Dynamics of Carbon Plasma Induced by an Excimer Laser in Nitrogen Environment

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Dynamics of carbon plasma induced by an excimer laser in nitrogen environment

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Abstract. The dynamics of laser-ablated carbon plume propagation through different background Nitrogen pressure have been investigated with time and space-resolved emission spectroscopy. Results of temporal and spatial evolution of CI and CII emissions lines at 4267Å and 2478Å respectively under different nitrogen pressure show that there are two stages of expansion in accordance with shock wave and drag force model propagation model.

1. Introduction

Reactive pulsed laser ablation deposition (RPLAD) consisting on the laser ablation of target in reactive gas has become an attractive technique for a wide variety of compound thin films synthesis. In order to produce high quality films with desired properties, the well understanding of the temporal behaviour of ejected species in the ablated plume is necessary. In this work, we report on emission spectroscopic diagnostic of carbon plasma in nitrogen environment at different pressures.

2. Experimental set-up

Carbon plasma is induced by KrF excimer laser radiation (λ=248 nm, τ =25 ns, f =10 Hz) at a fixed fluence of 12 J/cm². The laser beam is focused under an angle of 45°, onto a rotating graphite target surface. The chamber is evacuated at 10⁻⁶ mbar and then filled with N₂ at pressures in the range of 0.5 to 2 mbar.

In order to identify the emitting species and to analyse the plasma propagation, the plasma plume is imaged on the entrance slit of 0.8m spectrometer (Spex, 1200tr/mm) with a spatial resolution of 100 μm and a spectral resolution of 0.8Å. The light emission is collected by a fast photo-multiplier tube (Hamamatsu R928) connected to a fast digital oscilloscope (Tektronix TDS3032).

3. Experimental results

3.1. Temporal evolution

We show that as the gas pressure is increased, the propagation of the carbon species is more affected. We can see two stages of expansion. The first is well fitted using drag force model according to the following formula:

\[ d = \frac{v_0}{\beta} \left[ 1 - \exp\left( -\beta t_{\text{max}} \right) \right] + d_0 \]  

(1)

Where \( d \) is the stopping distance, \( v_0 \) the initial velocity, \( \beta \) the damping coefficient and \( d_0 \) a boundary condition [1].

The second stage is well fitted by the shock wave model according to the expression [2]:

\[ d = a t^{0.6} + d_0 \]  

(2)

Where \( a \) is constant.

Fig (1.a): \((t_{\text{max}}, d)\) plots of the CI emission line (247.8 nm) at different nitrogen pressures.

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The drag model fit parameters and the initial velocity $v_0$, are reported in Table 1, showing that the stopping distance $d_f$ decreases with increasing pressure in agreement with the expected confinement effect. The coefficient $\beta$ increases with increasing gas pressure. Initial velocity $v_0$ remains the same independently from the used pressure.

Initial velocity $v_0$ remains the same independently from the used pressure.

Table 1: $d_f, \beta$ values inferred from the simulation of the experimental data for the emission lines of C I and of C II by using the drag model and the corresponding calculated initial velocity.

<table>
<thead>
<tr>
<th>C II ((\lambda = 427.6) nm)</th>
<th>$d_f$ (mm)</th>
<th>$\beta$ ($\mu^2$)</th>
<th>$v_0$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 mb</td>
<td>7.27</td>
<td>3.74</td>
<td>2.7 x 10^6</td>
</tr>
<tr>
<td>1 mb</td>
<td>6.03</td>
<td>4.75</td>
<td>2.8 x 10^6</td>
</tr>
<tr>
<td>2 mb</td>
<td>4.36</td>
<td>5.18</td>
<td>2.3 x 10^6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C I ((\lambda = 427.86) nm)</th>
<th>$d_f$ (mm)</th>
<th>$\beta$ ($\mu^2$)</th>
<th>$v_0$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 mb</td>
<td>8.07</td>
<td>2.15</td>
<td>1.7 x 10^6</td>
</tr>
<tr>
<td>1 mb</td>
<td>7.44</td>
<td>2.12</td>
<td>1.6 x 10^6</td>
</tr>
<tr>
<td>2 mb</td>
<td>4.31</td>
<td>3.02</td>
<td>1.4 x 10^6</td>
</tr>
</tbody>
</table>

Figures (2.a) and (2.b) show the spatial evolution of maximum emission intensities of C I and C II respectively, at different nitrogen pressures. The curves are characterised by a strong continuum emission up to 3 mm from the target surface, which masks the transitions lines emission. At larger distances, the one can see a structure with maximum moving to the target surface as the pressure is increasing. This effect is due to the plasma confinement by N$_2$ gas molecules as it was previously observed with an inert gas [3].

4. References