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Transverse Fluctuations and Their Effects on the Stable Functioning of Semiconductor Devices

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Abstract: Semiconductor plasma is often found in chaotic unpredictable motion which shows some anomalous behaviors providing multiple challenges to work with the instabilities in a semiconductor device. Experimental studies have shown that these instabilities give rise to fluctuations and azimuthal non-uniformities, which are usually present in the semiconductor. The energy fluctuations have also been observed in some of the cases. In this paper, we have obtained the fluctuations in velocity field by integrating the linearized governing hydrodynamic equations with RungeKutta method of order four (RK4). Then, we have come up with a mathematical formulation, where these fluctuations can be obtained from a KdV family equation with homotopy-assisted symbolic simulation. We have also obtained the relative velocity between the solitary structures for different parameters. Finally, by giving a detailed explanation of the behavior of semiconductor devices, we can study the usefulness of formulating the plasma waves in the various regime, and predict their characteristics theoretically.

Keywords: Semiconductor plasma, Quantum degeneracy, Transverse fluctuation, Simulation, Quantum Hydrodynamics model, RungeKutta method

1. Introduction

In the context of the technological revolution in the 21st century, semiconductor plasma has been playing a major role since the last few decades in the solid-state electronics industry. Their study has been increasing exponentially with time [1]. Following, electron-hole plasma is found in high speed, high power semiconductor switches, and oscillators [2]. Plasma Processing of Semiconductors contains many contributions and covers plasma etching, plasma deposition, plasma-surface interactions, numerical modeling, plasma diagnostics, less conventional processing applications of plasma, and industrial applications [3, 4]. Their properties are used to describe the operation of high-gain photoconductive semiconductor switches (PCSS), resonant tunneling diodes, impact ionization avalanche transit time (IMPATT) devices and Gunn oscillators [5-10]. Models for electronic polarizability, plasma resonances, transit time effects, and plasma cooling in diodes, transistors, 2-dimensional field-effect transistors (FET), and quantum wires need to depart from the single particle interactions and include collective, many-body effects and hydrodynamic equations to agree with the experimental results. From the above argument, it is evident that we are way behind the point of applicability of semiconductor plasma studies in real life. However, a proper analytical and simulation study of semiconductor plasma can revolutionize the field of computation and electronic devices was presented by Lu *et.al.* [11]. It can greatly enhance the stability and predictability of the said devices. Keeping that in mind, we have tried to obtain the behavior of quantum plasma, considering three species in the system. In this context, the problem of exotic plasma is extensively studied by many research groups [12-17]. The same has been done for ion-acoustic mode in and electron acoustic mode in [18, 21, 22].

Nonlinear Fluctuations: The theoretical investigation of the nonlinear interaction of waves has been associated with numerous experiments. Nonlinear effects can be classified in plasma according to their degree of nonlinearity [23-26]. These plasma waves can evolve and form rogue waves as shown by some researchers [27-28]. The method of three-wave interaction is used to study nonlinear processes, where the energy of nonlinear interaction [29]. Is lower than that of interacting waves. This theory was first applied to the finite and inhomogeneous medium in the three-wave processes. The nonlinear mechanisms operate in multiple layers and are described by the terms appearing in the governing equations [30]. In periodic structures, the nonlinear excitation of the second harmonic can be investigated. The features of a nonlinear interaction arise from the periodicity of the potential structure [12, 31, 32]. The nonlinear resonance means that the matrix nonlinear element of the wave interaction is independent of the z coordinate within the nonlinear layers [33]. In a semiconductor periodic structure, the three-wave interaction happens which pumps the energy from the waves with lower frequencies to the waves with higher frequencies. The periodic structures are very effective for the efficient generation of waves, which may be used for frequency multiplication, conversion, studies of physical parameters of structures, etc.

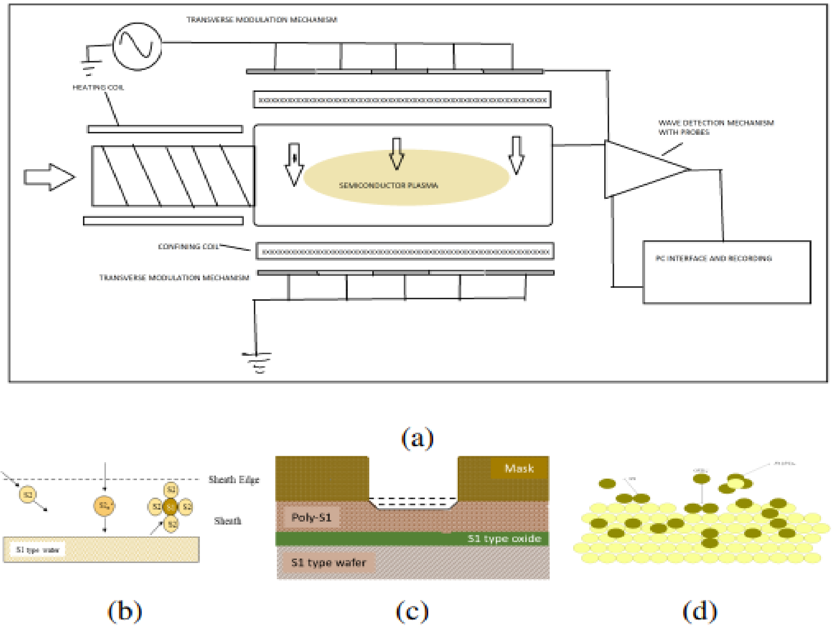


Figure 1. Schematic experimental Setup and formation of semiconductor plasma

As we know that plasma state is a non-equilibrium state having a very high collective fluctuation level so that the nonlinear interaction between the modes becomes essential. To form a quantitative theory of plasma turbulence, one must allow the non-linear wave interactions inside the plasma [34]. The non-linear fluctuation theory is applied to study the electromagnetic fluctuations in a non-equilibrium plasma and their time evolution; peculiar features of the fluctuation spectra [35] are associated with particle collisions and non-linear wave interactions [29] in non-linear plasma. Fluctuations and nonlinear Wave Interactions are a theory of fluctuations in a homogeneous plasma [36].

