CHARACTERISATION OF A HIGH-DENSITY GAS JET FOR LASER PLASMA INTERACTION STUDIES

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INTRODUCTION

Pulsed gas jets are now widely used as high power laser targets. The ion densities (up to $\sim 10^{21}$ cm^{-3}) found in gas jets are required for optical field ionisation x-ray laser experiments[1-3], incoherent x-ray generation[4-5], particle acceleration experiments[6], spectroscopy and harmonic generation studies[7,8]. A large volume of uniform, sub-critical plasma can be created, making the gas jet a suitable target.

Simple free expansion gas jets have been investigated [9,10] with small opening nozzle diameter. Supersonic low density gas jets which are suitable for molecular beam and cluster research have also been studied[11]. In these gas jets high pressure gas expands and cools within a tapered expansion nozzle to produce a supersonic low density region. To model and interpret laser interaction with a gas jet requires ideally a detailed knowledge of the density profiles present and their time evolution. In this paper, we use a Mach-Zehnder interferometer and employ an Abel inversion technique to characterise a free expansion gas jet.

ABEL INVERSION METHODS

In interferometery, the average value of phase shifts along a chord through the medium is measured. It is necessary to deduce local values of the refractive index from the available phase shift chordal measurements. Gas jets are cylindrically symmetric, which enables us to deduce the radial distribution of refractive index from the phase shift measurements using Abel inversion. Assuming a cylindrically symmetric refractive index variation n(r), the phase shift chordal measurements $\phi(y)$ can be written as

$$\phi(y) = \int_{-\sqrt{R^2-y^2}}^{+\sqrt{R^2-y^2}} (n_r - 1)dx \, . \qquad (1)$$

Re-arranging this expression so that the integration is with respect to r gives

$$\phi(y) = 2\int_y^R (n_r - 1)\frac{rdr}{\sqrt{r^2 - y^2}} \qquad (2)$$

The Abel inverse transform theorem states that

$$n_r - 1 = -\frac{1}{\pi}\int_r^R \frac{d\phi}{dy}\frac{dy}{(y^2 - r^2)^{1/2}} \qquad (3)$$

Several methods[12] for solving the Abel transform equation have been studied. A recent review[12] recommends polynomial curve fitting to the $\phi(y)$ data which leads to analytic solution for $\frac{d\phi}{dy}$ and analytic solution for $n_r - 1$ By substituting the 6th order polynomial fitting function to the phase shift $\phi(y)$ in the above integral, the refractive index is evaluated as simply

$$n_r - 1 = -\frac{1}{\pi}\left\{2cu + 4e\left(ur^2 + \frac{u^3}{3}\right) + 6g\left(ur^4 + 2\frac{u^3}{3}r^2 + \frac{u^5}{5}\right)\right\} \qquad (4)$$

where $U = \sqrt{R^2 - r^2}$ and c, e, and g are the coefficients of the polynomial fit to the phase shift, viz.

$$\phi(y) = a + by + cy^2 + dy^3 + ey^4 + fy^5 + gy^6 \, . \qquad (5)$$

EXPERIMENTAL SET-UP

A Mach Zehnder interferometer was constructed inside the TA4 target chamber at RAL using a low energy, ns probe beam from the VULCAN laser. Two Al mirrors (25 mm diameter) with flatness of $\lambda/20$ and two similar half silvered splitting mirrors were used to construct the interferometer. The 1.053 μm beam of the VULCAN laser was frequency doubled and used as a probe in the line of view normal to the gas jet flow. Pre-alignment and normalisation of the interferometric optics was carried out using a low power Green He-Ne (543 nm) laser diverted parallel and coincident with the main probe beam.

Neon and Nitrogen gas jets with backing pressure over the range of 13-17 atm have been characterised. A high pressure solenoid valve [13] controlled the output of gas from a high pressure reservoir. The opening time of the gas jet solenoid valve relative to the probe beam and duration of opening was controlled by pulse and delay generator. The gas valve opening times were in the range of 0.1 to 2 msec.

The fringe pattern generated by the phase shift induced on the probe beam by the gas jet integrated along the line of sight of the interferometer was detected by two CCD detectors and recorded using a frame store system (CEO). Two objectives with different magnification were used for the two Mach Zehnder image planes. Interference filters for the 0.53 μm wavelength probe beam were used to minimise back ground illumination of the CCD detectors.

DATA ANALYSIS

The phase shift produced by the gas jet was evaluated by measuring the displacements of fringes from their unperturbed positions (compared to the background fringes which were generated in the absence of the gas jet). Typical interferograms obtained from the CEO frame store computer system are shown in Figure 1. By counting the number of the fringes crossed moving along the y direction, a sampling of fringe shifts ($\delta\phi$) for a given distance from the gas jet surface was measured. The 6th order polynomial fitting function to the phase shifts was determined and used in the inverse Abel inversion integral (equation 4) to calculate the radial refractive index of the gas jet.

Figure 1-Typical interferograms of the N_2 gas jet at backing pressure of 70 atm.