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Article

Theoretical Study of Ultrashort Laser Produced Plasma of Heavy Ions

Mohammed H.Jawad[1] , Zahraa T.Turki[2]

1. College of Pharmacy/Ahl Al Bayt University/Karbala/Iraq; muhamedhamza99@abu.edu.iq
2. College of Health and Medical Technologies/ Department of Anesthesiology /University of Al Zahraa for Women/Karbala/Iraq; zahraa.talib@alzahraa.edu.com

* Correspondence: muhamedhamza99@abu.edu.iq

Abstract: We study in this paper the different lead plasmas properties involved mass density and electron density.This research examines plasmas generated by ultrashort laser pulses with wavelength ($\lambda = 800\ \ nm$).The study of plasma produced by ultrashort laser allowed to predicting spectral emissions such as EUV and X-ray for heavy ions .The spatial-temporal distribution The femtosecond laser pulse (500 fs) creates plasma with properties (mass density= $10^3\ \ g\ /\ cm^3\ \ and\ \ electron\ \ density = 10^{25} cm^{-3}$).

Keywords: Ultrashort , lead, femtosecond laser , plasma , heavy ion

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1. Introduction

It has been demonstrated that the femtosecond laser is an advanced material processing tool.The term "black and colored metals" refers to the ability we have recently gained to convert highly reflective metals into either completely absorptive or just reflecting a specific hue of light [1]. Lead is a valuable metal because of its special chemical, physical, and biological characteristics. When expanding and cooling in a vacuum, a laser-produced plasma (LPP) ablated by a femtosecond laser pulse is neither uniform nor static where electron densities can be from 10^{17} to 10^{22} $Cm^{-3}$and electron temperature from 1 eV to 100 eV. Numerous competing atomic processes that rely on electron density or temperature exist in such plasmas [2]. In these processes, photons, ions, and electrons all participate and interact with one another. A plasma is created when ultra-intense laser fields interact with matter, quickly ionizing the target. Laser-driven plasma-based particle and radiation sources are of significant interest due to their capacity to sustain acceleration gradients that are orders of magnitude bigger than those possible with traditional accelerators. These sources have applications in the fields of materials science, biology, and medicine[3, 4].

2. Materials and Methods

This work aims to theoretically investigate the hydrodynamic properties of plasma generated by femtosecond ultra-short lasers. A femtosecond laser's high intensity produces plasma with unique properties, and the laser-plasma interaction varies according to the laser's settings and features. This version offers a clearer picture of how laser pulse width affects plasma. The focus of the investigation will be on hydrodynamic plasma parameters for varying pulse durations in the femtosecond regime, including plasma ionization, average ion, electron temperature, electron density, mass density, pressure, and electron velocity.

2.1. Medusa Laser Produced Plasmas Interaction Hydrodynamics

In order to model the hydrodynamic and plasma processes in a laser-irradiated pellet, UKAE's Culham Laboratory created Medusa, a one-dimensional Lagrangian code for laser-plasma interaction, in 1974. Originally designed to assess the viability of producing controlled thermonuclear power, Medusa is currently employed to replicate emission and absorption within a rapidly growing plasma [5,6].

The main characteristics of the plasma in Medusa are its density, velocity, ion, mass, and electron temperature.An implicit heat conduction integration scheme and an explicit Navier-Stokes hydrodynamics are combined with a Lagragian difference mesh. For every realistic laser pulse, the model geometries are spherical, cylindrical, or planar [7].

2.2. Laser Pulse Duration

Laser pulses that last less than a few picoseconds are referred to as ultrashort pulses. (10^{-12}s) long. Techniques like Kerr-lens mode locking, which permit pulse duration down to about 5 femtoseconds, are the result of recent research (10^{-15}s). Mode-locked lasers are used to create ultrashort pulses, which are defined as having a pulse duration of no more than a few tens of picoseconds [8,9].

This can be used to define pulse duration, but the most widely accepted definition, as shown in Figure (1), is based on the full-width at half-maximum (FWHM) principle of optical power against time.

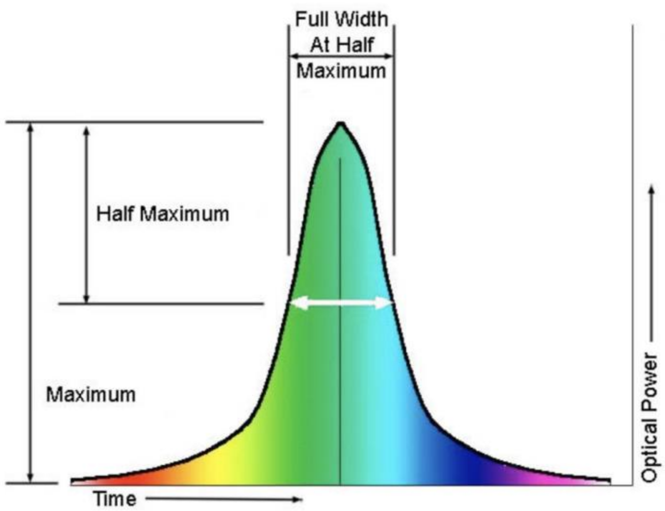

Figure 1. The pulse's [FWHM] value [10].