Table 1. Typical values of the parameters for different semiconductors

Material	n_0 in cm^{-3}	m_e^* in m_eg	m_h^* in m_eg	ϵ
GaAs	4.7×10^{16}	0.067	0.5	12.8
GaSb	1.6×10^{17}	0.047	0.4	11.3
InP	5.7×10^{17}	0.077	0.6	12.6

The spectral distribution of stationary field fluctuations [37]. is determined and the possibility of induced fluctuation enhancement by external fields and the scattering and transformation of waves and radiation in non-equilibrium plasma can be studied based on a generalized kinetic equation allowing for interaction between waves and fluctuation fields in plasma [38]. Fluctuations inside a semiconductor plasma are highly related to the temperature profile inside a plasma. When fluctuations are excited in plasma, the ion temperature becomes high. Electron density fluctuations in a two-component plasma of electrons and positive ions are developed within the random phase approximation. A dielectric formulation is used extensively to describe the fluctuations [39-41]. investigation of various examples clarifies such facts as collective vs. individual particle aspects of fluctuations [42, 43]. B. Experimental Observations From the words of Maude, we learn that, for both low (2-20kHz) and intermediate frequency (20-100kHz) range experimental observations, there may be oscillations in crossed field closed electron drift hall discharges which can be useful for identification and extraction of properties of coherent structures associated with different plasma instabilities within the discharge channel [44]. Hence we can analyze the phase velocity over the various frequency range. Under external magnetic field as given in [45]. This phenomenon evidences how fluctuations can be influenced in this hall discharges and opens up another interesting field Quantum Hall Effect under low pressure in semiconductor plasma due to many body effects. Here we consider different general states with different spin polarization at any given fraction and hence observe the quantum phase transition as a function of the energy which is changing with the spatial separation for different magnetic field strength [46]. This kind of nonlinear dynamical behavior of electron discharge is useful in the enhancement of turbulence which influences the axial electron transport widely used in generating a relatively high-velocity ion beam used in stationary plasma thruster for space propulsion application [47]. Fig. (1d) show an experimental setup with GaAs semiconductor plasma under the external electric and magnetic field where fluctuations in energy arise due to the influence of Fermi pressure on interacting electrons, ions, and holes. Related works can be found in the works of Markowich Herbots and others [48-51].

2. Mathematical Formulations

2.1. Quantum Hydrodynamics

The theoretical description of quantum plasmas must consider quantum degeneracy effects such as non-locality, spin-statistics, and correlations (non-ideality) appropriately on the relevant scales [52, 53]. In such cases where correlations and their dynamics are of minor importance, simpler approaches such as Quantum hydrodynamics (QHD) is being used for quantum plasmas [13, 54-57]. In the framework of the local density approximation of the free energy for finite temperature plasmas, QHD theory is consistently derived with first-order density gradient correction. The key ingredients of QHD are often used for the ideal Fermi pressure and the socalled Bohm potential in the context of quantum plasmas. The random phase approximation (RPA) must be corrected by constant pre-factors for both the Fermi pressure and the Bohm potential to reach an agreement with the results of the more fundamental kinetic theory in its simplest form [58-60]. For the QHD model, a fully non-local Bohm potential goes beyond all previous results and is linked to the electron polarization function in the random phase approximation. For the case of the relaxation time approximation the dynamic QHD exchange-correlation potential is introduced in the framework of local field corrections

[54,61,62]. In lower dimensions, the consistent derivation of the quantum potential can be used for the formulation of a QHD model for confined electrons.

2.2. Governing equations

Here, we consider a collision less, inhomogeneous electronion plasma. For all the mathematical purposes, we have modelled our system as three species plasma using QHD model equations [63, 64, 66, 67-75, 76-83]. Let us consider an electron fluid with number density ne, fluid velocity u_e, charge −e, mass m_e, exchange correlation potential V_{xce} and scalar quantum degeneracy pressure P_e. Similarly, we take ions with number density n_i, fluid velocity u_i , charge e, mass mi and holes with number density n_h, fluid velocity uh, charge e, mass m_h, exchange correlation potential V_{xch} and scalar quantum degeneracy pressure P_h. Taking electrostatic potential ϕ, we get the following governing equations where

$$\mu_{h,i}=\frac{m_e^*}{m_{h,i}^*},A_e=\frac{1}{K_BT_{Fe}},A_h=\mu_hA_e,B_e=\left(\frac{\pi n_{e0}^2}{3}\right)^{\frac{1}{3}}\frac{\pi\hbar^2}{m_e^*K_BT_{Fe}},\ B_h=\left(\frac{\pi n_{h0}^2}{3}\right)^{\frac{1}{3}}\frac{\pi\mu_h\hbar^2}{3m_h^*K_BT_{Fe}},K_BT_{Fe}=\frac{\hbar^2}{2m_e^*}\left(3\pi^2n_{e0}\right)^{2/3},\ \delta$$

is the holeto electron equilibrium density ratio, $H=\frac{\hbar\omega_{pe}}{2K_BT_{Fe}}$ is the quantum diffraction parameter, and $\omega_{pe}=\sqrt{\frac{4\pi e^2n_{e0}}{m_e^*}}$ is the plasma frequency, $R_j=\frac{eB_0C_s}{cE_{Fi}\omega_{pi}}$ is the normalised cyclotron frequency of j^{th} species. At equilibrium, the charge neutrality condition $n_{e0}=n_{i0}+n_{h0}$ is applied.The physical quantities in Eqs. (1)–(5) are appropriately normalized by the transformation

$x\rightarrow\frac{x\omega_i}{c_s},\ t\rightarrow t\omega_i,\ \phi\rightarrow\frac{2K_BT_{Fe}}{e}\phi\ ,\ n_j\rightarrow\frac{n_j}{n_0},\ u_j\rightarrow\frac{u_j}{c_s}$ For detailed calculation refer to the works of Das et al [6]. Eq. 1 represents the continuity of electrons, holes and ions respectively. While Eq. 2, Eq. 3 and Eq. 4 represent the momentum equations in that order. Eq. 5 is the Poisson's equation for this system (one dimensional time independent potential). A detailed explanation of the equations has been given in [84-85].

$$\frac{\partial n_{e,h,i}}{\partial t}+\frac{\partial n_{e,h,i}u_{e,h,i}}{\partial x}=0 \tag{1}$$

$$\left(\frac{\partial}{\partial t}+u_e\frac{\partial}{\partial x}\right)u_e-\mu_e\frac{\partial\phi}{\partial x}-R_ev_{e\perp}+A_e\frac{\partial V_{xce}}{\partial x}+B_en_e^{-\frac{1}{3}}\frac{\partial n_e}{\partial x}-H^2\frac{\partial}{\partial x}\left(\frac{1}{\sqrt{n_e}}\frac{\partial^2\sqrt{n_e}}{\partial x^2}\right)+v_eu_e-\eta_e\frac{\partial^2u_e}{\partial x^2}=0 \tag{2}$$

$$\left(\frac{\partial}{\partial t}+u_h\frac{\partial}{\partial x}\right)u_h+\mu_h\frac{\partial\phi}{\partial x}-R_hv_{h\perp}+A_h\frac{\partial V_{xch}}{\partial x}+B_hn_h^{-\frac{1}{3}}\frac{\partial n_h}{\partial x}-\mu_h^2H^2\frac{\partial}{\partial x}\left(\frac{1}{\sqrt{n_h}}\frac{\partial^2\sqrt{n_h}}{\partial x^2}\right)+v_hu_h-\eta_h\frac{\partial^2u_h}{\partial x^2}=0 \tag{3}$$

$$\left(\frac{\partial}{\partial t}+u_i\frac{\partial}{\partial x}\right)u_i+\mu_i\frac{\partial\phi}{\partial x}=0 \tag{4}$$

$$\frac{\partial^2\phi}{\partial x^2}=n_e-\delta n_h-(1-\delta)n_i \tag{5}$$

Here we have considered that the ions form a stationary background for the mobile electrons and holes. The various terms in the momentum equation represent different dynamical factors [86], considered in this model. These are given below.

