Material Imaging Via X-RAY Emitted from laser produced plasma

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Abstract .The present work represented to the new idea techinque of imaging material through X-ray emitted from laser produced plasma, here, the plasma intensity in uv-visible region spectrum was measurement from the interaction of the 1.06 m of nedumium-glass laser pulse duration of energy 4J, with five target laser: Al, Cu, C, Pb and Stainless Steel(St.St). Astudy of the X-ray emission intensity as a function of laser produced plasma density and surrouding pressure has been a complished using a high sensitive photon detection and counting technique assoicated with an X-ray intensifying screen whose function is based on X-ray florescence . the stainless --stell target was found to have the highest plasma emission intensity, and as a result it has higher X-ray emission intensity . the results show that the plasma X-ray emission intensity is increased with decreasing surrouding pressure, while this emission intensity is increased with increasing the laser power density. In order to study the spatial scanning of transmitted plasma X-ray intensity and study the factors affecting the x-ray imaging process, a special designed Cu specimen of varying thickness was used. The spatial scanning of transmitted x-ray emission intensity shows a comparative picture to the Cu specimen from the recorded x-ray intensity, in which it decreases at thicker region acorrding to lamberts absorbtion law.

1. Introduction

X-rays can be generated in several ways[1,2]. One of them is to focuse an intense laser pulse from a high-power laser onto a small spot of a solid target to creat a plasma[3-6]. When laser beam incident is absorbed in the surface region of a condensed matter target, the electromagnetic energy is converted into heat as plasmons and the response is described by the dielectric function[5,7-11].The present work goal is make a routine x-ray photographic tool of thin materials and biological tissue. Laser-produced plasmas have attracted strong interest for its potential use as an X-ray source with their high brightness and small source size[12].Many experiments have been done to chearcterize the x-ray emitted from laser produced plasma [13]. The spectra emission depend on the type of targets [14,15 ]. The present work is produced new system of material imaging through x-ray emitted from laser produced plasma of different materials .this emission in the uv-visible region produced from the interactin of a 1.06 m and 300 s Nd-glass laser pulse duration of energy 4 J with five different
targets namely C, Al, Cu, Pb, and stainless steel(St.St). The results show that the plasma x-ray emission intensity is increased with decreasing surrounding pressure and with increasing the laser power density. Our final goal is to make a system a routine x-ray photographic tool of thin materials and biological tissues.

2. Experimental Procedure

Fig. (1) illustrates a diagram for the experimental set–up.

The procedure steps employed for the laser system preparation to produce the desired laser pulse energy are follow:

1. Resonator mirrors, laser rod ends, and the focusing lens were carefully cleaned, and the target sample was placed inside the vacuum chamber. The target position was shifted 2mm after every laser shot.
2. The water chiller was operated to cool the rod and the flash lamp before operating the laser power supply and during the operation.
3. The He-Ne laser at 632.8 nm wavelength was used for Nd-glass laser alignment and as a guide beam to identify the spot of the Nd-glass laser pulse shot.
4. Laser energy required for the plasma generation was measured using a ED-200joule meter. This was done using a sheet of glass as a beam splitter to reflect 7% of Nd-glass energy on the head of joule meter. A voltage signal from the joule meter was recorded on an oscilloscope. The energy level was then calculated by dividing the recorded voltage by 9.3V/J, which represents the calibration factor of the joule meter used.
5. To study the emission of plasma in the Uv-vis region by using the present PMT, the pressure inside the chamber was kept between the atmospheric pressure and 0.01 mbar by operating rotary pump. The diffusion pump can be used to reach the pressure of 0.001 mbar.
6. The measure of the X-ray emission intensity, the x-ray intensifying screen was fixed before the PMT in order to convert the frequency of the incident x-ray photons to lie in a lower value in UV and visible region by fluorescence process.
7. The study of the spatial distribution of x-ray intensity was performed into two parts, part I: using a copper sample of varying thickness was shifted horizontally in 1mm step using a micropositioner in order to scan and take an x-ray image which shows the variation in transmission caused by the structures in the sample of varying thickness. Part II: using different filters of varying thickness were mounted on a glass slide and shifted in 7mm steps using the same micropositioner used in part I. This was performed in order to record an x-ray spatial...
distribution which shows the variation in transmission caused by the object of varying density and atomic composition.

8. Different x-ray filters of varying thickness were shifted in 7mm steps using the same micrometer in order to study the soft x-ray accumulated energy spectra and determine the absorption coefficient and the transmitted energy of the material of each filter.

