

## **DIAGNOSE AND INVESTIGATION OF ANGULAR DISTRIBUTION OF COPPER PLASMA IONS\***

**Rabia Qindeel, Noriah Bidin and Yaacob Mat Daud**

Laser Technology Laboratory, Physics Department  
Faculty of Science, University Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia  
E-mail: [plasma\\_qindeel@yahoo.com](mailto:plasma_qindeel@yahoo.com)

### **ABSTRACT**

A Q-switched Nd:YAG laser with fundamental wavelength of 1064 nm delivering pulse energy of 125 mJ and pulse duration of 8 ns was employed as a source of energy to generate plasma. The laser was focused on copper as a target material. The angular distribution of ejected ions species were collected by a developed Faraday cup. The cups were arranged radially at the range of angles from 5° to 90° with two radiuses of 5 cm and 10 cm. The cups were coupled to high speed oscilloscope to display and measure the ion flux and charge state. The exposed Faraday cup was also studied by metallurgical technique. The results obtained show that the maximum flux of copper ion collected by Faraday cup was  $11.7 \times 10^{16}$  charge /sec. The maximum number of charge state was  $\text{Cu}^{+4}$  at 5 cm and  $\text{Cu}^{+3}$  at 10 cm. In general the angular distribution of ions flux is maximum in axial direction and decreases in radial direction. The temperature and density of copper is measured with electronic probe. Various elements are found deposited on Faraday cup with majority lines of copper cluster.

**Keywords:** Nd:YAG laser, plasma, Faraday Cup, angular distribution

### **INTRODUCTION**

The interaction of laser with materials and properties of the plasma produced have been investigated for many years. Nevertheless, the generation of high-density and high temperature plasmas by focusing high peak power laser radiation onto a solid target is still a growing field in basic science, engineering and material processing technology [1-2]. The strong interest in this field is largely due to the fact that both fundamental aspects of laser-solid interaction and consequent plasma generation, and applied technique in material processing technology and sample elemental analysis are involved in particular, plasmas evaporated by irradiating solid targets with visible and ultraviolet nanosecond laser pulses at moderate energy density are widely used for the deposition of thin solid films, are the technique has been applied successfully to a wide range of materials including metals, semiconductors, insulators and superconductors.

Very high energy densities with production of plasma and high ionization states can be obtained by focusing an intense laser pulse on a solid target. The process of the laser beam interaction with the matter is controlled mainly by the wavelength, pulse energy, pulse width, irradiation time and choice of the solid target. The interaction produces atoms, molecules and clusters in neutral and ionic states. Experimental studies of fast ions emitted from laser-produced plasmas have been performed in many laboratories around the world. The studies are motivated by the possibility of numerous applications of laser ion source e.g. heavy ion accelerations [3], direct ion implantation [4], as well as, by the fact that the fast ions bear essential information on physical phenomena taking place in the laser-created plasma [5]. The different diagnostic techniques for the measurement of

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velocity, energy, flux and angular distribution of ions from laser induced plasma are including of Micro channel plate (MCP), Solid state nuclear track detector (SSNTD), Faraday cups (FC), Photomultiplier tube (PMT).

Torrise *et al*, (2001) showed that when Nd:YAG laser is focused on different metallic targets; the interaction produces a high etching for pulsed energy higher than a threshold value typical of each metal. Near the threshold a strong neutral emission takes place; at high pulse energy a stronger ionic emission occurs. The experimental thresholds of ion emission are very similar to the threshold of the neutral emission. The atomic neutral emission is monitored by mass quadrupole spectrometer and by vapor thin film deposition technique. The ionic emission is detected through ion collectors (IC) using Faraday cups and time of flight measurements. The energy threshold, emission yields, the angular distribution, the fractional ionization, the kinetics and characteristics of the plasma production and the ion charge state are presented and discussed. Other researchers [7-10] also reported about ionic emission with different material, its characteristics and measurements techniques. The aim of this present paper is to investigate the anisotropic behavior of flux of Copper ions emitted from laser induced plasma.

### THEORY

Whenever the laser is irradiated on the target the electromagnetic energy is firstly converted into electronic excitation and into thermal energy. Some parts of its energy converted into mechanical energy to cause evaporation, ablation, and hence plasma formation. This resulting plasma plume consists of atoms, ions, molecules and electrons. The electrons are more mobile than ions and neutrals, but they cannot escape the plasma due to strong space charge incurred by collectively moving away from the ions. The Coulomb's attraction of the ions by electrons produces a space charge field that tends to accelerate ions according to their charge  $eZ$ .

$$q = neZ \tag{1}$$

Where  $q$  is total charge due to ions and  $n$  is the number of ions and  $eZ$  is an ion's charge. Therefore the rate of ions,

$$\frac{dn}{dt} = \frac{V}{eZR} \tag{2}$$

Where  $V$  and  $R$  are the voltage and load resistance respectively. By using Equation (2), the ion flux at different distances and different angles can be computed. At maximum energy there is maximum probability of scattering after collision. When two high-energy ions come in close interaction with each other then large electrostatic forces of repulsion appear between them. As a result, ions are scattered at different angles.