a) Momentum flux across boundary: The first term gives the conservation of momentum flux and thereby quantifying the difference between the influx and outflux of the momentum. This unbalance is later described by the rest of the terms.

b) Electromagnetic force: The second term, given by the spatial derivative of electric potential times the charge of the particles, gives the electric Lorentz force acting on the particles. It is then divided by the mass of the constituents to be incorporated into the momentum equations.

c) Exchange and correlation effects: The third term incorporates exchange and correlation effects as given by Manfredi et al. [87]. The effect of this term has been demonstrated in [88] for semiconductor plasma, in [89] for single-walled carbon nanotubes and in [87] for thin metal films. Here, Vxc is given by Eq. (6).

$$V_{xc} = -0.985\frac{e^2}{\epsilon} n_e^{1/3}\left[1+\frac{0.034}{a_B n_e^{1/3}}\ln\left(1+18.37 a_B n_e^{1/3}\right)\right] \quad (6)$$

Here, αB* is the Bohr radius and ϵL is the dielectric constant. This term is present in the equations for electrons and holes but they are excluded in the momentum transfer equation of ions since they are assumed to form a stationary background.

d) Quantum degeneracy pressure: When the electrons and holes are shrunk into the degenerate energy levels, they tend to act against it and rearrange themselves into a more relaxed state. This phenomenon gives rise to quantum degeneracy pressure. Since we have Fermions like electrons and holes on our hand, for our studies we will use Fermi pressure as given in contrary to the relativistic degeneracy as given in [90-93]. It is expressed mathematically in Eq. (7).

$$P = \frac{\left(3\pi^2\right)^{\frac{2}{3}}\hbar^2}{5m} n^{\frac{5}{3}} \quad (7)$$

We have taken the divergence of the Fermi pressure and divided it by mass and number density to incorporate into our momentum conservation equation. Ions are assumed to be immobile. Hence they don't contribute to the Fermi gas. Thus there is no point in incorporating the pressure term in the momentum equation for ions.

e) *Bohm potential*: The central concept of one of the de Broglie–Bohm formulations of quantum mechanics is the quantum potential, introduced by David Bohm in 1952 [94-96]. It is previously known as quantum-mechanical potential, subsequently quantum potential. Later Bohm and Basil Hiley elaborated in its interpretation as an information potential that acts on a quantum particle [97]. It is sometimes known as quantum potential energy, Bohm potential, quantum Bohm potential or Bohm quantum potential [98]. In the de Broglie–Bohm theory, the quantum potential is a term within the Schrodinger equation to guide the movement of quantum particles. The difference of the Weyl and Riemann scalar spatial curvature is produced by an ensemble density of paths associated with one, and only one particle can be shown due to the proportionality of Bohm's quantum potential $V_Q = -\frac{\hbar^2}{2m}\frac{\partial}{\partial x}\left(\frac{1}{\sqrt{n}}\frac{\partial^2\sqrt{n}}{\partial x^2}\right)$, where $-\frac{\hbar^2}{2m}$ is the constant of proportionality. It can be generalized to the relativistic case. The Schrodinger, Klein–Gordon and Dirac equations can be derived by this geometrization process of quantum mechanics. The Bohm interpretation is based on these principles [99, 100, 95, 96, 101].

- Every particle travels in a definite path [97].
- The state of N particles is affected by a 3N dimensional field, which pilots the motion of the particles. This field evolves according to the Schrodinger equation. The positions of the particles do not affect the wave function corresponding to the field.
- Each particle must have momentum and with probability density, the particles form a statistical ensemble.

f) *Viscosity:* Viscosity term is responsible for plasma wave amplification and hence generating instability [102–104]. This kind of phenomenon is applied to study electron transmission in solid-state electronic devices. There can be both drift and diffusion due to this viscosity term which stabilizes the plasma waves.

2.3. Perturbation

The following perturbation expansion has been used for our system:

$$\psi = \psi^{(0)} + \sum_{n=1}^{\infty} \varepsilon^{n+1}\psi^{(n)}$$ where

$$\psi = (n_e, n_h, n_i, u_e, u_h, u_i, \phi) \text{ with}$$
$$\psi^{(0)} = (1,1,1,0,0,0,0),\ \nu_e = \grave{o}^{3/2}\nu_{e0},\ \nu_h = \grave{o}^{3/2}\nu_{h0},\ \nu_{e\perp} = \varepsilon^{3/2}\nu_{e\perp 0},\ \nu_{h\perp} = \varepsilon^{3/2}\nu_{h\perp 0},\ \eta_e = \varepsilon^{1/2}\eta_{e0},\ \eta_h = \varepsilon^{1/2}\eta_{h0}$$

2.4. Stretching

Additionally, we have used the following stretching terms $\xi = \varepsilon^{1/2}(x - \lambda t), \tau = \varepsilon^{3/2}t$

2.5. KdV-like equation

Using the governing equations and the perturbation relations along with the stretching terms given above, we get the following KdV like equations in Eq. (8)

$$D_6\phi_1 + D_7\xi + D_3\frac{\partial^2}{\partial\xi^2}\phi_1 + D_2\frac{\partial^3}{\partial\xi^3}\phi_1 + D_1\frac{\partial}{\partial\tau}\phi_1 + D_5\frac{\partial}{\partial\xi}\phi_1 + D_4\phi_1\frac{\partial}{\partial\xi}\phi_1 = 0$$

Where $A_1 = \frac{D_5}{D_1},\ A_2 = \frac{D_3}{D_1},\ A_3 = \frac{D_2}{D_1},\ A_4 = \frac{D_6}{D_1},\ A_5 = \frac{D_4}{D_1}\ and\ A_6 = \frac{D_7}{D_1};$,

The coefficients D_1 to D_7 are detailed functions of the parameters which can be obtained from the authors upon request.

