레이저 플라즈마 상호작용을 위한 가스 분출 특성
Long gas jet characterization for laser plasma interaction

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The laser plasma interaction has various applications in the area of high harmonic generations, far UV and X-ray lasers, laser driven electron accelerators, and intense guided field nonlinear optics. These applications require high intensity laser pulses, generally above the ionization threshold of atoms. With the use of the chirped-pulse amplification in solid-state materials such as Nd:glass or Ti:sapphire, it is now possible to reach picosecond or subpicosecond pulses at a multiterawatt level with a focused intensity of 10^{18} W/ cm^2 in vacuum. Such a high intensity laser pulse is achieved in a tightly focused beam and interacts with free electrons which have small interaction cross sections. The cross sections of the laser-electron interaction are several orders of magnitude smaller than those of the laser-atom interaction. An optical beam propagating through a neutral gas is affected by diffraction, refraction, nonlinear self focusing, ionization, and plasma defocusing and so on. After focusing a laser beam, the subsequent spreading of the beam due to the diffraction imposes a severe limitation on the total interaction length. For a focused Gaussian beam, the interaction length is approximately given by a parameter $2Z_0$, where $Z_0 = n\pi w_0{}^2/\lambda$ is the Reyleigh length, n is the refractive index of the medium, w_0 is the $1/e^2$ intensity radius of the beam, and λ is the vacuum wavelength.

To focus laser pulses over the Reyleigh length, a preformed plasma channel by another laser pulse is proposed.[(1)] For optical guiding of laser pulses in plasmas, the radial profile of the index of refraction $\eta(r)$ must have a maximum on axis (minimum plasma density on axis), causing the wavefront to curve inward and the laser beam to converge. When this focusing force is strong enough to counteract the diffraction of the beam, the laser pulse can propagate over a long distance and maintain a small cross section. The index of refraction for a plasma is given by $\eta(r) = 1 - (\omega_p^2/\omega_0^2)[n_e(r)/n_{e0}\gamma(r)]$, where ω_p is the plasma frequency of electron density n_{e0}, ω_0 is the laser frequency, $n_e(r)$ is the radial distribution of electron density, and $\gamma(r)$ is the relativistic factor associated with the electron motion transverse to the laser propagation. When laser pulses meet a plasma, the laser ponderomotive force expels electrons from the axis and prevents them from returning, despite the Coulomb force, which arises from charge separation. If the laser pulse duration is long enough, the ions start to move out as a result of this coulomb force and gain momenta during the process. After the laser pulse has gone, electrons quickly return in order to neutralize the bare ions. However, the ions keep moving off the axis as a result of the ion momentum gained during the laser pulse. By this mechanism, a plasma density depression on axis is obtained. High density ($\geq 10^{19}$ cm^{-3}) plasma channel with a narrow width (≤ 30 μm) is produced and becomes deeper and wider with time. Such a plasma channel can be used to guide a second laser pulse.[2] This two pulses technique makes guiding possible in a linear propagation regime closely resembling that in solid optical fibers. Moreover, the preformed plasma channel supports not only high intensity pulses, but also wavelengths extending into the soft x-ray region. As the shock wave expands, the curvature of the density profile relaxes and the size of the lowest order guided mode increases. This allows the relative delay of the two pulses to be adjusted to optimize the matching of the input beam size to the lowest order mode of the channel, resulting in high input coupling efficiencies. The channel diameter, the length, the depth of the refractive index difference, and the central plasma density can be varied over a wide range.[3]

In this work, long gas jet characterizations are performed with an interferometry as a preliminary study for plasma channel experiments. The experimental setup and a basic result are shown in Fig. 1. 10 nsec pulses width Nd:YAG laser pass through neutral He gas ejected from the long gas jet. The length of the gas jet nozzle is 5 mm, the width is 0.5 mm, and the pressure of He gas is about 50 Torr. Fringe patterns of He gas are obtained from the interferometer and the resulting electron density $n_e(r)$ is calculated by using Abell inversion. The dynamics of the gas jet is studied by changing the delay between the laser pulse and the gas jet.

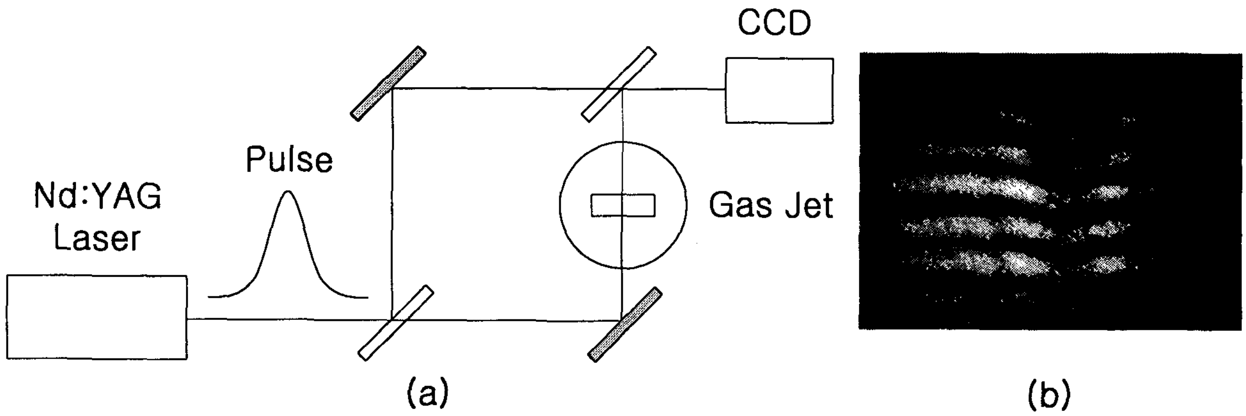

Fig. 1. (a) Optical arrangement of a gas jet interferometry. 10 nsec pulse width Nd:YAG laser pulses prove the electron density $n_e(r)$ interferometrically. (b) Interferogram of neutral He gas from 5 mm long, 0.5 mm width gas jet. The pressure of He gas is 50 Torr.

Reference

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