List of Figures

1.1 Schematic diagram of (a) LWFA, (b) PBWA, (c) SM-LWFA and (d) resonant laser pulse train. The excited plasma wave potentials and laser intensity envelopes moving towards right are represented by the solid and dashed lines respectively [43]. 9

1.2 Schematic diagram of electron heating via resonance absorption process [19]. 11

1.3 Schematic diagram of the fast ignition in inertial confinement fusion after the termination of the pulse which drives the implosion and compresses the fuel [65]. 13

1.4 Schematic diagram of ion acceleration by TNSA mechanism [62]. . . . 14

1.5 Schematic diagram of ion acceleration by RPA mechanism [100]. . . . 18

1.6 Double layer of the laser piston formed by the radiation pressure. a is the laser field amplitude (blue dotted-dashed), I is the laser intensity (brown thin solid), n_e is the electron density (green dashed), $\vec{E}_x$ is the longitudinal electrostatic field (red thick solid), n_i is the ion density (black solid). Ion charge separation layer (x_i,0) is situated in front of electron sheath (0,x_e) [102]. 19

1.7 Schematic diagram of ions accelerated by MVA mechanism [123]. . . . 23

1.8 Physical mechanism of Weibel instability induced by two counter-propagating electron beams [136]. 24

1.9 Schematic diagram of toroidal magnetic fields generated by the $\nabla T_e \times \nabla n_e$ mechanism [138]. 25

1.10 Schematic diagram of potential-well ($V(r)$ vs r) distortion (a) tunnel ionization and (b) barrier suppression ionization (BSI) [153]. 27

1.11 Figure-eight-orbit of an electron in a linearly polarized plane electromagnetic wave. $\vec{E}$, $\vec{B}$ and $\vec{k}$ denote the electric field, magnetic field and the wave propagation vector respectively [160]. 28

1.12 Charge distribution at the plasma-vacuum boundary. Plus and minus represents constant positive background charge due to fixed ions and the negative charge due to back and forth electron motion across the boundary respectively [160]. 29

1.13 Mathematical grid set into the plasma region in order to measure charge and current densities [170]. 30

1.14 A typical cycle, one time step in a particle in a cell (PIC) simulation program [170]. 31

1.15 The Yee Cell. The cell vertex labeled (i, j, k) is associated with the components of $\vec{E}$, $\vec{B}$ and $\vec{J}$ displaced by half a cell width at the locations shown above. The charge q is located at the mesh point [171]. . 32

1.16 Schematic diagram for the calculation of $tan\frac{\theta}{2}$ [170]. 34

1.17 Schematic diagram of the velocity space showing the rotation from $\vec{v}_-$ to $\vec{v}_+$. The velocities shown are the projections of the total velocities onto the plane perpendicular to $\vec{B}$ [170]. 35

1.18 Schematic diagram of leap-frog integration method showing time-centering of force $\vec{F}$ while advancing $\vec{v}$, and of $\vec{v}$ while advancing $\vec{x}$ [170]. 35

1.19 Particle weighting process to calculate charge densities. (a) A part of the charge cloud which is in the j^{th} cell is interpolated at X_j (fraction (a)), and the part of the cloud which is in the $(j+1)^{th}$ cell is interpolated at X_{j+1} (fraction (b)). (b) The grid density $n_j(x_i)$ at point x_i as the particle moves past X_j displaying the effective particle shape $S(x)$ [170]. 36

2.1 3D-PIC geometry of the simulation box. 60

2.2 Proton density distribution in the central YZ plane (X = 10 μm) for the target of thickness 8 μm at time (a) 37.63 T_0, (b) 54.47 T_0 and (c) 104 T_0. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3}. 62

2.3 Longitudinal electric field E_z normalized by the laser electric field E_0 in the central YZ plane (X = 10 μm) for the target of thickness 8 μm at time (a) 31.69 T_0 and (b) 54.47 T_0. 62