3. Results

Initially, we have solved the linear versions of the governing equations using the RungeKutta (RK4) method excluding ions and obtained the plots given in Fig. (2) for arbitrary parameters. Then, considering the parameters for different types of semiconductors, we have obtained the following. In case of a two-dimensional semiconductor plasma, while we are analyzing fluctuations in density with respect to the spatial coordinates for some specific values of viscosity, collision term, time, and charge carrier density we see in Fig. (5) that there are certain peaks for electrons for a localized region in the positive direction while the same profile is repeated for holes but in the negative direction. This kind of transverse fluctuation arises due to external perturbation i.e. electric field and magnetic field which orient the particles in a particular direction and hence the particles accumulate for a particular location at a particular frequency. Due to these transverse fluctuations in the density of electrons inside the semiconductor plasma under perturbative effects, the field velocity also shows oscillation for a particular instant of time. When electrons localize at a particular region they either try to converge or diverge from the field as given in Fig. (3) for the X component and Fig. (4) for the Y component. Therefore we come across the peaks in velocity profile in opposite directions for electrons and holes respectively at around y=0.7 and x=0.2. The velocity streamline shows the direction of electrons. The same kind of fluctuations are observed in the x directional velocity and y directional velocity and electric field profile for a particular instant time. There we observe both diverging and converging fields depending upon the doping concentration of the semiconductor used. The sinusoidal effects attenuate at the boundary. The effects of the electric field have been given in Fig. (6) and the velocity field in Fig. (7). The aforementioned quantities have also been plotted for GaAs in Fig. (8), in Fig. (9) forGaSb and in Fig. (10) forInP. As given in, the typical values of the parameters for the different semiconductors are given in Table- (I) [105]. We have obtained a similar kind of result, regardless of the parameters or the semiconductor materials. Thus, it might imply a general theory for these semiconductors.

Further, we have moved on to observe, how plasma waves are generated in these semiconductors. Here, we have obtained a new kind of KdV family equation as our evolutionaryequation i.e. Eq. (8). The equation has been reduced and given in Appendix (-A) as Eq. (9). In this equation, the first term signifies the time evolution of the system. The second term with coefficient A1 gives velocity dependent damping. The term with coefficient A2 gives viscosity effect. The terms with the coefficients A3, A4 A5 and A6 gives dispersive effect, amplitude dependent damping, nonlinear effect and drift effects respectively. Solving our evolutionary equation in a method called Homotopy Assisted Symbolic Simulation as given in [106, 107], we have obtained the following results. From Fig. (11), we can see that the soliton is not stationary. It propagates with time, through space and there is some kind of amplitude modulation as shown in [20, 108, 106, 19]. Thus, this might be a envelope soliton [109, 71], as obtained from the solution of Eq. (8). From Fig. (12), Fig. (13) and Fig. (14) we can see the relative motion of solitary structures in spatial coordinate for the variance in time, for different parameters and its evolution with time. In Fig. (12a), we can see the different solitary structures for different fractional presence of the ions in the plasma. In Fig. (12b), as the time evolves, the order is not the same anymore.

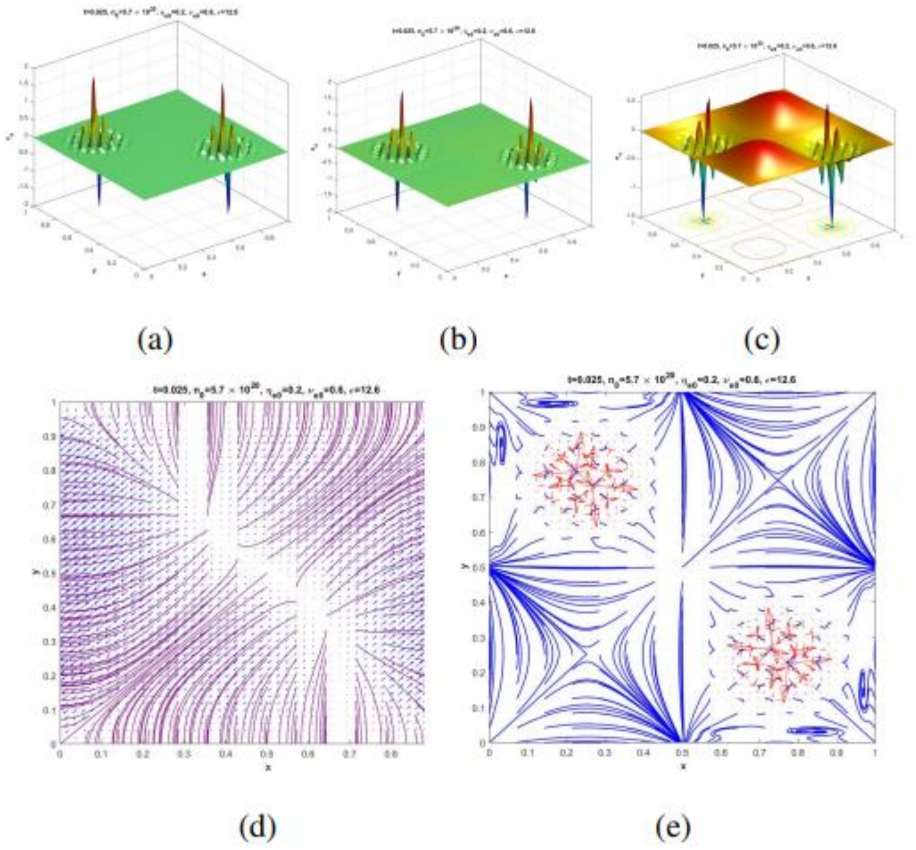
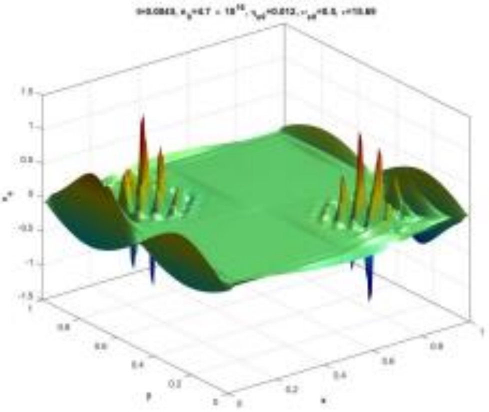
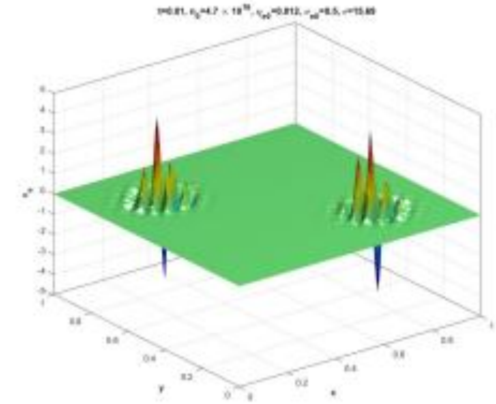


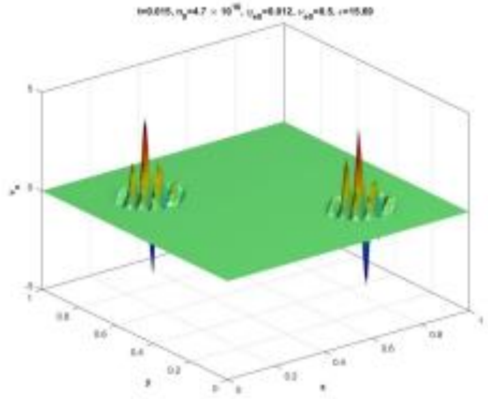
Figure 2. (a) Fluctuation in y component of velocity (b) Fluctuation in x component of velocity (c) Fluctuation in density (d) Fluctuation in electric field and (e) Velocity field profile for a two component e-h plasma for arbitrary parameters