The development of ultrashort (less than 1 ps) pulse length laser technology has been driven by the need to comprehend the intricacies of electronic excitation and de-excitation. This is because these processes can have timescales as small as tens of femtoseconds [11]. Mode-locking is occasionally used in conjunction with cavity population modulation to produce laser pulses with such brief durations. Furthermore, only materials with a sufficiently large spectral (and consequently frequency) spectrum can produce ultrashort pulses[12].

3. Results and Discussion

3.1. *Electron Density*

The electron density fluctuation as a function of time and distance is displayed in Fig. (2). When the target and laser start interacting, the peak electron density is (10^{25} Cm^{-3}). Then the plasma starts to expand, and the electron density becomes (10^{19} Cm^{-3}) at about (70 um) distance and (0.62 ns) time , at the plasma edge it reaches to (10^{18} Cm^{-3}) after (210 um) distance and (1.8 ns) time. Because collisional recombine becomes more prevalent at greater electron densities, the average charge within the plasma falls as the density of electrons increases[13].

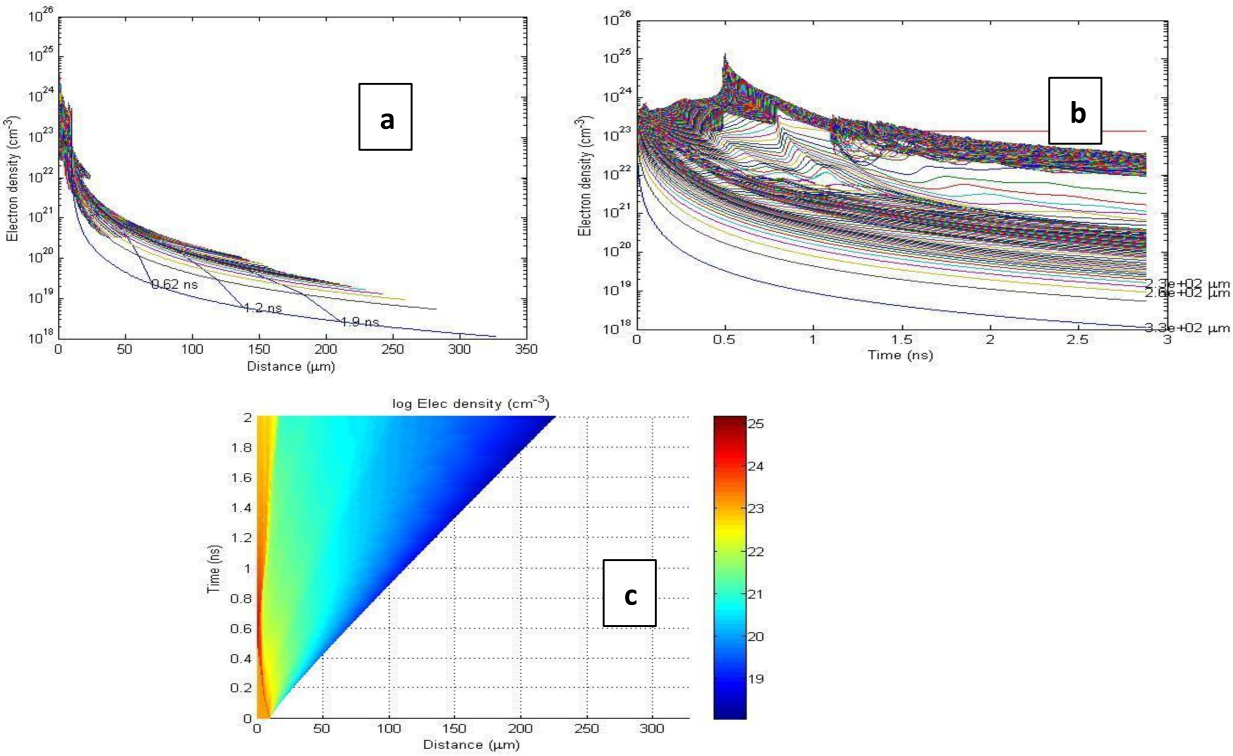

Figure 2. The change in Pb plasma's electron density over time and space

3.2. *Mass Density*

As shown in Figure (3(a)) , at the intended area (10 µm) The highest mass density in variation throughout space is (10^3 g/cm^3). And after that, it begins to progressively decline until it slightly below ($10^{-4} g/cm^3$) at (220 µm) distance and (1.9 ns) time.

