Featurization of Ultrafast Expansion and Geometrical Properties of Heterogeneous Colliding Plasmas

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Abstract. Numerous fields of research and industry have undergone revolutionary change because of the unique characteristics of ultrashort laser pulses. Moreover, the ultrafast imaging sensors, such as ICCD technique, can help to understand the ionization features and expansion properties of colliding laser-induced plasma (CLPP) and related stagnation layer (S.L.) geometry. In this work, the effort will be focused on CLPP experiments from two seeds of heterogeneous elements. The research’s goal is to analyse the geometrical development of the colliding plasma, the temporal evolution of plume composition features and its associated characteristics. The expansion velocity and forward propagation range (FPR) of the stagnation layer in a nanosecond scale—both of which have been discovered. The ultrafast imaging results give the sight and explain the possibilities of extant technologies that can help to re-engineer the plasma characteristics for the next generation of lithography applications or new selective physical concepts.

1 Introduction

The effect of the atomic mass of the ablating target on the formation and expansion of the interaction region in laterally colliding plasmas has been focused on many scientific contributions, where several techniques and setups were applied to achieve colliding laser-produced plasmas of different elements [1–4]. Some reasons behind these studies focused on the possibility to enhance specific emission lines from one of the dual materials by introducing the presence of the other target material or used the outcomes for particular applications of nanocomposites, additionally, investigated the plume-front velocity in different environments as well as the effect of the different surrounding media on the electron density and its temperature. The present work will be focused on colliding plasmas create from two seeds of heterogeneous flat targets where Nd:YAG Laser with a pulse duration of ~5 ns and λ= 1064 nm was used.

2 Methodology

A detailed description of the digital nanosecond imaging architecture of colliding laser-produced plasma can be found in Refs. [5,3]. Figure 1 explains the temporal evolution example of the Si–Al stagnation layer and its related features using a bandpass filter 450 nm. Figure 2 shows the visible intensity emission using six different bandpass filters bandwidths. It is also evident in this figure that the majority of the species emission is in the bandwidth of the 450nm and 400nm filters. This contains more than 60% of total emission at different laser energies.

3 Results

All the digital analysis was performed using advanced codes inside the MATLAB digital environment.

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It is clear, the interaction zone starts formation earlier at the seed separation of 1.66 mm. The stagnation layer density seems more intense and has a bigger area at $D=2.16$ mm and $\Delta t=350$ ns if compared with the same case at $D=1.66$ mm, as shown in Figure 4b and Figure 4d.

Figure 5 shows the group behaviour and displacement range of the multifarious ionic species inside the Si-Al stagnation layer (red ▲), obtained using the 450 nm filter, and the centroid velocity (blue ●) is observed to be smaller than the max/e velocity (blue ●).

The velocity of expansion tends to decrease with increasing laser energy as explained in Figure 6. From the linear fit shown in Figure 6, the dropping rate of the maximum expansion velocity $v_{\text{avg,exp}}$ per unit laser energy is around $3.51\times10^3$ cm/s for each one millijoule (mJ) at max/e and will be $2.45\times10^3$ cm/s per millijoule (mJ) at centroid at $D=1.66$ mm.

Table 1 compares the stagnation layer dynamic at quasi-similar laser power density at two different seed separation values (i.e. using $D=1.66$ mm, and $D=2.16$ mm), where the average expansion velocity has a higher value by 40% at shorter separation distance (i.e. $D=1.66$ mm) if compared with $v_{\text{avg,exp}}$ value at $D=2.16$ mm where $v_{\text{avg,exp}}=4.05\pm0.34\times10^6$ cm/s and $2.36\pm0.31\times10^6$ cm/s at max/e and centroid, respectively. In the same scenario, the FPR recorded greater values at $E_L=456$ mJ and $D=1.66$ mm for both cases if compared with the values at $E_L=670$ mJ and $D=2.16$ mm.

### References