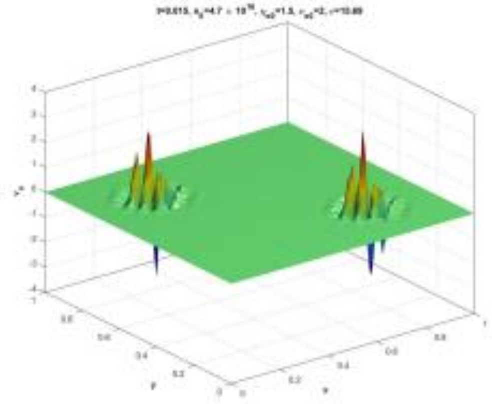
(a) $t=0.0045, \eta_{e0}=0.012, \nu_{e0}=0.5$



(b) $t=0.01, \eta_{e0}=0.012, \nu_{e0}=0.5$

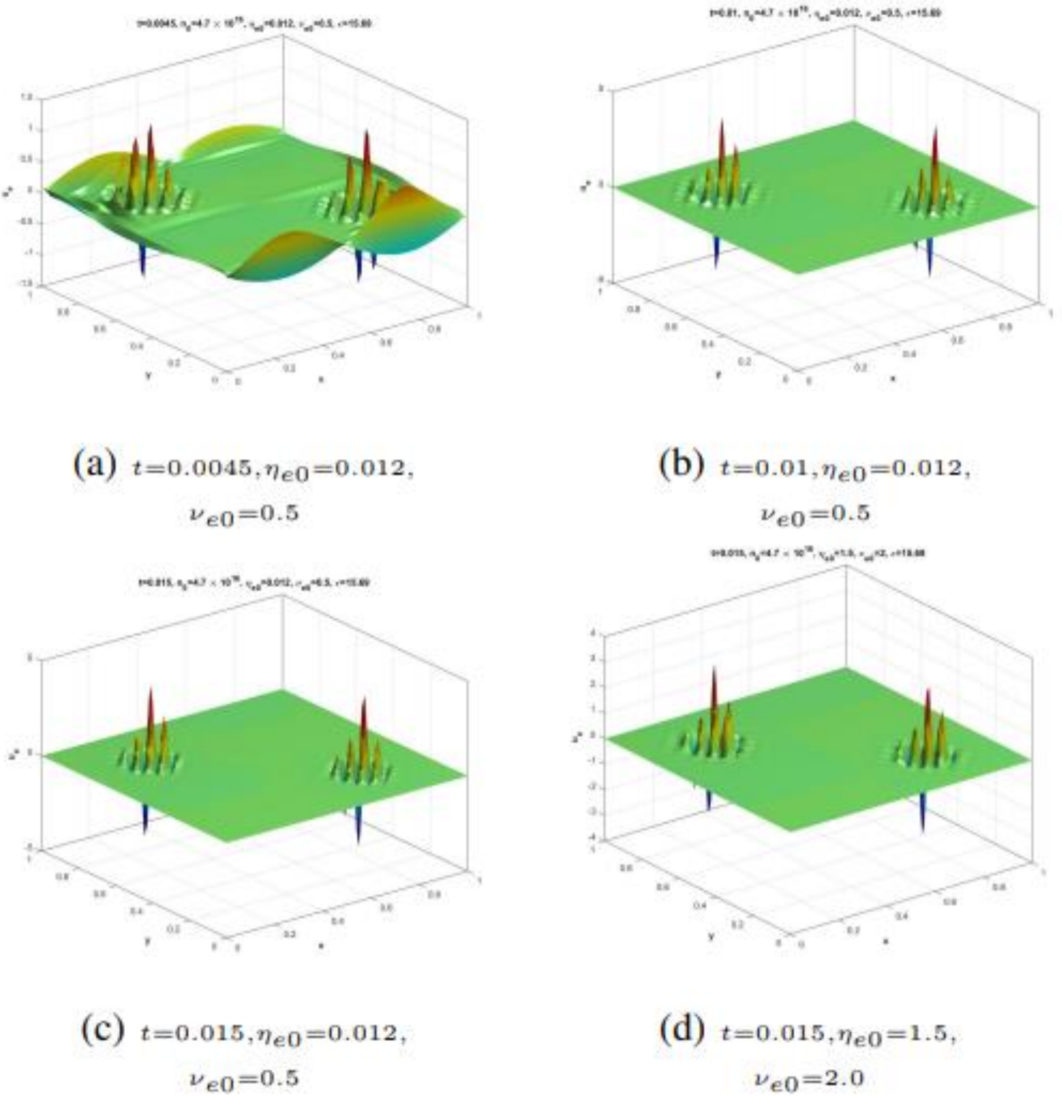


(c) $t=0.015, \eta_{e0}=0.012, \nu_{e0}=0.5$



(d) $t=0.015, \eta_{e0}=1.5, \nu_{e0}=2.0$

Figure 3. Transverse (Y) component of velocity for n0 = 4.7 × 1016, ϵ = 15.69 in GaAs



(a) $t{=}0.0045, \eta_{e0}{=}0.012, \nu_{e0}{=}0.5$

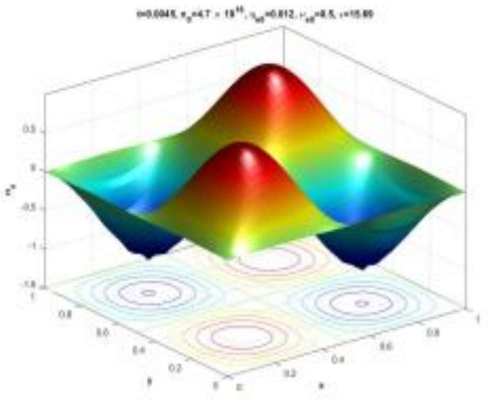
(b) $t{=}0.01, \eta_{e0}{=}0.012, \nu_{e0}{=}0.5$

(c) $t{=}0.015, \eta_{e0}{=}0.012, \nu_{e0}{=}0.5$

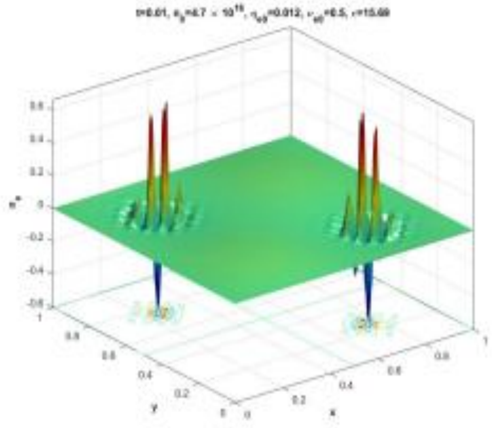
(d) $t{=}0.015, \eta_{e0}{=}1.5, \nu_{e0}{=}2.0$

