Laser non-uniformity smoothing using gas jets

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Abstract. An experimental investigation about laser beam homogenization using gas jets is presented in this paper. The results, obtained at PALS iodine laser facility using the 3ω wavelength and irradiances of about 10^{15} W/cm^2, showed that the use of high pressure gas jets (up to 10 bar of Argon) can be effective in reducing strong laser beam non-uniformities artificially introduced by inserting a wedge arrangement on half of the beam.

1. Introduction

The question of smoothing of laser non-uniformities is crucial for improving the possibility of getting IFE. This requirement finds however a limitation in the finite number of laser beams (therefore requiring a large number of beams [1]) and in the intensity distribution of each beam, which may contain "hot spots". Introduction of optical smoothing techniques in the '80s (e.g. Random Phase Plates [2], Phased Zone Plates [3], Kinoform Phase Plates [4], Smoothing by Spectral Dispersion [5], Induced Spatial Incoherence [6]) marked a clear progress in reducing non-uniformities. The introduction of such techniques has dramatically improved our control on laser-implosions and laser-plasma interactions; in particular it has contributed to strongly reducing parametric instabilities in the plasma corona [7]. However, there still remains an issue of non-uniformity at very early times, called "laser imprint" problem [8, 9].

In this context a new approach has been recently proposed based on the use of a gas jet to smooth laser non-uniformities [10]. The authors observed how propagation in a gas jet, and ionization induced processes, effectively eliminated small scale (≈ 3 μm) laser speckle patterns. However, in that experiment, the effects of coupling the gas jet to a payload target were not evaluated. To this goal, we performed an experiment at the PALS Laboratory using a 0.44 μm, 400 ps laser beam and we irradiated 10 μm Al targets placed after a gas jet (Argon and Helium gas jets at various pressures) with different laser energies. In order to study the smoothing effect, we created a deliberately non-uniform

irradiation using a prism on half of the laser beam. This produced two focal spots in the focal plane with diameter ≈ 30 μm separated by ≈ 85 μm, which is a *large* non-uniformity and *a-priori* very difficult to be smoothed. We recorded static and dynamical images of the focal spot using a CCD and a streak camera respectively. A strong smoothing due to the presence of the Argon gas was observed, while the effect was practically absent with the Helium gas. Further, we studied the coupling of the laser beam with and without the gas jet to the Al payload by recording the time-resolved self-emission from the rear surface of the targets. The shock breakout clearly showed a strong smoothing effect with increasing the Argon gas pressure. Results were also confirmed by X-ray images recorded on the front of the targets using a pin-hole camera. The analysis of the experimental results shows that the smoothing effect arises as a consequence of the non-uniform ionization of the plasma and of the consequent self-refraction of the laser beam.

2. Experimental set-up

The iodine laser of PALS facility provides a single beam at 0.44 μm (3ω) with a pulse duration (FWHM) of 350 ps, energies up to 400 J and an intensity of $\approx 10^{15}$ W/cm^2. The experimental set-up used for the laser smoothing experiment is shown in figure 1.
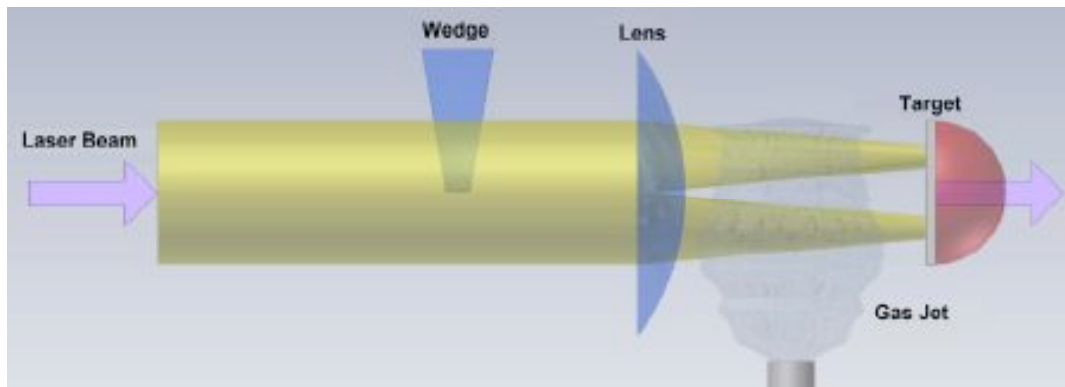

Figure 1: Scheme of the experimental set-up employed for the smoothing experiment.

