Chapter 7

Summary and Outlook

The present thesis deals in studying some of the important aspects in the interaction of short high-intensity laser pulses with plasmas such as second harmonic generation, proton acceleration and magnetic field generation. Second harmonic generation has been studied analytically. Though analytical calculations can be very useful in understanding the physics of laser-plasma interactions, but PIC simulations provide a more detail insight of the physical processes occurring in such kind of interactions. A major part of the work presented in this thesis is contributed to 3D-PIC simulation studies on proton acceleration. Generation of strong multi-megagauss magnetic fields is also studied via 3D-PIC simulations. Magnetic fields can play an important role in such interactions due to cyclotron effects which can cause a change in the dielectric constant of the plasma. In the present thesis, generation of high amplitude magnetic fields as well as second harmonic generation and proton acceleration in presence of magnetic field have been studied. The simulation results presented in this thesis are obtained by using the code Picpsi-3D.

7.1 Summary

In **Chapter 2**, 3D-PIC simulations have been done to investigate the role played by the target thickness in generating high energetic protons by a circularly polarized laser from mass-limited targets (MLT). Hole boring due to intense radiation pressure causes a deformation of the target front side which changes the effective angle of incidence causing vacuum heating and results in the generation of hot electrons which can travel towards the target rear side and accelerate protons via TNSA. It has been observed that the protons which are accelerated more effectively from the target front side due to the radiation pressure of a circularly polarized laser are much more energetic and collimated than the ones which are accelerated by the TNSA mechanism from the target rear side. As the RPA accelerated protons are highly energetic, they travel much faster through the target and reach the rear side as the target thickness is decreased. Thus, RPA becomes more dominating as the target thickness is decreased which leads to an increase in maximum proton energy and beam collimation. A circularly polarized laser reduces volumic heating which minimizes the generation of hot electrons and also prevents the effect of transverse hot electron recirculations which improves the collimation. Multidimensional effects result in the generation of hot electrons which degrades the monoenergetic nature of RPA as observed in the energy spectrum. Maximum proton energy as well as the number of accelerated protons increases on decreasing the target thickness. It is also observed that TNSA dominates over RPA for a p-polarized laser, while the reverse happens for a circularly polarized laser for the same values of laser intensity and target thickness. Optimum target thickness at which the proton energy is found to be maximum is obtained at 0.5 μm.

In **Chapter 3**, 3D-PIC simulations have been done to investigate the effect of an axial magnetic field on proton acceleration by an ultraintense short pulse circularly polarized laser from an overdense plasma target. Due to cyclotron effects, the ponderomotive force gets enhanced in case of a RCP laser which enhances the generation of hot electrons. On the other hand, in case of a LCP laser, the ponderomotive force gets suppressed over a short distance as the electrons get accumulated at the laser pulse front resulting in strengthening of the laser piston. Thus, in presence of an axial magnetic field, a RCP laser favours TNSA and a LCP laser favours RPA. The transverse proton momentum gets reduced due to cyclotron effects which enhances the collimation. However, collimation is highest in case of a LCP laser as the proton beam is observed to have a comparatively smaller spot size. As the effect of radiation pressure gets enhanced in case of a LCP laser, proton energy is observed to be highest in this case and lowest in case of a RCP laser. Optimum thickness for maximum proton energy is increased slightly in presence of magnetic field and the maximum proton energy at the optimum target thickness is observed to highest in case of a LCP laser.

In **Chapter 4**, 3D-PIC simulations have been done to investigate the effect of magnetic field on collimation of energetic protons from near-critical plasmas. Protons get accelerated via TNSA mechanism and the cyclotron effects cause a reduction of the transverse momentum which enhances the collimation. Protons are observed to gain highest energy in case of a CP laser as compared to all other cases. Although, the protons get accelerated mainly via TNSA mechanism, but traces of RPA has also been observed in case of a CP laser in absence of magnetic field and a LCP laser in presence of magnetic field due to effective radiation pressure. The acceleration gets enhanced in case of a LP laser in presence of an axial magnetic field as the hot electron flow along the laser axis across the target rear side is increased resulting in stronger sheath formation which enhances the acceleration. As evident from the smallest spot size, collimation appears to be highest in case of LP laser. However, protons accelerated in case of a RCP laser are not only more energetic but are also in good collimation. The transverse proton momentum rises sharply at the target rear side as the acceleration process starts. In presence of magnetic field, the transverse proton momentum after rising experiences a sharp fall causing the proton beams to emerge out with reduced values of transverse momentum and thus become highly collimated. Since, the transverse proton momentum has a significant contribution towards maximum energy, the presence of an axial magnetic field though helps in achieving collimation, but in turn reduces the maximum proton energy.