Figure 4. Longitudinal (X) component of velocity for different parameters in GaAs

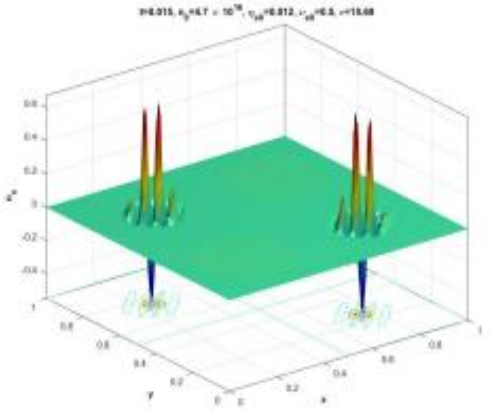
Thus, they may have a relative motion. In Fig. (12c), this relative motion becomes more prominent. In Fig. (13) and Fig. (14), the same relative motion has been shown for different viscosity coefficients and initial number density of holes respectively. In Fig. (15), the energy fluctuations in spatial and temporal coordinates have been shown for different types of semiconductor materials. In each of these cases, we can see the zigzag pattern, as the fluctuations evolve. Due to the periodic boundary conditions, however, we can see the complete fluctuation profile in the taken range.



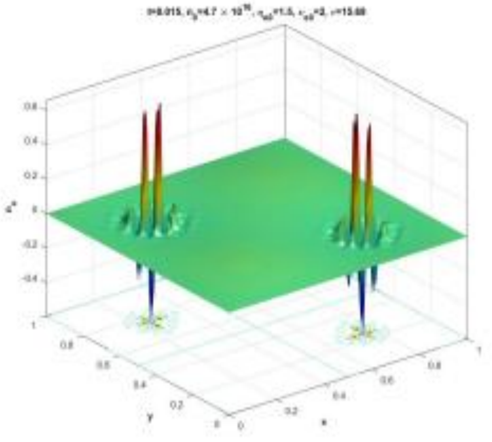
(a) t=0.0045, η_{e0}=0.012, ν_{e0}=0.5



(b) t=0.01, η_{e0}=0.012, ν_{e0}=0.5

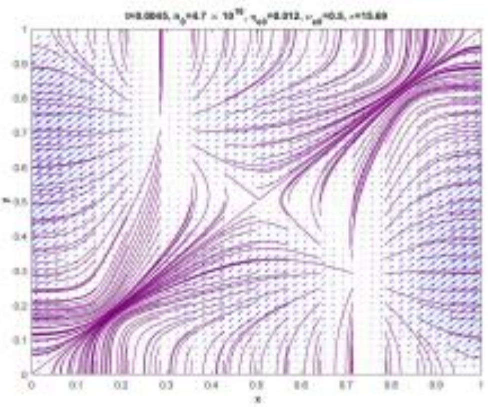


(c) t=0.015, η_{e0}=0.012, ν_{e0}=0.5

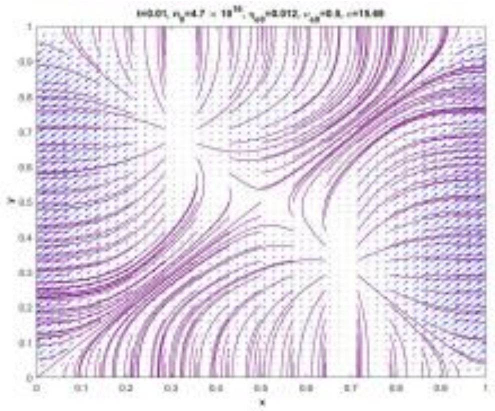


(d) t=0.015, η_{e0}=1.5, ν_{e0}=2.0

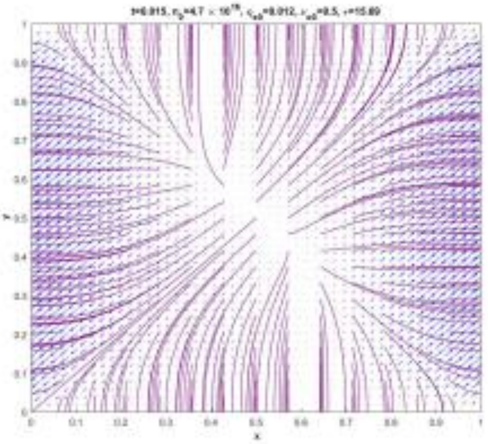
Figure 5. Density profile for different parameters in GaAs



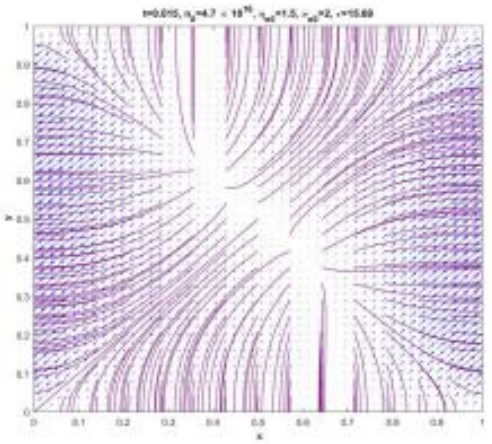
(a) t=0.0045, η_{e0}=0.012, ν_{e0}=0.5



(b) t=0.01, η_{e0}=0.012, ν_{e0}=0.5

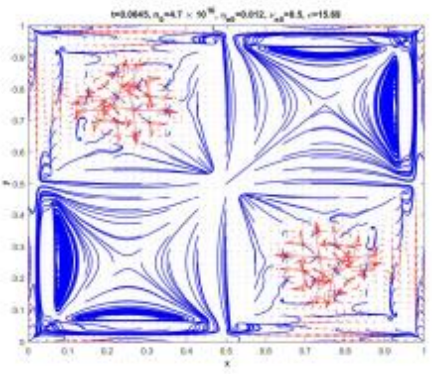


(c) t=0.015, η_{e0}=0.012, ν_{e0}=0.5

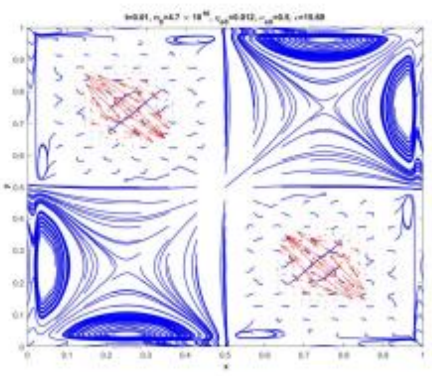


(d) t=0.015, η_{e0}=1.5, ν_{e0}=2.0

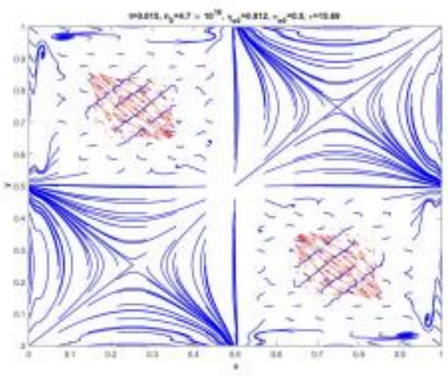
Figure 6. Electric field lines for different parameters in GaAs



