Knowledge Consortium of Gujarat
Department of Higher Education - Government of Gujarat
Journal of Science - ISSN : 2320-0006

Continuous Issue - 20 | April – May 2019

SPECTROSCOPIC STUDY OF LASER PRODUCED HIGH DENSITY ALUMINIUM PLASMA

Abstract – *High power pulsed Nd:YAG laser is a good source for producing plasma with high electron density. The plasma plume formed interacts with the surrounding medium and evolves in time. In addition to the laser parameters, the ambience also plays a role in the evolution of plasma. Spectroscopy is a well-known technique for the plasma diagnostics. The broadening of emission lines can be used for the estimation of plasma electron density and the line intensity ratio can provide the temperature information. In this work the plasma produced is studied using the spectroscopic techniques.*

Keywords- *optical emission spectroscopy (OES); plasma parameters; broadening; shifting*

Introduction – Powerful laser beams are capable of producing several spectacular effects. High power laser pulses focused onto a solid target not only vaporizes the material at the focal spot but also generates bright luminous plasma along with ejection of material in different forms from this point (Harilal, 1997). Laser induced plasmas are currently a topic of considerable interest in fundamental and applied areas of scientific research (D.M. Devia, 2015). The subject has made significant progress in its application to many fields of basic research and material technology such as thin film deposition, production of clusters, lithography, etching, annealing, and in the fabrication of micro-electronic devices. The interaction of high power laser beams with matter is a very complex phenomenon and it gives rise to a number of exotic processes.

Production of plasma- When a high-intensity laser beam is focused on a metal, the localized and instantaneous laser energy will deposit on the metal surface, leading to mass migration from the metal surface. Lot of atoms, electrons and ions ionized by the high-intensity laser beam eject and expand outward, forming high density plasma. This plasma absorbs the falling part of the laser pulse, shielding the metal surface from the incoming beam and moves into the surrounding atmosphere quickly.

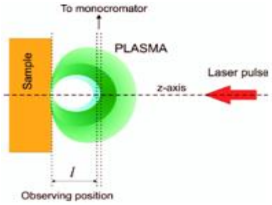

Figure 1

Experimental setup- Here we use high power Nd:YAG laser with pulse time of 10 nano second for the production of high density Aluminum plasma. Energy of laser beam is approx 600 mJ. Laser is routed through mirrors and enters into the vacuum chamber. We use rotary pump as a vacuum pump for creating vacuum up to 0.01 mbar. We use Pirani gauge for measuring the vacuum of vacuum chamber. In vacuum chamber plasma plume is formed on an Aluminum plate. The image of plasma plume is aligned to a fiber array using a two lens imaging system.

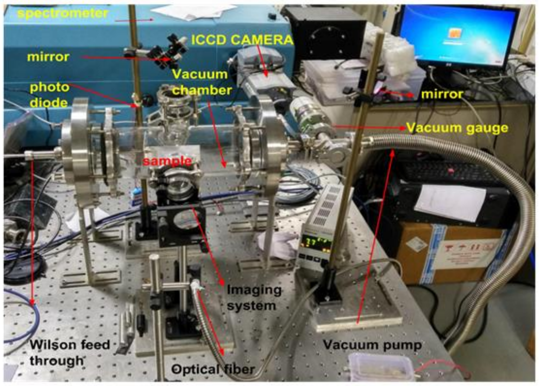

Figure 2

Spectrum acquisition: The Optical fiber coupled to the spectrometer transfer the plasma image to the entrance slit of the spectrometer. We calibrate the spectrometer through the standard Hg lamp for 546.07 nm. The spectral resolution of spectrum is estimated as 0.07 nm. For spatial calibration we put the wire grid at the exact location of plasma plume and optical fiber array is rear illuminated to precise location of imaging volume. The spectrally dispersed light is detected by an ICCD. The spectrum is acquired to a PC interfaced to the ICCD.

Observation:

Here we take observations under two different conditions.

1. At different pressure : 0.01 mbar, 1 mbar, 5 mbar, 10 mbar, 20 mbar
2. At different time delay : 200 ns, 300 ns, 500ns, 800 ns

Evolution of plasma emission spectrum at 1 mbar, 200 ns

Here, we have spectrum of Al2 prominent lines at pressure 1 mbar and time delay of 200 ns. We have nine different spectrum images for nine different optical fibres. As we can see that up to 4th optical fibre we have single prominent line at 466 nm but in other fibres we have prominent lines at different locations. This behaviour is due to different temperature of plasma. We can calculate the temperature profile of plasma with these consecutive lines.

