DECLARATION

I declare that the thesis entitled, ELECTRON ACCELERATION BY LASER IN VACUUM AND PLASMAS, has been prepared by me under the guidance of Dr. Niti Kant, Associate Professor of Physics, Lovely Professional University. No part of the thesis has formed the basis for the award of any degree or fellowship previously.

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DATE: 28th October, 2015

CERTIFICATE

I certify that Harjit Singh Ghotra has prepared his thesis entitled, ELECTRON ACCELERATION BY LASER IN VACUUM AND PLASMAS, for the award of Ph. D. degree of the Lovely Professional University under my guidance. He has carried out the work at the Department of Physics, Lovely Professional University.

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ABSTRACT

Laser induced acceleration of electron in vacuum and plasmas has been studied. In chapter-3, the role of azimuthal magnetic field has been realized theoretically for electron acceleration by linearly polarized (LP) as well as circularly polarized (CP) laser pulse in vacuum. The results obtained indicate the confined trajectory of electron under the influence of azimuthal magnetic field for longer distance than that without magnetic field. The energy gain by the electron with a CP laser pulse is seen higher than that with a LP laser for same intensity.

In chapter-4, we employ a LP chirped laser pulse for electron acceleration with azimuthal magnetic field. The accelerating distance is observed to be of three times the Rayleigh length. We observe electron energy gain of about $1.47GeV$ with azimuthal magnetic field of about $438kG$ with an intense LP chirped laser pulse of peak intensity of about $3.4\times10^{21}W/cm^2$.

In chapter-5, the acceleration of electron with a frequency chirped CP laser pulse in vacuum under the impact of an azimuthal magnetic field has been studied. Linear frequency chirp plays a vital role to extend the time of interaction of laser pulse with electron and hence enforces the resonance for longer duration. The presence of azimuthal magnetic field strengthens the electron acceleration and keeps the electron motion close to the direction of propagation of laser pulse. Thus, resonant enhancement appears due to the combined role of azimuthal magnetic field and CP chirped laser pulse. Pre-accelerated electron with few MeV of initial energy gains high energy of the order of GeV from laser field of CP chirped laser pulse.

In chapter-6, we examine the acceleration of electron by a radially polarized (RP) laser pulse in vacuum under influence of a strong axial magnetic field. The presence of axial magnetic field improves the contribution of $\vec{v}\times\vec{B}$ force which supports the retaining of betatron resonance for longer durations. Up to 70% enhancement is observed in electron energy gain with an axial magnetic field of about $3MG$. We observe the sensitiveness of axial magnetic field on the acceleration of electron. Our results also show

relatively smaller scattering of the electrons under influence of externally applied axial magnetic field.

In chapter-7, a relativistic single particle simulation for the acceleration of electron with a high intensity RP chirped laser pulse in vacuum has been presented. An electron gains ultrahigh energy and retains it for longer duration due to a RP chirped laser pulse. The energy gain variation with chirp parameters of linear and periodic functions has been studied. It is observed that the maximum energy gain by an electron with a RP periodic chirp laser pulse is about two times higher than that with a linear chirp. Our observations reveal electron energy gain of about $10.5GeV$ with a periodic chirped RP petawatt laser pulse in vacuum.

In chapter-8, we present a scheme for electron injection for enhanced energy gain with a RP laser pulse in vacuum under the influence of magnetic wiggler. Four times higher electron energy is observed with a RP laser pulse of peak intensity $8.5\times10^{20}\ W/cm^2$ under existence of magnetic wiggler of $10.69kG$ than without magnetic wiggler. We have analyzed the electron injection for enhanced energy gain by the electron and observe that this gain is relatively higher with a sideway injection than that of axial injection of electron. Injection angle δ is optimized and found that at $\delta=10^\circ$ to the direction parallel to the propagation of laser pulse, the maximum energy is obtained.

In chapter-9, we analyze the effect of laser beam width parameter on electron acceleration in magnetized plasma. An electron accelerates during interaction with a CP Gaussian laser pulse in plasma. The variations of laser spot size for different intensity parameters have been presented graphically for electron acceleration. Electron accelerates and gain energy due to strong laser field where beam width parameter is small and loss energy where field is weak due to large beam width parameter. A significant enhancement in electron acceleration gets maintained for larger propagation distance in the presence of axial magnetic field in plasma. We have observed an energy gain above $1GeV$ for laser intensity of about $I\sim6.8\times10^{21}\ W/cm^2$ with laser spot size $\sim75\mu m$ in the presence of axial magnetic field of about $15MG$ in plasma.

In chapter-10, the electron acceleration by a circularly polarized (CP) Hermite-Gaussian (HG) laser beam in the plasma has been investigated theoretically for the different mode indices (m, n) as (0, 1), (0, 2), (0, 3), and (0, 4). HG beam possesses higher trapping forces compared to standard Gaussian beam fields due to their propagation characteristics during laser electron interaction. A single particle simulation indicates a resonant enhancement of electron acceleration with HG laser beam. The dependence of beam width parameter on acceleration distance effectively influences the electron dynamics. Electron acceleration for longer distance is observed with the lower modes. However, the higher electron energy gain is observed with higher modes for shorter distance of propagation.

In chapter-11, we examine the electron acceleration during laser-cluster interaction. In addition to the electrostatic fields of individual clusters, and field of short pulse laser, there exists an external transverse wiggler magnetic field. Single particle simulation has been presented with a short pulse linearly polarized (LP) as well as circularly polarized (CP) laser pulses for electron acceleration in cluster. The persisted Coulomb field during laser-cluster interaction enforces the electron to be in phase with laser pulse. Thus, ensures an efficient energy gain by the electron from laser fields. The wiggler field increases the field strength which enhances the electron acceleration. A long duration resonance appears with an optimized magnetic wiggler of field about $3.4kG$. Hence, the relativistic energy gain by the electron is enhanced up-to the order of higher MeV energies with an intense short pulse laser of intensity in the order of $10^{18} W/cm^2$.

PREFACE

The acceleration of electron by laser in vacuum and plasmas is studied. In this work, we examine the laser induced dynamics of electron in vacuum and plasmas. We study the electron trajectory under interaction with laser pulse with variation of laser parameters. Electron acceleration by laser is widely studied by researchers and scientists as the accelerated electron attain high energy during interaction with laser pulse. We analyze that the attained energy by an electron during interaction with laser pulse is further enhanced by considering applied magnetic field in vacuum and plasma. We examine the role of polarization of laser beam, beam width parameter, frequency chirp and electron injection for electron acceleration. We have focused our attention on enhancing the electron energy gain by the proper selection of various parameters of laser, magnetic field and electron injection for laser electron interaction in vacuum and plasma. We have investigated the mode indices based electron acceleration by Hermite-Gaussian laser beam in plasma. Finally, we present the electron acceleration due to laser-cluster interactions. The enhancement in electron energy gain by laser pulse has been observed and reported in the present study.

I am highly thankful to Dr. Niti Kant for valuable guidance to complete this work. I am deeply thankful to my wife and family for their co-operative attitude during the entire period of this work.

Harjit Singh Ghotra

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