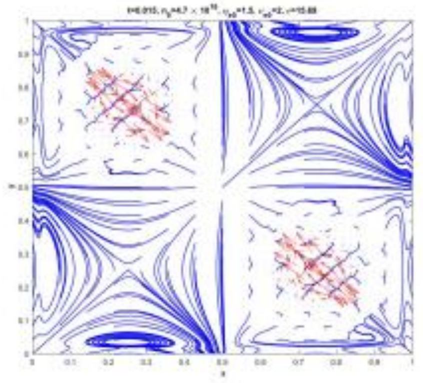
(a) $t{=}0.0045, \eta_{e0}{=}0.012, \nu_{e0}{=}0.5$



(b) $t{=}0.01, \eta_{e0}{=}0.012, \nu_{e0}{=}0.5$

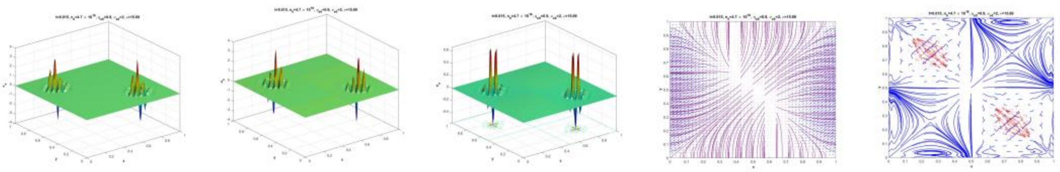


(c) $t{=}0.015, \eta_{e0}{=}0.012, \nu_{e0}{=}0.5$



(d) $t{=}0.015, \eta_{e0}{=}1.5, \nu_{e0}{=}2.0$

Figure 8. Velocity streamlines for different parameters in GaAs along with the fluctuations



(a) (b) (c) (d) (e)

Figure 8. Field variables of GaAs: (a) Transverse component of velocity, (b) Longitudinal component of velocity, (c) Density profile, (d) Electric field lines, (e) Velocity streamlines

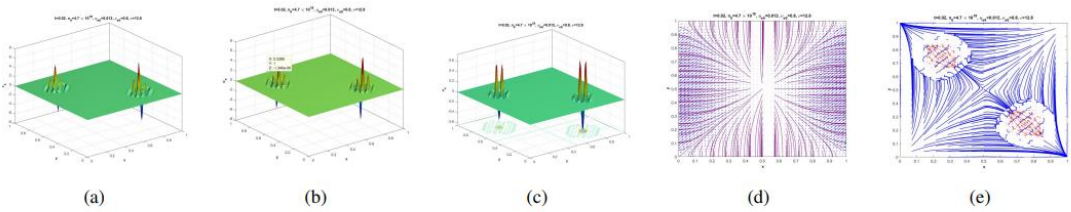


Figure 9. Field variables of GaSb: (a) Transverse component of velocity, (b) Longitudinal component of velocity, (c) Density profile, (d) Electric field lines, (e) Velocity streamlines

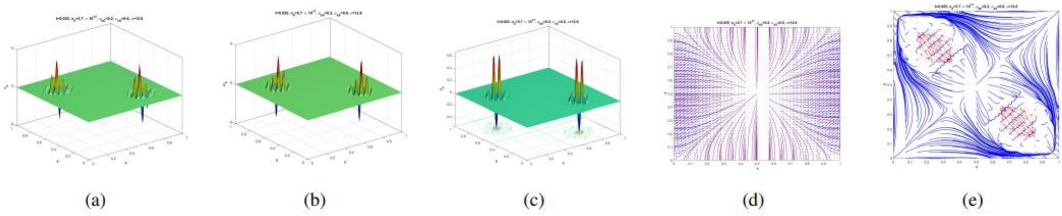


Figure 10. Field variables of InP: (a) Transverse component of velocity, (b) Longitudinal component of velocity, (c) Density profile, (d) Electric field lines, (e) Velocity streamlines

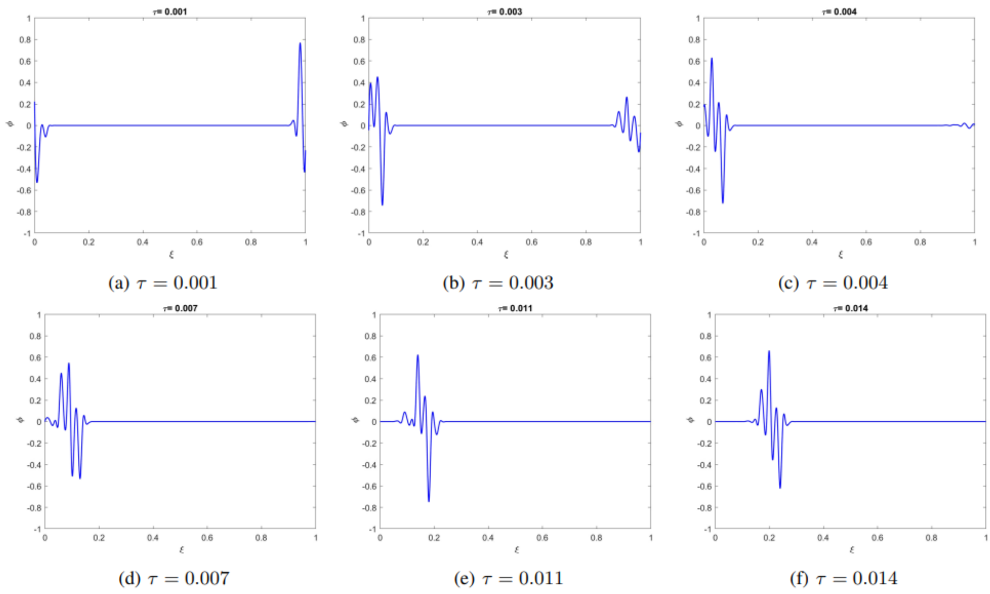
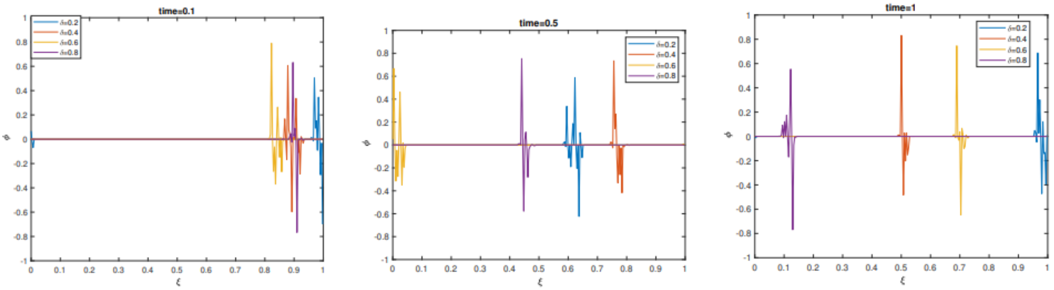
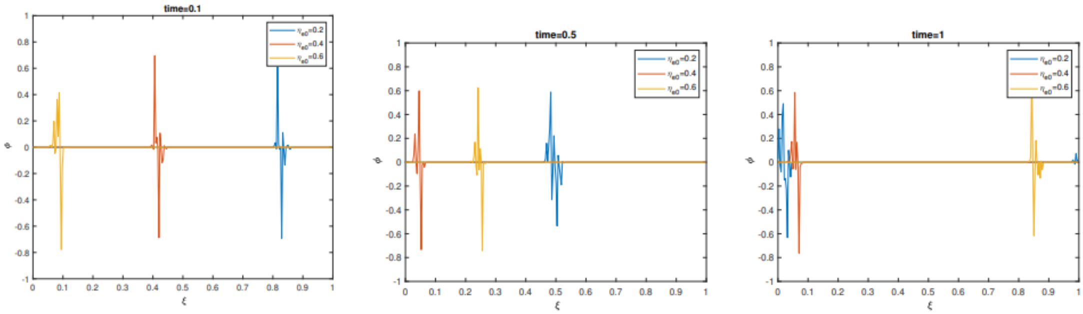