In the temporal variation , Figure (3(b)) , at the beginning of the laser pulse, the mass density is about (10^2 g/cm^3) at the surface of the target (10 µm), and then at time(1.2 ns), the maximum mass density value is about (10^3 g/cm^3) and at the plasma's edge, it begins to descend.

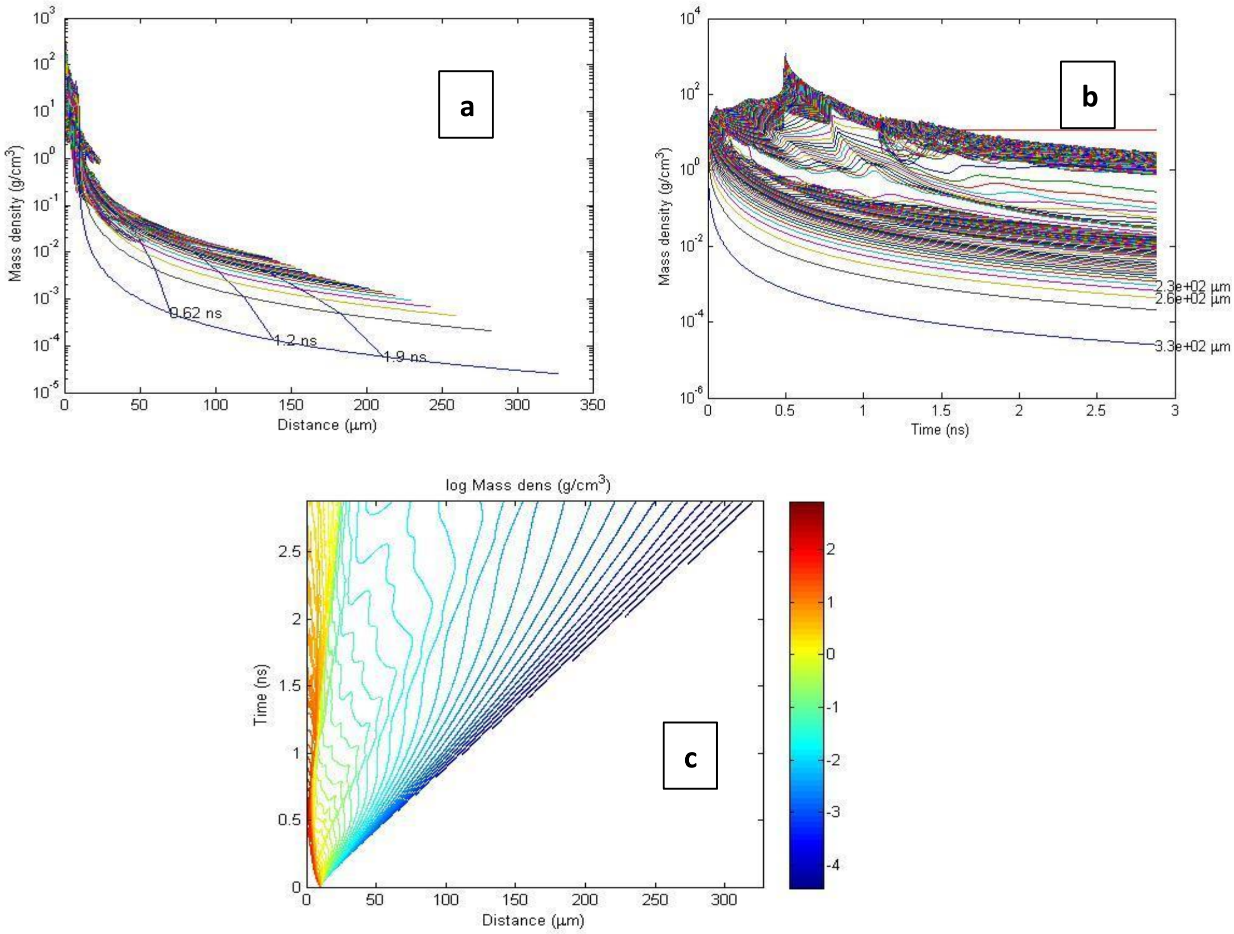

Figure 3. The change in Pb plasma mass density over time and space.

4. Conclusion

Based on the study's findings, it is hypothesized that multiphoton ionization a process that produces a large number of electrons is how femtosecond laser pulses make plasma. Furthermore, the femtosecond laser has a shorter duration than the electron-lattice relaxation period, thus the electron thermal conductivity is directly proportional to temperature. Target electrons are required for femtosecond laser irradiation. Thermal diffusion will swiftly transfer the absorbed laser energy to the deeper target when the target temperature is high.

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