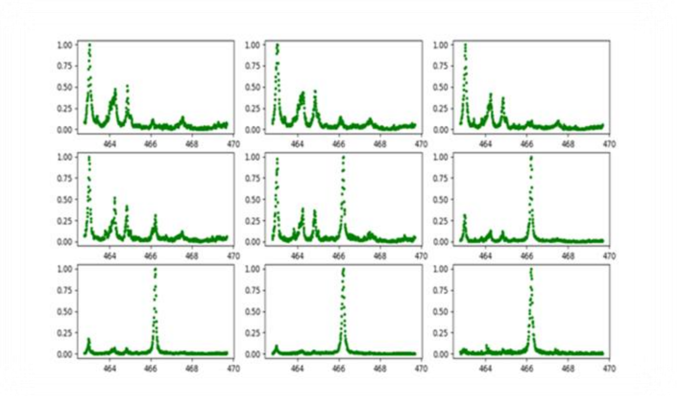

Figure 3

Evolution of Aluminium 466.3 nm line at 10 mbar pressure

We have four different graphs for four different time delay. We can see the different locations of Al2 prominent line for different time which shows how plasma plume is evolved with time. We can get spatial and temporal information of plasma plume with the help of optical fibre.

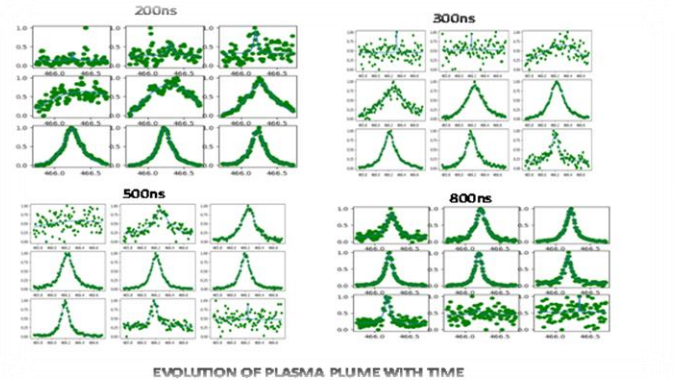

Figure 4

Result and discussion-

Electron density from the stark broadening method

One of the most widely used spectroscopic techniques for determining the electronic density results from the Stark broadening of measured spectral lines (L. Cadwell, 2004). The stark effect results in a shift or division of the spectral line into several components due to the presence of an electric field (H.Griem, 1964). The stark effect is produced by collision of charge particle that have a permanent, strong dipole moment (Griem, 1974). A strong and chaotic electric field produces stark broadening and static electric field induces shifting. In this method, the absolute intensities are not required, only the relative lines and shape. For densities $\eta_e \geq 10^{15}\ \mathrm{cm}^{-3}$, the broadening is high and standard spectrometers are sufficient. We can find the electron density from the following equations (J.Camacho, 2011).