9. Each single x-ray emission measurement was repeated for at least three times to ensure high accuracy.

3. Results and Discussion

3.1. Effect of the Target Thermal Properties on the Plasma Emission Intensity

Five different target; Pb, Al, C, Cu, and St.St. were used to investigate the effect of the target thermal conductivity on the intensity of the plasma photon emission. The laser power density was fixed in this experiment at 7.9x10^6 W/Cm^3 and the air pressure inside the vacuum chamber was varied from atmospheric pressure to 0.01 mbar. It can be recognized from Fig(2), a significant dependence of the plasma emission intensity on the target thermal conductivity. Hence, the plasma intensity increases with decreasing the thermal conductivity of the targets. Table(1) shows the plasma intensity measurements at three different pressures. The plasma intensity is decreased with increasing the thermal diffusivity K of the targets except for St.St. and Pb. However, the thermal diffusivity of St.St. and Pb is higher than other targets.

![Figure (2)](image-url)

**Figure (2)** Illustrates the variation of the plasma emission intensity with the thermal conductivity of the target at different surrounding pressures.

**Table (1)** Variation of plasma intensity with the thermal conductivity of target at different surrounding pressures.

| Target | Thermal conductivity K(W/m.K) | Thermal diffusivity K(m^2/s) | Intensity at atmosphere pressure | Intensity at 0.1 mbar pressure | Intensity at 0.01 mbar pressure |
|--------|-------------------------------|-------------------------------|---------------------------------|-------------------------------|---------------------------------|
| St.St. | 0.113                         | 2x10^{-2}                     | 35389                           | 51780                         | 61832                           |
| Pb     | 35.3                          | 2.4x10^{-5}                   | 14935                           | 26592                         | 39618                           |
| C      | 141                           | 1.19x10^{-5}                  | 9642                            | 18460                         | 28657                           |
| Al     | 237                           | 9.6x10^{-5}                   | 6380                            | 13189                         | 19980                           |
| Cu     | 398                           | 11.6x10^{-5}                  | 4768                            | 6744                          | 7400                            |
3.2. **The effect of the surrounding pressure on the plasma emission intensity**

The practical parts in the present work were performed under different surrounding pressures. The decreasing the air pressure, causes a significant increase in the expansion of the plasma plume.

3.3. **X-ray Production:**

3.3.1. **The effect of the surrounding pressure and laser power on the x-ray emission intensity**

Plasma x-ray production was performed using five different targets; Pb, Cu, C, St.St. and Al. Different laser power densities were used in this work ranging between 1.02-7.9 MW/cm². Figures 3,4,5,6 and 7 shows the relationship between the laser power density and the plasma x-ray intensity. One can noticed that with increasing laser power density the emitted x-ray intensity increased for all targets.

![Figure 3](image3.png)  
**Figure (3)** Variation of x-ray emission intensity as a function of laser power density for C target at different pressure.

![Figure 4](image4.png)  
**Figure (4)** Variation of x-ray emission intensity as a function of laser power density for Pb target at different pressure.

![Figure 5](image5.png)  
**Figure (5)** Variation of x-ray emission intensity as a function of laser power density for Cu target at different pressure.

![Figure 6](image6.png)  
**Figure (6)** Variation of x-ray emission intensity as a function of laser power density for Al target at different pressure.
Figure (7) Variation of x-ray emission intensity as a function of laser power density for St.St. target at different pressure.

3.3.2. **Spatial scanning of plasma x-ray transmitted intensity:**

These parts have been performed to check the ability of using the emitted plasma x-rays to get instant images.

**Firstally:** this practical part was performed using a copper target Fig.(8) of varying thickness which made in this special way in order to take a comparative picture using the same detection system accompanied with 1mm width, 3mm thickness lead slit. This target was moved by a micropositioner with 1 mm step in order to scan the transmitted plasma x-ray intensity.

![Photographic picture shows Cu target of varying thickness](image)

**Secondly:** The necessary attributes for x-ray imaging are: x-ray source, object and radiation detector(image receptor). The source was the laser produced plasma and the object is a set of different filters, namely: Cu,Al and Pb. These filters are mounted onto a thin slide of glass of thickness 25 μm. Fig.(9) represents the spatial scanning arrangement for x-rays imaging testing process.
Figure (9) shows the spatial scanning of plasma x-ray emission intensity of Cu target.

The air pressure inside the vacuum chamber was set at 0.01 mbar while the laser power density was fixed at $7.9 \times 10^6$ W/cm$^2$.

In this work the variation in distance was achieved using the same micrometer which used in firstally part. A slide glass is moved in 7 mm step in order to ensure that the incident x-rays fall exactly on the certain filter thickness, Fig (10) represents an x-ray scanning profile, which represents transmission caused objects of varying thickness, density, and atomic number. From table 2, it is obvious that the recorded transmitted x-ray intensity decreased as the thickness of the filter increased according to lamberts law.

