solved both analytically and numerically. This assures the analytical accuracy of the analysis accomplished with experimentally reported parametric values. The damping of the SPR at the IFB centre is noticed and it is observed to behave as a cavity resonator under certain critical values of the SPR frequency. The applications of both the IFB and the SPR are outlined summarily.

*In **Chapter-3**, we analyse the plasma fireball sheath instability using a standard technique of quasilinear (first-order nonlinear) perturbation formalism. The development of a quasilinear formalism of plasma fireball sheath instability has not been reported elsewhere. This serves as the primary motivation for this quasilinear instability analysis. The quasilinear formalism reduces the analysis into a second-order nonhomogeneous differential equation with variable coefficients. The methodological application of the boundary conditions on the numerical solution of the differential equation yields atypical peakonic patterns. The peakonic patterns form a special class of peaked solitons, where nonlinear effects dominate over smooth linear dispersive effects. The analytical model-based results are compared with the available experimental reports. The technological applications of plasma fireball sheath instability are also outlined summarily.*

*In **Chapter-4**, we analyse the sheath plasma instability (SPI) in a spherical inverted fireball (IFB) system using a quasilinear model formalism. The novelty of quasilinear SPI analysis in IFB systems is the principal motivational force for this analysis. The model confirms the evanescent and standing wave-like behaviour of potential and field perturbations inside the IFB as experimentally reported. The electrons are proven to have a nonzero inertia during the SPI excitation. The same also yields a* $180°$ *phase difference in between the electric field and electronic (ionic) velocity. This work proves the efficacy of both bifluidic plasma model and the quasilinear analysis in dealing with SPIs in the IFBs. The applications of SPI excited IFB models across the*

plasma environments, such as the laboratory plasma, space plasma, and astrophysical plasma are elaborately presented at the end.

*In **Chapter-5**, we analyse the plasma fireball sheath instability excitable up to its fourth-order of nonlinearity. The investigation of the influence of nonlinearity enhancement on the fireball sheath instability is the main motivation for this higher-order nonlinear analysis. The analysis is carried out through the resultant nonhomogeneous differential equations (DEs) with variable multi-parametric coefficients. The saturation of the instability with the increasing nonlinearity is unequivocally proved. The physically feasible numerical solutions are finally shaped by neglecting the redundant terms using the boundary conditions. Since, nonlinearity is the final stage of an instability after its linear and quasilinear stages. Therefore, this work manifests the final phase of plasma fireball sheath instability through the nonlinear perturbation and apparent saturations.*

*In **Chapter-6**, all the specific major outcomes from the respective compiled chapters are pointwise outlined. The systematic fulfilment of the objectives through these chapters, possible future refinements in the fireball model, various applications of the fireball model are summarily highlighted. The non-trivial future scopes of the entire thesis are finally indicated alongside the inherent facts and faults.*

Keywords: *Plasma fireball, regular fireball, inverted fireball, instability*