Figure 11. Temporal evolution of the soliton



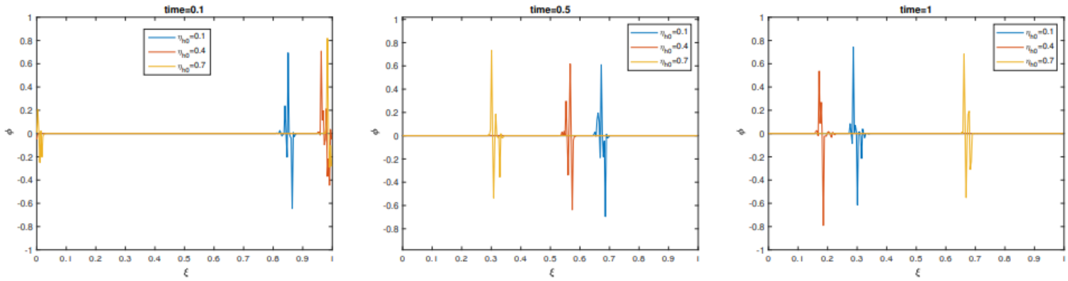
(a) time=0.1s (b) time=0.5s (c) time=1.0s

Figure 12. Evolution of the soliton for different equillibrium ratio of electrons to holes (δ)



(a) time=0.1s (b) time=0.5s (c) time=1.0s

Figure 13. Evolution of the soliton for different viscosity constant of hole fluid (ηe0)



(a) time=0.1s (b) time=0.5s (c) time=1.0s

Figure 14. Evolution of the soliton for different viscosity constant of hole fluid (ηh0)

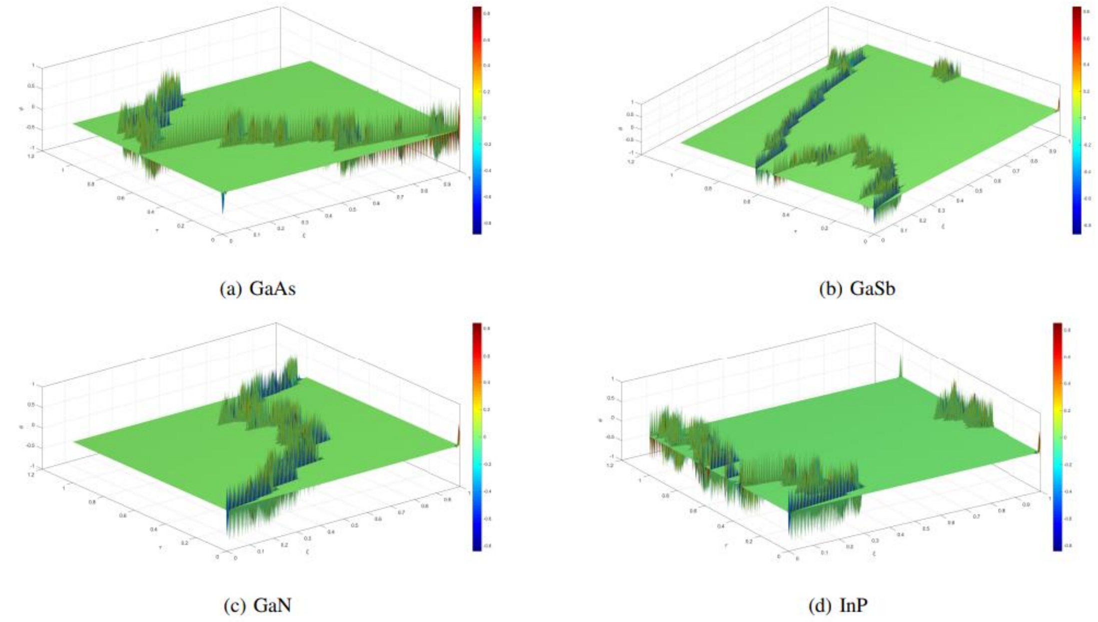


Figure 15. Fluctuations in different types of semiconductors

4. Conclusions

Here we can conclude that the nature of ion-electron implantation and diffusion in a semiconductor device under a high-pressure regime results in random fluctuations in energy. This is kind of a nonlinear behavior is pronounced in ultra-small i.e nanoscale semiconductor devices enforcing the spatial scale of doping with anomaly. Considering the quantum effects, it can be further used to design fluctuation-resistant structures of semiconductor devices. In our future work we can extend our analysis including the study of variations for different doping concentrations for different compounds at different time scales and investigate whether there can be any kind of instability might arise due to particle interactions. This theoretical concept can also be further implemented in some experimental research especially in the nanophysics regime of space plasma field as well. We can further extend our analysis including the study of variations for different doping concentrations for different compounds at different time scales and investigate whether there can be any kind of instability arising due to particle interactions. Experimental results on the kink instability in silicon semiconductor plasma has motivated us to further investigate this kind of instability in the presence of electric and magnetic field. The instability of electron-ion hole acoustic waves due to the electron beam in semiconductor quantum plasma can be useful in finding the variation of the growth rate of the unstable mode, over a wide range of system parameters. The thermal effects are another important topic we can investigate through our further instability analysis.

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The related data can be obtained from the corresponding author upon suitable request.

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