In **Chapter 5**, 3D-PIC simulations have been done to investigate the role played by the angle of incidence of a short pulse laser in the generation of magnetic field via Weibel instability from overdense plasmas. In case of normal incidence, the laser pulse gets self-focused at a very short distance and the axial intensity rises up to several times the fundamental laser intensity. Strong current filamentation is observed, which causes the generation of high magnetic fields across the current filament. The amplitude of the reflected laser pulse becomes stronger on increasing the angle of incidence. At higher angle of incidences, the laser penetration is very less and laser as a whole gets reflected and propagates almost parallel to the surface through vacuum.

When the laser pulse is obliquely incident, periodic density ripple like structures are observed at the plasma front surface which are formed due to emission of energetic electron jets caused by vacuum heating. The periodic structures carry forward and return currents which results in the formation of periodic magnetic field structures having strong magnetic fields. The inter spacing distance of these periodic structures coincides with the incident laser wavelength. The magnetic energy is found to be highest in case of normal incidence which is due to strong current filamentation. The filamentation becomes weaker as the angle of incidence is increased.

In **Chapter 6**, second harmonic generation by an obliquely incident s-polarized laser from an underdense plasma has been investigated analytically. An expression for the relativistic factor in presence of magnetic field has been obtained. The efficiency of second harmonic radiation is calculated as a function of angle of incidence, electron plasma density, laser electric field amplitude and the magnetic field. The efficiency is observed to get increased with the angle of incidence up to the critical angle. It is observed that the value of the modified relativistic factor increases with an increase in magnetic field. In turn, the conversion efficiency decreases with an increase in magnetic field. It has been observed that the conversion efficiency gets affected by the magnetic field due to modified relativistic factor. In absence of magnetic field, the second harmonic conversion efficiency increases with an increase in the laser electric field amplitude and the angle of incidence. However, in presence of magnetic field, the conversion efficiency starts decreasing as the magnetic field is increased.

7.2 Outlook and future prospects

The target geometry can play a significant role in intense laser-plasma interactions. Experiments are generally done by irradiating lasers on solid, gaseous and cluster targets. Experiments on acceleration of ions is generally done by the interaction of lasers with solid foil targets which is well explained by TNSA and RPA mechanism. Modification of the target geometry can significantly enhance the acceleration. In the present thesis, we have used mass-limited targets for proton acceleration. However, targets used are rectangular in shape.

Zou et al. [1] have demonstrated through 2D-PIC simulations that TNSA can be achieved in a controlled manner by using a guiding cone. They have observed that both the collimation and the number density of proton beams has a substantial improvement as compared to the conventional planar targets producing high-quality proton beams which can move through longer distances without degradation. Gong et al. [2] have shown in their 2D-PIC simulation results that the maximum proton energy increases for a right-circularly polarized laser interaction with a cone target exposed to a longitudinal magnetic field. Korneev et al. [3] have shown the generation of gigagauss-scale quasistatic magnetic fields in a snail-shaped target. Thus, it can be understood that target geometry plays an important role in the physical processes occurring in laser-plasma interactions. At present, the target initialization of code Picpsi-3D is limited to a plasma target having rectangular and spherical geometry. The code can be modified in the future to include various other target geometries.

In the present thesis, simulations have been done with protons. In the future, investigations can be done by using heavier ions. Moreover, the code can be modified to include ions having higher charge states. Modification can also be done to include a mixture of ions having different atomic numbers.

Bibliography

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