The laser beam has been focused on a 10 μm Al foil by using f/2 optics [11]. A double spot of about 30 μm of diameter separated by ≈ 90 μm has been artificially realized by putting a prism on half of the beam, therefore creating a very large non-uniformity. A CCD (512 × 512 pix), a streak camera (Hamamatsu C7700) and a X-ray pinhole camera have been used as diagnostics. A nozzle arrangement provides a pulsed gas jet of 2 mm diameter. The correlation between backing pressure and neutral density at the nozzle exit has been determined in previous experiments [12].

3. Results and Discussion

Static and time resolved images have been taken coupling the laser beam with and without target payload. The Helium gas did not provide any smoothing effects even at pressures of 75 bar. The results for Argon are presented in figure 2 and 3.

Figure 2 represents the static images focal spot images obtained without Al target on a CCD: in vacuum (left) and with Argon at 5 bar (right). In this condition the space between the two spots has been almost filled-in in presence of gas. Figure 3 reports the time resolved self-emission diagnostic obtained from the shock breakout of the rear side of the 10 μm Al target of the double focal spot.
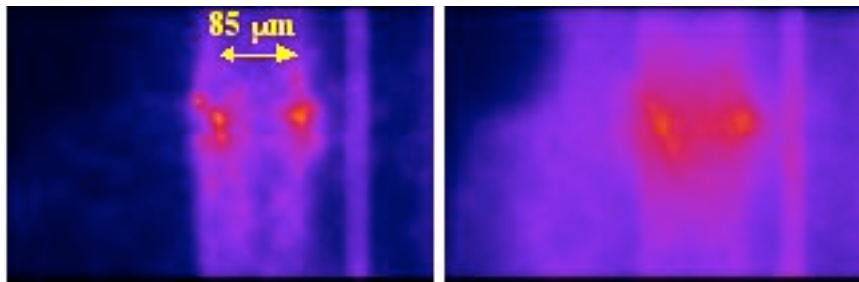
Figure 2: No target. Time integrated images (top): vacuum (left), Argon jet at 5 bar (right).
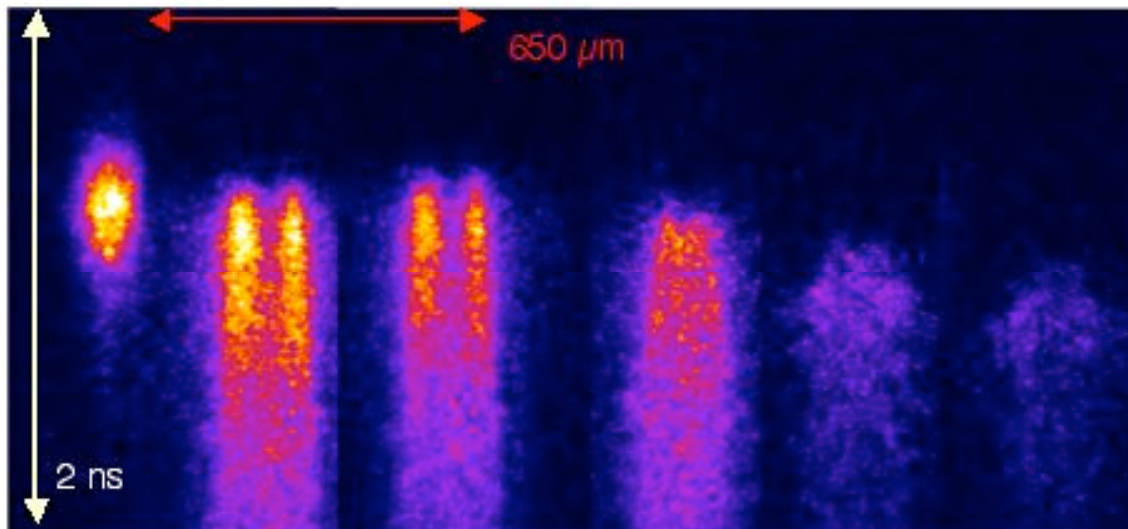

Figure 3: Time resolved shock breakout images from the target of the double focal spot; from left: vacuum 18 J; 1 bar 18 J; 2 bar 18 J; 5 bar 18 J; 10 bar 25 J.