2.4 Proton density distribution (a1-a3) and longitudinal electric field E_z (b1-b3) in the central YZ plane (X = 10 μm) for targets of thicknesses 3, 2 and 1 μm at times 54.47 T_0, 49.52 T_0 and 41.60 T_0 respectively. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3} and the longitudinal electric field E_z is normalized by the laser electric field E_0. 64

2.5 Electron density distribution in the XY plane at the rear edge of the target of thickness (a) 8 μm at Z = 10 μm and time 54.47 T_0, (b) 3 μm at Z = 5 μm and time 54.47 T_0, (c) 2 μm at Z = 4 μm and time 49.52 T_0 and (c) 1 μm at Z = 3 μm and time 41.60 T_0. The electron density n_e is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3}. 65

2.6 Normalized axial momentum p_z/m_ic (a1-a4) and transverse momentum p_y/m_ic (b1-b4) phase space for targets of thicknesses 8, 3, 2 and 1 μm at times 104 T_0, 74.28 T_0, 68.34 T_0 and 61.41 T_0 respectively. . . 66

2.7 Proton density distribution in the central YZ plane (X = 10 μm) when the protons gain maximum energy for the target of thickness (a) 3 μm at time 74.28 T_0, (b) 2 μm at time 68.34 T_0 and (c) 1 μm at time 61.41 T_0. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3}. 67

2.8 Proton energy spectrum for the target of thickness 8 μm (red solid) at time 104 T_0, 3 μm (green solid) at time 74.28 T_0, 2 μm (blue solid) at time 68.34 T_0 and 1 μm (black solid) at time 61.41 T_0. The proton number N is normalized by the total number of protons N_0 in each case. 68

2.9 Proton energy spectrum for the target of thickness 8 μm at time 37.63 T_0 (red solid) and 104 T_0 (green solid). The proton number N is normalized by the total number of protons N_0. 69

2.10 Variation of maximum proton energy with target thickness. 70

2.11 (a) Proton density distribution in the central YZ plane (X = 10 μm) and (b) Axial momentum p_z/m_ic phase space when the protons gain maximum energy for the target of thickness 2 μm by a p-polarized laser at time 98.05 T_0. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3}. 71

2.12 Proton energy spectrum for the target of optimum thickness 0.5 μm by a circularly polarized laser (red solid) at time 57.44 T_0 and a p-polarized laser (blue solid) at time 73.29 T_0. The proton number N is normalized by the total number of protons N_0. 72

3.1 Schematic diagram of the cyclotron effects in case of (a) RCP and (b) LCP. 79

3.2 3D-PIC geometry of the simulation box. 81

3.3 Proton density distribution (a1-a3) and axial electric field (b1-b3) in the central YZ plane (X = 10 μm) at time 51 T_0 respectively for B = 0, RCP with B = 50 MG and LCP with B = 50 MG. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3} and the axial electric field E_z is normalized by the laser electric field E_0. 82

3.4 (a) Electron energy spectrum (b) Electron density distribution along Z direction (X = 10 μm, Y = 10 μm) at time 51 T_0 for B = 0 (red solid), RCP with B = 50 MG (green solid) and LCP with B = 50 MG (blue solid). The electron density n_e is normalized by the critical density $n_c = 1.12 \times 10^{21}$cm^{-3}. 83

3.5 Normalized electron axial momentum p_z/m_ec phase space for (a) B = 0, (b) RCP with B = 50 MG and (c) LCP with B = 50 MG at time 51 T_0. 84

3.6 Normalized proton axial momentum p_z/m_pc phase space for (a) B = 0, (b) RCP with B = 50 MG and (c) LCP with B = 50 MG at time 95 T_0. 84

3.7 Proton density distribution in the central YZ plane (X = 10 μm) for (a) B = 0 at time 98 T_0, (b) RCP with B = 50 MG at time 101 T_0 and (c) LCP with B = 50 MG at time 95 T_0. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$cm^{-3}. 85

3.8 Proton energy spectrum for B = 0 (red solid) at time 98 T_0, RCP with B = 50 MG (green solid) at time 101 T_0 and LCP with B = 50 MG at time 95 T_0 (blue solid). 86