One of the quantities of interest in plasma Physics is the temperature of the plasma. For example, when plasma is used for fusion reactions, this is the parameter that most concerns us and that we would like to predict how it varies with other parameters of the plasma. Plasma temperature is very high and as such measurement with physical objects is not feasible. The electron temperature ( $kT_e$ ) is calculated by taking the slope of the corrected curve at the origin should be [11],

$$\frac{dI}{dV} = I(V_p) \left[ \frac{e}{2kT_e} \right] \tag{3}$$

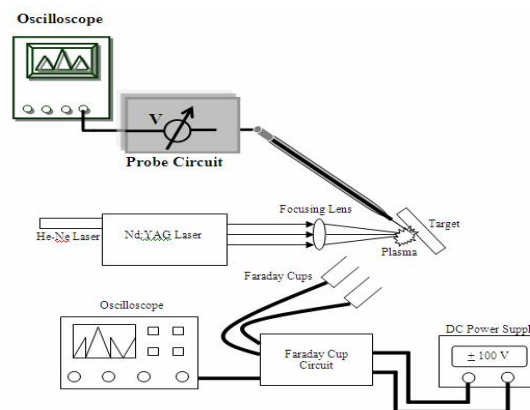
Hence  $2kT_e/e$  is the voltage at which a straight line, tangent at origin, assumes the value of  $I(V_p)$ . The density of plasma depends on plasma temperature and electron current. Plasma density is measured by using following relation;

$$n_e = \frac{I(V_p)}{A_p} \left[ \sqrt{\frac{2\pi m_e}{e^2 kT_e}} \right] \tag{4}$$

$A_p$  is the area of the probe,  $m_e$  is the mass of electron,  $e$  is the electron charge and  $kT_e$  is the electron temperature in eV [12].

### EXPERIMENT

A HY200 Q-switched Nd:YAG pulsed laser with wavelength of 1064 nm and delivering energy of 125 mJ, pulse duration of 8 ns was employed as a source of ablation. A plate of copper was conducted as a target material. The laser was focused using a biconvex lens with focal length of 20 cm. The target was irradiated with Nd:YAG laser at an angle of  $45^\circ$ . The Langmuir probe is inserted very near to the target where rich collection of ions is present. The cups are arranged at a distance of 5cm and 10 cm. The separation of electrons and ion in the plasma plume, setup an electric field, due to which ions were accelerated away from target and made incident on cups. The ion beam entered into the cup after passing through the collimation hole that discharge the capacitor. Faraday cups were places at various angles including  $5^\circ$ ,  $30^\circ$ ,  $45^\circ$ ,  $60^\circ$ , and  $90^\circ$  with respect to the target surface. The signals were displayed on Tektronix TDS 3054B Digital Storage Oscilloscope with sampling rate of 5 G/s. The exposed cup was observed under scanning Electron Microscope (SEM). The schematic diagram of whole experimental arrangement is shown in Figure 1.



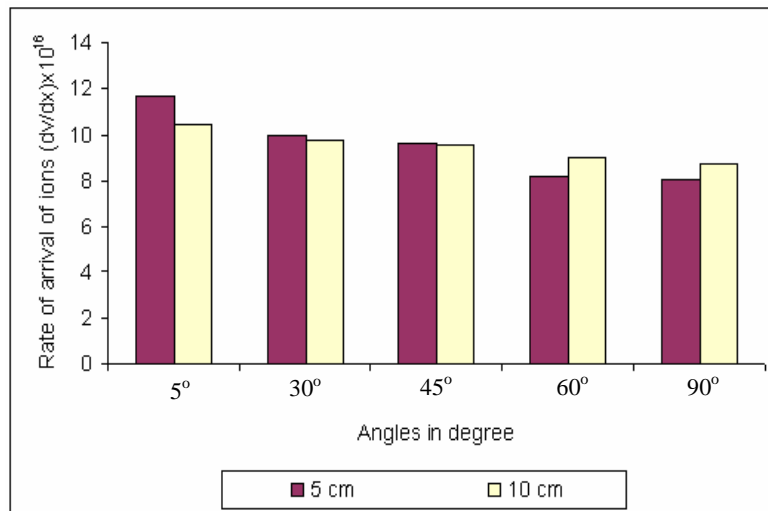
**Figure 1:** Schematic diagram of experimental setup

## RESULTS AND DISCUSSION

In this experiment the charges are attracted by using Faraday cup technique. The Faraday cups were biased by  $-100$  V. An anisotropic behavior and flux of Cu ion were then capable to be detected and measured. The output was taken across a load resistor. The ion current signal was manifested on a 500 MHz Digital Storage Oscilloscope through an integrated circuit. From obtainable signal, the flux or rate of arrival of ions can be estimated. The time of flight measurement of ion reaching to the Faraday cups at different angles is almost the same because the cups are located at radial direction.