Two effects can be recognized: one is that, starting with a pressures of 2 bar, a smoothing effect appears and second that the shock breakout is delayed as the pressure grows as a consequence of both the reduction of the laser intensity on the target due to losses in gas ionization and the distribution of the laser energy over a larger area because of smoothing.

These results have been confirmed by X-ray pin-hole camera images. Figure 4 illustrates pictures taken at 45° in front of the target and showing that the plasma formed in the vicinity of the target surface merges for backing pressures from 2 bar of Argon on.

The plasma created by the laser while propagating through the gas medium has a strong influence on the laser propagation. In fact, the non-uniform electron density distribution, which is higher on the beam axis and arises from local ionization, electron heating and avalanche ionization, causes a phase shift (because of the presence of a refractive index gradient) of the beam itself. As a consequence, the focal spot will get spread out, thus canceling the two-spot initial separation. On the other hand with Helium, the refractive index change is not enough to overcome such strong non-homogeneity [13].
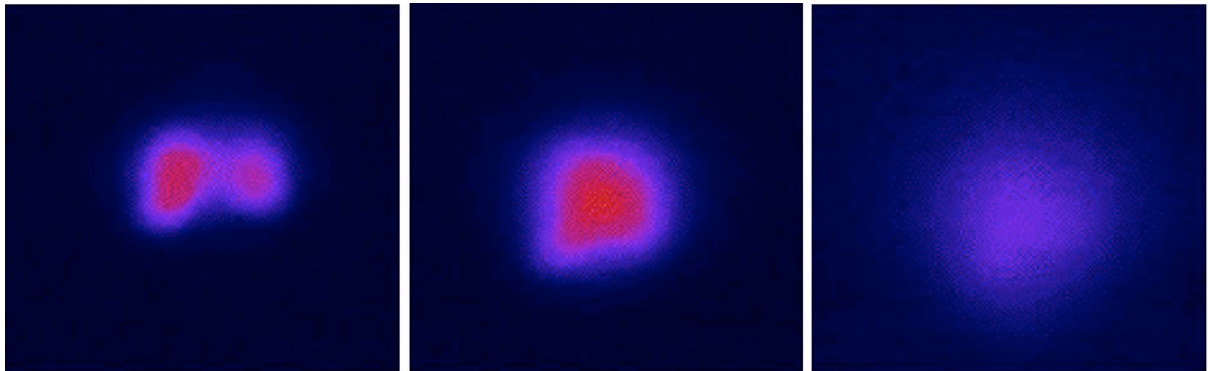
Figure 4: X-ray pin-hole camera images obtained with Argon at 1 bar 18J (left); 2 bar 18J (centre); and 10 bar 25J (right).

4. Conclusion

In this paper, Argon gas jets have been used to correct large-scale non-uniformities (≈ 85 μm) produced by using a wedge placed on half of the laser beam. Results show that Argon at backing pressures ≥ 2 bar produces a broadening of the two spots. This is caused by self-refraction of local high intensities that re-distribute the laser energy over larger surfaces thus resulting in their smoothing. The simplicity of the scheme makes this technique suitable and effective for further investigations. As compared to other smoothing mechanisms (i.e. the introduction of foam layers) this scheme seems to be quite simple and it does not rely on changing the target design. Injecting a gas atmosphere around the pellet could be done at the same time as the injection of the pellet itself. Of course this implies technical issues, which however, does not seem to be much more difficult than the pellet injection. At the same time, we estimated the energy losses, coming both from ionization of the gases and from heating of the created plasmas, and we found that they are completely negligible (less than 1%) which is another advantage of the proposed scheme.

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