$$\Delta\lambda_{½} = 2 * \mathrm{width} * \frac{N_e}{10^{16}}$$

For 466.3 nm Al2 line

$$N_e = \mathrm{width} * \frac{10^{16}}{2 * 0.00491}$$

fiber no	w_0.01	D_0.01 mbar	w_1	D_1mbar	w_5	D_5mbar	w_10	D_10 mbar	w_20	D_20 mbar
1	7.20E-02	7.34E+16	1.04E-01	1.06E+17	9.26E-01	9.43E+17	5.05E-03	5.14E+15	2.95E-01	3.01E+17
2	5.81E-02	5.92E+16	8.50E-02	8.66E+16	4.51E-01	4.59E+17	1.43E-04	1.46E+14	2.19E-01	2.23E+17
3	6.41E-02	6.53E+16	6.59E-02	6.71E+16	2.57E-01	2.62E+17	7.32E-01	7.45E+17	1.66E-01	1.69E+17
4	6.76E-02	6.88E+16	6.98E-02	7.11E+16	1.82E-01	1.85E+17	3.85E-01	3.92E+17	4.49E-01	4.57E+17
5	6.62E-02	6.74E+16	7.22E-02	7.35E+16	1.46E-01	1.49E+17	3.04E-01	3.10E+17	7.32E-01	7.45E+17
6	6.38E-02	6.49E+16	8.40E-02	8.55E+16	1.34E-01	1.36E+17	2.46E-01	2.51E+17	4.64E-01	4.73E+17
7	7.03E-02	7.16E+16	7.75E-02	7.89E+16	1.24E-01	1.26E+17	2.09E-01	2.13E+17	3.89E-01	3.97E+17
8	9.84E-02	1.00E+17	8.63E-02	8.79E+16	1.26E-01	1.28E+17	1.92E-01	1.96E+17	3.02E-01	3.07E+17
9	6.36E-02	6.48E+16	8.89E-02	9.05E+16	1.30E-01	1.32E+17	1.28E-01	1.30E+17	3.41E-01	3.47E+17

Table 1

Our experimental results are given in table. Here we calculate the electron density from stark width for different spatial locations.

Variation of electron density-

Here we compare the electron density at different optical fibre with different time delay at constant pressure 10 mbar. We can see that electron density is highest at time delay of 200 ns and lowest at time delay of 800 ns. So we can see from the graph that as the time delay increases the electron density decreases.

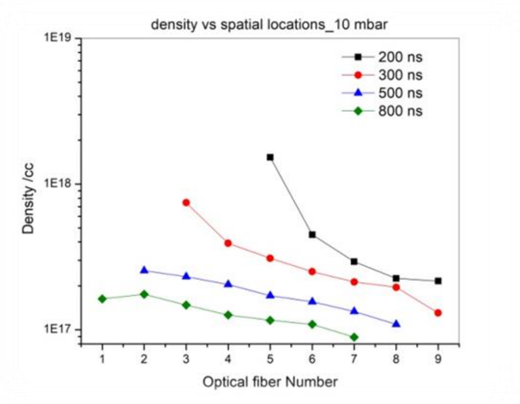

Figure 5

Here we compare the electron density at different pressures with constant time delay of 200 ns. We can see that electron density is highest at 20 mbar pressure and lowest at 0.01 mbar pressure. So we can see from the graph that as the pressure increases the electron density also increases with the time.

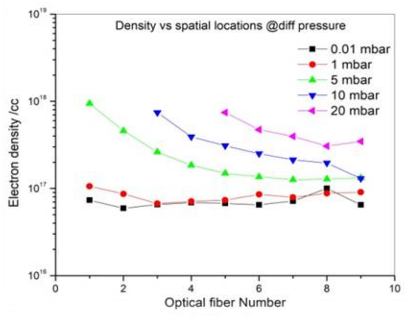

Figure 6

Conclusion: An experimental set up for plasma generation and characterisation is developed. The plasma parameters are estimated using the spectroscopic techniques. It is observed that the plasma plume density is depends significantly on the background pressure. As the pressure increases the density of plume also increases. It is also observed that the background pressure restricts the plasma from expanding as the plume is not propagating much in to the background medium.

Acknowledgement: I acknowledge the help and contributions from the Institute for plasma research (IPR), Ahmedabad Summer school program which provided the opportunity to work in this field and the IPR faculties who guided me to complete this work.

Bibliography

I. D.M. Devia, L. R. (2015). Methods Employed in Optical Emission Spectroscopy Analysis: a Review. Ingenieria y Ciencia , 239-267.

II. Griem, H. (1974). Spectral line broadening by plasmas. New York: Academic Pres.

III. H.Griem. (1964). Stark broadening calculations. Journal of Quantitative Spectroscopy & Radiative Transfer .

IV. Harilal. (1997). Optical emission dignostics of laser produced plasma from graphite and yba2cu3o7.

V. J.Camacho, L. M. (2011). Time-resolved optical emission spectroscopic measurments of He plasma induced by a high power CO2 pulsed laser. Atomic Spectroscopy .

VI. L. Cadwell, L. H. (2004). Time resolved emission spectroscopy in laser generated argon plasmas - determination of Stark broadening parameters. Journal od Quantitative Spectroscopy & Radiative Transfer , 579-598.

****

Mr. Darshitsinh Parmar
M.sc physics
Department of Physics
Gujarat Arts and Science College
Ahmedabad