X-RAYS EMISSION FROM LASER INDUCED COPPER PLASMA UNDER EXTERNAL MAGNETIC FIELD

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Abstract: Influence of external magnetic field on space and time resolved X-ray emission from laser plasma is investigated. 4 N pure Copper target (2 x 2 x 0.2 cm³) is irradiated with Nd: YAG Laser. Magnetic field of strength 1.2 Tesla (T) is applied perpendicular to the target normal. A computer controlled pinhole CCD based image capturing system was employed for space resolved X-Rays imaging. PIN photodiode connected to digital storage oscilloscope through a biasing circuit was employed for storing time resolved x-rays signals. The results reveal that the X-rays emission intensity as well as energy enhances under the influence of external magnetic field.

Key Words: X- Rays, Nd: YAG, Magnetic Field, Pinhole, CCD Camera, PIN photodiode, space and time resolved, external magnetic field.

PACS: 52.38Dx, 52.38 Ph, 52.70 La

1- Introduction

Laser produced plasma (LIP) is an attractive, compact, inexpensive high brightness X-rays source [1, 2]. Vast applications in industries like lithography and diffraction and medical fields like investigation of the biological objects stimulate scientists to work in this field [3-5]. Many laser-based diagnostic tools are used in the study of atomic emission from various solid, liquid, and gas samples. The spectral properties of X-ray emitted from laser produced plasma under the influence of external magnetic field depend on wavelength, pulse duration, choice of target material and external magnetic field [1-6].
When a high power laser pulse, above ablation threshold, is focused onto a target, hot plasma is formed that may absorb the incoming laser pulse [6-9]. A significant amount of absorbed laser is converted into X-rays via the phenomena of bremsstrahlung, free-bound transition and Bound-bound transition. The knowledge about the X-rays is essential for evaluation of laser produced plasma, its characterization and uses [1, 3 and 10]. There are many sources of x rays but LIP is better than any other X-ray source [2]. The energy of laser transported to target causes ablation of the solid target. Kinetic energy and momentum conservation implies that the target is accelerated inwards and compressed as the plasma expands in the forward direction in the absence of external magnetic field. X-rays are emitted from the plasma predominantly from the region which combines both high temperature and high density [6, 7 and 11].

LIP expanding across a steady magnetic field shows that line emission from the plasma enhances in the presence of a magnetic field, whereas background emission decreases [12,13]. Optical properties of laser-induced plasma show an enhancement in intensity, effective density, confinement of plasma and increase in the rate of recombination in the plasma [13-15]. Changes in plume structure and dynamics, enhances the emission, ionization, conversion efficiency of the laser energy incident onto a solid target into the x-ray emission and velocity in the presence of the magnetic field [3, 13]. The significant, spatial and temporal, characteristics of the x-ray source may be provided by numerical simulations and a simplified analytical model. Optimal time separation of the laser pulses is searched for in order to reach the maximum conversion of laser energy into the emission of selected x-ray theoretically. Plasma photography using pinhole CCD may be used as diagnostic tools experimentally for space resolved x-rays emission laser-plasma plume [16-22]. For the time resolved analysis, a PIN photodiode is used with a filter [17-24]. Many working scientists have been investigating x-rays emission from laser induced metallic plasmas [16-24].

This paper stresses on investigation on space and time resolved analysis of X-ray emission from laser produced plasma.
in the absence and presence of external transverse magnetic field under vacuum.

2- Experimental Setup

A Q switched Nd: YAG laser (1064nm, 10 mJ, 1.1 MW, 9-14 ns) is tightly focused on 4 N pure, annealed copper target (2 x 2 x 0.2 cm$^3$) to produce x-rays from LIP in the absence and presence of external magnetic field of strength 1.2 Tesla. Laser spot size and laser intensity at the focus are 12 µm and 3 $10^{12}$ Wcm$^{-3}$ respectively. The target is set rotating continuously with uniform speed to minimize local thermal effects and to prevent crater formation on the target [6, 7]. The experiments are performed in an eight port stainless steel chamber under vacuum ~ $10^{-3}$ torr. A computer control pinhole CCD based image capturing system was employed to grab space resolved X rays images. A PIN photodiode connected to 200 MHz UTT series digital storage oscilloscope through a biasing circuit to store time resolved X-rays signals. A schematic of the experimental is given somewhere [13].

