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Study on the collinear delay double pulse laser induced air plasma expansion by optical interference

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ABSTRACT

In this paper, the air plasma expansion dynamics induced by collinear delayed double nanosecond laser pulses are studied by optical interference method, and comparative analyzed the difference of the air plasma expansion generated by single pulse laser and collinear delayed double pulse laser. The experimental results show that the air plasma expansion distance, expansion velocity and shock wave pressure produced by collinear delay double pulse laser are all larger than that of single pulse because of existing the second laser pulse interaction with the air plasma formed by the first one, and the plasma action time is effectively delay. Finally the mechanisms of the inter-pulse delay time effect on air plasma expansion process are analyzed.

1. Introduction

Laser induced plasma, LIP, is a topic of growing interest in different fields such as material processing, diagnostic techniques and space applications. Laser induced breakdown in gases has been studied extensively since the 60's, for different applications. LIP in air at an atmospheric pressure has been used to simulate the chemical and physical properties of natural lightning. Nitrogen oxides (NO, NO_2) produced by this process are a source of fixed nitrogen to the biosphere. The induced breakdown mechanism and characteristics of air plasma have been theoretically and experimentally researched for several years. Zhang et al. [1] measured the three dimensional distribution of electron density behind the laser-induced blast wave in air by using the Mach Zehnder interferometer. Soileau et al. [2] numerically studied the laser-generated plasma plume interaction with a background gas and developed a three-dimensional combined model to describe the plasma plume formation and its expansion in vacuum or into a background gas. Tambay and Thareja [3] investigated the spatial-temporal evolution of ns laser ablation plumes at an atmospheric pressure by the optical shadowgraph and fast photography and provided valuable insight into the expansion dynamics and shock structure of the plasma plume. To further explore the principle and technique of delay laser-air plasma recombination process meeting the needs of laser interaction with air plasma [4–8], we studied the expansion dynamics of air plasma induced by the collinear delayed double pulse lasers using optical interference method. We analysis the effect of the inter-pulse delay time on the air plasma expansion distance, expansion velocity and shock wave pressure compared with that of single laser pulse expansion.

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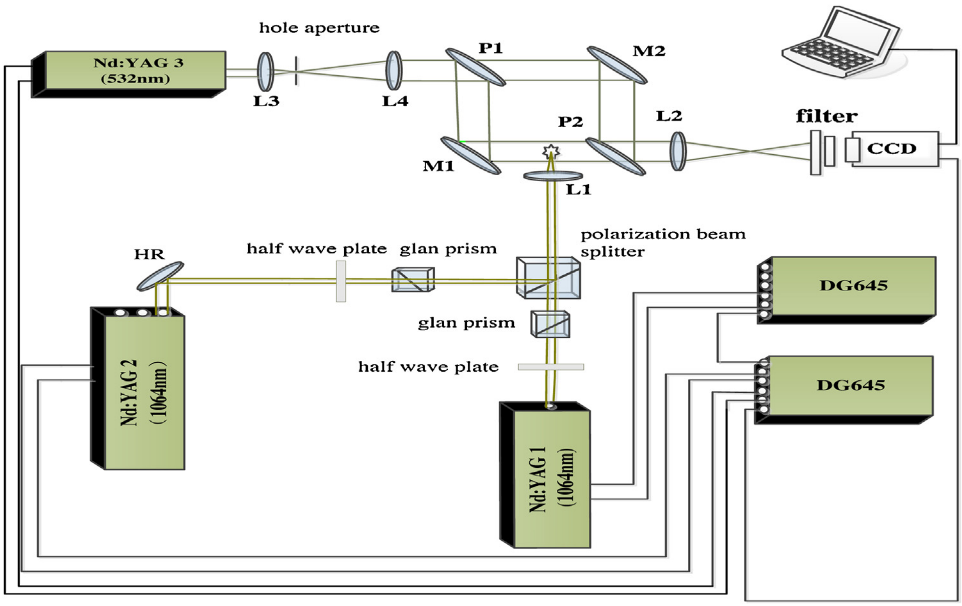

Fig. 1. The experimental setup for delay double pulse laser induced air plasma expansion by Mach-Zehnder interferometer.

2. Experimental set up

The schematic diagram of experimental setup for delay double pulse laser induced breakdown air plasma is shown in Fig. 1. The delay double pulse lasers are consist of a Q-switched lasers YAG1(Continuum, Power8000) and a YAG2(Continuum, Surellite II) operating both at fundamental wavelength 1064 nm with a repetition rate of 10 Hz, which pulse width and laser beam size for laser YAG1 and YAG2 are 20 ns and 6 mm, 20 ns and 7 mm, respectively. The polarized directions of two laser beams are perpendicular to each other. The delay double pulse laser collinear transport using by a polarization beam splitter and are focused by a plano-convex lens with a 50 mm focal length to breakdown air gas and generate the air plasma. The laser pulse energy is adjusted by using a combination of half wave plate and glan prism. Mach-Zehnder interferometer consists of two aluminum holophotes (M1, M2) and two splitting wedges (P1, P2) as the arms of the probe beam and the reference beam. A charge coupled device (CCD, Princeton Instruments) camera is used to capture the interference fringes of laser-induced air plasmas. Neutral density filter and 532 nm interference filter are placed to protect CCD camera over exposure. The laser YAG3(Innolas, Splitlight Compact 400) as the interference source with 532 nm wavelength and FWHM 8 ns is expanded ten times by lens L3 and L4. A hole aperture is placed at the co-focus of a lens L3 and L4 as the spatial filter to improve the quality of interference fringes. The CCD camera was synchronized to the interference source laser and the delay time among the three lasers (YAG1, YAG2, YAG3) which were controlled using by two delay time generators (DG645).

3. Results and discussion

For the collinear double laser pulses, the total energy is 100 mJ which consists of YAG1 50 mJ and YAG2 50 mJ with some delay time. The inter-pulse delay time of the collinear double laser pulse is the interval time between YAG2 laser and YAG1 laser arriving the lens focus. Fig. 2 are the time-resolved interference images of air plasmas produced by the delay double laser pulse with inter-pulse delay time 30 ns and 100 ns and single pulse at same total laser energy of 100 mJ.

Fig. 2 shows that the shock wave front distance increases with delay time for collinear delay double pulse laser and single pulse laser, and the expansion process of a shock wave produced by collinear delay double pulse laser is significant difference compared with that of single pulse laser. Fig. 2(a) and (b) are seen that when the second pulse laser is inputted to the air plasma, a new air plasma showing as a tip occurs on the air plasma front produced by first laser pulse of 50 mJ due to the inverse bremsstrahlung absorption, and the two air plasmas gradually coincide with each other and outer expand as a whole together with time increasing. Especially the air plasma shape changes from spherical to the plane shape for the inter-pulse delay time 100 ns, due to the second laser pulse interaction with air plasma, the new air plasma expands rapidly in the inverse direction of laser irradiation with showing the spherical shape again as time elapsing. Fig. 2(c) is seen that the air plasma shape of single pulse laser with of 100 mJ expands as spherical shape with time increasing. The plasma expansion displace inverse direction of laser irradiation are greater than that of along the direction of laser irradiation for both cases of single pulse laser and collinear delay double pulse laser.

The air plasma expansion distance as a function of time can be deduced from the air plasma interferometer image for both cases of SP and collinear DP lasers as seen Fig. 3 with laser energy of 100 mJ.