3.9 Proton density distribution in the XY plane (Z = 11 μm) for (a) B = 0 at time 98 T_0, (b) RCP with B = 50 MG at time 101 T_0 and (c) LCP with B = 50 MG at time 95 T_0. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}\text{cm}^{-3}$. 87

3.10 Variation of maximum proton energy with target thickness for for B = 0 (red solid), RCP with B = 50 MG (green solid) and LCP with B = 50 MG (blue solid). 88

3.11 Electron density distribution (a-c) in the central YZ plane (X = 10 μm) and axial electric field (a1-c1) in the XY plane (Z = 7 μm) at time 60 T_0 respectively for B = 0, RCP with B = 50 MG and LCP with B = 50 MG. The electron density n_e is normalized by the critical density $n_c = 1.12 \times 10^{21}\text{cm}^{-3}$ and the axial electric field E_z is normalized by the laser electric field E_0. 89

3.12 Normalized proton axial momentum p_z/m_ic vs Z (μm) phase space for B = 0 (a,b and c), RCP with B = 50 MG (a1,b1 and c1), LCP with B = 50 MG (a2,b2 and c2) at times 50 T_0, 60 T_0 and 75 T_0 respectively. 90

3.13 Proton energy spectrum at (a) 50 T_0, (b) 60 T_0 and (c) 75 T_0 for B = 0 (red solid), RCP with B = 50 MG (green solid) and LCP with B = 50 MG (blue solid). 91

4.1 3D-PIC geometry of the simulation box. 100

4.2 Proton density distribution (a1-a5) and axial electric field (b1-b5) in the central YZ plane (X = 7 μm) at time 101 T_0 respectively for (a1,b1) CP with B = 0 G, (a2,b2) RCP with B = 50 MG, (a3,b3) LCP with B = 50 MG, (a4,b4) LP with B = 0 G and (a5,b5) LP with B = 50 MG. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3} and the axial electric field E_z is normalized by the laser electric field E_0. 102

4.3 Normalized proton axial momentum p_z/m_ic phase space for (a) CP with B = 0 G, (b) RCP with B = 50 MG, (c) LCP with B = 50 MG, (d) LP with B = 0 G and (e) LP with B = 50 MG at time 101 T_0. . . 103

4.4 Proton density distribution (a1-a5) in the central YZ plane (X = 7 μm) and normalized proton axial momentum p_z/m_ic phase space (b1-b5) at time 147 T_0 respectively for (a1,b1) CP with B = 0 G, (a2,b2) RCP with B = 50 MG, (a3,b3) LCP with B = 50 MG, (a4,b4) LP with B = 0 G and (a5,b5) LP with B = 50 MG. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3}. 104

4.5 Normalized proton momentum phase space (a1-a5) p_y/m_ic vs Z (μm) and (b1-b5) p_y/m_ic vs p_z/m_ic at time 147 T_0 respectively for (a1,b1) CP with B = 0 G, (a2,b2) RCP with B = 50 MG, (a3,b3) LCP with B = 50 MG, (a4,b4) LP with B = 0 G and (a5,b5) LP with B = 50 MG. 105

4.6 Proton density distribution in the XY plane (Z = 23.6 μm) for (a) RCP with B = 50 MG at time 147 T_0, (b) LCP with B = 50 MG at time 150 T_0 and (c) LP with B = 50 MG at time 154 T_0. The proton density n_p is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3}. 106

4.7 Proton energy spectrum for CP with B = 0 G (red solid), RCP with B = 50 MG (green solid), LCP with B = 50 MG (blue solid), LP with B = 0 G (pink solid) and LP with B = 50 MG (orange solid) at time 147 T_0. The proton number N is normalized by the total number of protons N_0 in each case. 107

5.1 3D-PIC geometry of the simulation box when the laser is incident normally ($\theta = 0^0$) on the target. 118