3- Results And Discussion

X rays, from LIP, depend on wavelength, pulse width, energy and fluence of laser, size of pinhole and time duration of X-ray emission [19]. Pinhole image of the X-ray source from a LIP has a roughly circular image with a diameter comparable with the laser spot size. This is consistent with X-ray emission occurring mainly from plasma densities well above critical [20, 21]. A sensitive filtered pinhole camera for imaging and a filtered PIN diode for detection of X-rays are employed for X-ray detection and signal amplification and imaging [22]. Spatially resolved X-rays images and time resolved x rays signals analysis, in the absence and presence of 1.2 T transverse magnetic field, shows that the intensity of X-rays emission from laser produced plasma under the transverse magnetic field is increases (see figure and signal 2). The intensity is maximum at the center of plume and goes on decreasing as the distance increases away from the center (figure 1). Interactions of plasma particles with laser and electrons generates X-rays from plasma [1,10].
Fig. 1: (a) Pinhole x-ray image (b) Time resolved X–ray analysis and Nd YAG laser without magnetic field

Fig. 2: (a) Pinhole x-ray image (b) Time resolved X–ray analysis and Nd YAG laser with magnetic field

From figure 2 it is seen that the values of different parameters of the X-rays enhances by the application of magnetic field. In the absence of external magnetic field, electron-ion interaction probability is small. In the presence of external magnetic field charged particles start gyratory motion. If they enter magnetic field in any direction they start motion in helical path. If both electron
and positive ion enter perpendicular to the magnetic field then they move in circular path and in opposite direction. There is maximum probability of interaction that is why the X-rays emission is enhanced under the magnetic field [13, 23].

Figure 1 (a) and figure 2(a) show X-rays intensity increases from 170 a. u. in the absence of magnetic field to 220 a. u. in the presence of uniform constant magnetic field a at constant laser energy above the threshold. However, if laser and magnetic intensities are both changed, the signal will be changed in both cases. In the absence of a magnetic field, saturation in intensity is weak whereas, it became pronounced in the presence of magnetic field due to the plasma confinement [13].

Table 1: Different Parameters of incident laser and Soft X-rays (B=0)

<table>
<thead>
<tr>
<th>SIGNAL (without B)</th>
<th>PEAK_VOLTAGE Vp (mV)</th>
<th>FWHM (ns)</th>
<th>Peak Current Ip (mA)</th>
<th>Energy (KeV)</th>
<th>AREA UNDER THE CURVE</th>
<th>Quantum Efficiency η = Ex/El</th>
</tr>
</thead>
<tbody>
<tr>
<td>LASER</td>
<td>281</td>
<td>10</td>
<td>5.5</td>
<td>49.525</td>
<td>1.404*10^10</td>
<td>0.04</td>
</tr>
<tr>
<td>SOFT X-RAYS</td>
<td>80</td>
<td>4.8</td>
<td>1.5</td>
<td>1.851</td>
<td>1.9*10^10</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Different Parameters of incident laser and Soft X-rays (B=1.2 T)

<table>
<thead>
<tr>
<th>SIGNAL (with B)</th>
<th>PEAK_VOLTAGE Vp (mV)</th>
<th>FWHM (nS)</th>
<th>Peak Current Ip (mA)</th>
<th>Energy (KeV)</th>
<th>AREA UNDER THE CURVE</th>
<th>Quantum Efficiency η = E_x/E_l</th>
</tr>
</thead>
<tbody>
<tr>
<td>LASER</td>
<td>281</td>
<td>10</td>
<td>5.5</td>
<td>49.525</td>
<td>2.169*10^10</td>
<td>0.28</td>
</tr>
<tr>
<td>SOFT X-RAYS</td>
<td>160</td>
<td>8.8</td>
<td>3.1</td>
<td>14.029</td>
<td>7.04*10^10</td>
<td></td>
</tr>
</tbody>
</table>
It is clear from figure 2a and figure 2b that the peak voltage, peak current, area under the curve and hence the conversion of laser energy into X-rays increases with the application of magnetic field of 1.2 T due to plasma confinement [13,23]. Table 1 and table 2 show the time resolved data for X-rays in the absence and presence of 1.2 T transverse magnetic fields respectively.

4- Conclusions

The intensity of X-rays is found maximum at the center of the plasma plume. X-rays emission intensity enhances in the presence of uniform transverse magnetic field. The values of peak voltage, peak current, energy and area under the curve for X-rays emission along with quantum efficiency of PIN photo diode increase in the presence of transverse magnetic field.

References