Figure (10). The spatial variation of x-ray emission intensity.

| Edge distance (mm) | Filter | Thickness (μm) + 25 μm glass | X-ray intensity (count/shot) |
|-------------------|--------|-------------------------------|----------------------------|
| 0                 | Cu     | 130                           | 300                        |
| 7                 | Cu     | 390                           | 180                        |
| 14                | -      | 0                             | 550                        |
| 21                | Al     | 25                            | 480                        |
| 28                | Al     | 75                            | 370                        |
| 35                | -      | 0                             | 500                        |
| 42                | Pb     | 230                           | 110                        |
| 49                | Pb     | 690                           | 20                         |
4. Conclusion

The following concluding remarks were extracted from the present results: firstly the intensity of the emitted plasma photons is significantly affected by the surrounding pressure inside the vacuum chamber. The plasma emission intensity is increased with decreasing in the surrounding pressure. As result the emitted x-ray intensity will be increased too. Secondly: The target thermal conductivity is an important parameter that should be taken into account for the choice of the target material. The intensity of the plasma x-ray emission intensity is significantly increasing with decreasing thermal conductivity of the target material. Finally the increasing of laser power density leads to increase the amount of ionized vapor for all the investigated target. This results in an increase in the plasma density leading to an increase in the plasma temperature. Thus, the emitted x-ray intensity will be increased also.

5. References

[1] Alaterte, P., Pépin H., Fabbro R., and Faral, B. (1986). Modeling of X-Ray Emission Created by Short Wavelength Laser Target Interaction. In: Laser Interaction and Related Plasma Phenomena, ed. Hora, H., Miley, G. H., Plenum Press, New York, pp 225-239.
[2] Bushberg, J. T., Seibert, J. A., Leidholdt, E. M., and Boone, J. M. (2012). Interaction of Radiation with Matter In: the essential physics of medical imaging, ed. Mitchell, Lippincott Williams & Wilkins, USA, C. W., pp 33-59.
[3] Carranza, J. E., and Hahn, D. W. (2002). Sampling statistics and considerations for single-shot analysis using laser-induced breakdown spectroscopy. Spectrochimica Acta Part B. 57: pp 779–790.
[4] Ditmire, T., Donnelly, T., Falcone, R. W., and Perry, M. D. (1995). Strong X-Ray Emission from High Temperature Plasmas Produced by Intense Irradiation of Clusters. Phys. Rev. Lett. 75: pp 3122.
[5] Dutta, J., Bisoi, A., Pramanik, D., Ray, S., Saha, A., Tapader, S., and Sarkar, M. S. (2012). Characteristics of Si-PIN diode X Ray Detector with DSP electronics. In: Proceedings of the DAE Symp. on Nucl. Phys., India, 57: pp 904-905.
[6] Giuliani, D., and Gizzo, L. A. (1998). X-ray emission from laser-produced plasmas. La Rivista del Nuovo Cimento. 21: pp1.
[7] Johnson, M. (2003). Photo Detection Basis: In Photodetection and Measurement: Maximizing Performance in Optical Systems, McGraw Hill Professional, New York, pp 1-18.
[8] Kodama, R., Mochizuki, T., Tanaka, K. A., and Yamanaka, C. (1987). Enhancement of keV X-ray emission in laser produced plasmas by a weak prepulse laser. Applied Physics Letter. 50: pp 720-722.
[9] Hudson, L., and Seely, J. Laser produced x-ray sources, Radiation Physics and Chemistry 79 (2010) 132–138.
[10] Liu, Y., Dong, Q., Peng, X., Jin, Z., and Zhang, J. (2009). Soft X-ray emission, angular distribution of hot electrons, and absorption studies of argon clusters in intense laser pulses.
[11] Mc. A., Luk, T. S., and Rhodes, C. K. (1994). Multiphoton induced X-ray emission from Kr clusters on M-shell (~100 Å) and L-shell (~6 Å) transitions. Phys. Rev. Lett. 72: pp 1810-1813.
[12] Nada, H. (2005). Material Imaging via x-ray emitted from laser produced plasma. MSc thesis, institute of laser for postgraduate studies. University of Baghdad, Iraq.
[13] Patran, A. (2002). Electron and medium energy X-ray emission from a dense plasma focus. Ph.D thesis, National Institute of Education, Singapore.
[14] Spencer, J. B., Alman, D. A., Ruzic, D. N., and Jurczyk, B. E. (2005). Dynamics of a laser produced plasma for soft X-ray production. In: Proceedings of SPIE The international society for optical engineering, USA, 5751: pp 798-807.
[15] Mahrukh Bukhari1, S.J. Iqbal1, M Iqbal2, M S Rafique2 (2012). STUDY OF SOFT X-RAY EMISSION FROM LASER PRODUCED PLASMA OF DIFFERENT MATERIAL 2nd ed. Aspen publishers, Gaithersburg, Md, pp 165-167.