5.2 3D-PIC geometry of the simulation box when the laser is incident obliquely ($\theta = 30^0, 60^0$) on the target. 118

5.3 (a) Electron density distribution in the central YZ plane (X = 5 μm). Magnetic field generated along (b) X direction B_x in the central YZ plane (X = 5 μm), (c) Y direction B_y in the central XZ plane (Y = 5 μm) at time 107.72 T_0 for $\theta = 0^0$. The electron density n_e is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3}. The magnetic field B_x is normalized by the laser magnetic field B_0. 119

5.4 Current density distribution along Z direction J_z (kA/μm^2) in the XY plane (Z = 6 μm) at time 107.72 T_0 for $\theta = 0^0$. 120

5.5 Axial intensity I vs Z (μm) for $\theta = 0^0$ at times 75.40 T_0 (red solid), 82.58 T_0 (green dashed) and 89.77 T_0 (blue dotted). The intensity is normalized by the fundamental laser intensity I_0. 120

5.6 Electron density distribution in the XY plane at the plasma surface (Z = 2 μm) for (a) $\theta = 30^0$ and (b) $\theta = 60^0$ at time 75.40 T_0. The electron density n_e is normalized by the critical density $n_c = 1.12 \times 10^{21}$ cm^{-3}. 121

5.7 Electron phase space p_z/m_ec vs Z(μm) for $\theta = 60^0$ at time (a) 64.63 T_0 and (b) 68.22 T_0. 122

5.8 Electron phase space p_z/m_ec vs Z (μm) for (a1) $\theta = 30^0$, (a2) $\theta = 60^0$ and electron phase space p_z/m_ec vs Y (μm) for (b1) $\theta = 30^0$, (b2) $\theta = 60^0$ at time 75.40 T_0. 123

5.9 Current density along (a1 and a2) Y direction J_y (kA/μm^2), (b1 and b2) Z direction J_z (kA/μm^2) for $\theta = 30^0$ and 60^0 respectively and magnetic field along (c1 and c2) Y direction B_y, (d1 and d2) Z direction B_z for $\theta = 30^0$ and 60^0 respectively at time 75.40 T_0 at the plasma surface (Z = 2 μm) in the XY plane. The magnetic field B_y and B_z are normalized by the laser magnetic field B_0. 124

5.10 Current density along (a1 and a2) Z direction J_z (kA/μm^2) in the XY plane at Z = 4 μm for $\theta = 30^0$ and 60^0 respectively and magnetic field along (b1 and b2) X direction B_x in the central YZ plane (X = 5 μm) for $\theta = 30^0$ and 60^0 respectively at time 89.77 T_0. The magnetic field B_x is normalized by the laser magnetic field B_0. 125

5.11 Normalized magnetic energy (B^2/B_0^2) vs Time (T_0) for $\theta = 0^0$ (red solid), $\theta = 30^0$ (green dashed) and $\theta = 60^0$ (blue dotted). 126

6.1 Schematic of second harmonic generation process by an obliquely incident s-polarized laser. 134

6.2 Modified relativstic factor γ as a function of normalized electric field amplitude a_0 and applied magnetic field b at $\omega_p^2/\omega^2 = 0.1$, $\theta = 70^0$ and $\omega = 1.88 \times 10^{14}$ Hz. 141

6.3 Conversion efficiency η as a function of applied magnetic field b and angle of incidence θ at $a_0 = 1$, $\omega_p^2/\omega^2 = 0.1$ and $\omega = 1.88 \times 10^{14}$ Hz. . 142

6.4 Conversion efficiency η as a function of applied magnetic field b and normalized electron density ω_p^2/ω^2 at $a_0 = 1$, $\theta = 70^0$ and $\omega = 1.88 \times 10^{14}$ Hz. 142

6.5 Conversion efficiency η as a function of applied magnetic field b and normalized electric field amplitude a_0 at $\omega_p^2/\omega^2 = 0.1$, $\theta = 70^0$ and $\omega = 1.88 \times 10^{14}$ Hz with (a) modified γ (b) unmodified γ'. 143