The angular distribution of copper plasma was measured at two distances. The Faraday Cups were placed at radius of 5 cm and 10 cm from the target. At the working distance of 5 cm the charged states obtained from copper plasma plume are  $\text{Cu}^{+4}$ ,  $\text{Cu}^{+3}$ , and  $\text{Cu}^{+2}$  and  $\text{Cu}^{+1}$  while the charge states reduced to  $\text{Cu}^{+3}$ ,  $\text{Cu}^{+2}$  and  $\text{Cu}^{+1}$  at radius of 10 cm.

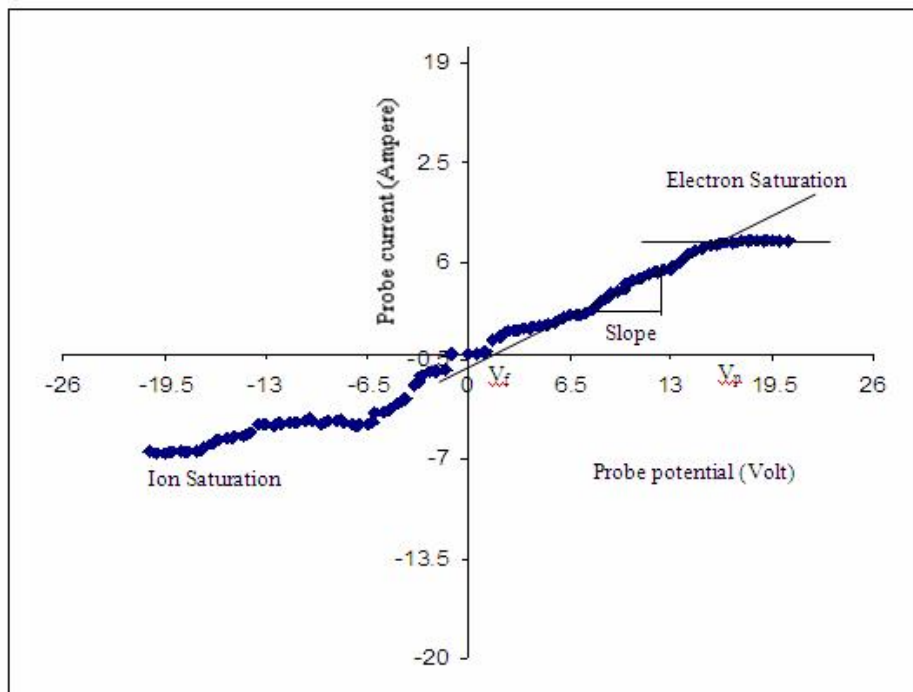
The pulse width of each of the current signal was measured as the flight time of each of the charge state. The accumulation of the flight time from each pulse was considered as the total flight time of copper ion at each radius. In average the flight time of copper at radius 5 cm is 84 ns and 92 ns at radius of 10 cm. In Figure 2 shows comparison histogram of the rate of arrival of ions at a radius of 5 cm and 10 cm of Faraday cup from copper target at different angles.



**Figure 2:** Angular distribution of copper ion at radius of 5 cm and 10 cm.

The optimum rate of arrival of copper ion flux at  $5^\circ$  with respect to the target normal is  $11.70 \times 10^{16}$  charge/sec at radius of 5 cm. The flux of ions is almost the same at  $60^\circ$  and  $90^\circ$  which is  $8.181 \times 10^{16}$  and  $8.05 \times 10^{16}$  charge/sec. The maximum collection of ion's flux is again obtained at the smallest angle of  $5^\circ$ . The minimum of ion's flux is collected by Faraday Cup at the greatest tested angle of  $90^\circ$ . With the increasing angle from  $5^\circ$  to  $90^\circ$ , the ion flux was found to be decreased from  $10.42 \times 10^{16}$  to  $8.74 \times 10^{16}$  charge/sec. So the flux of ions was collected greater towards smaller angle or along the normal line of the target surface.

Langmuir probe was inserted in laser produced copper plasma. Both of positive and negative current signals in term of voltage amplitude are increasing via the increment of bias voltage in the range of -20 V to +20 V. The collected data upon injected bias voltage and LP current produced are used to plot graph of LP current versus probe voltage. The graph is shown in Figure 3. The trend of the graph obtained as similar as the theoretical IV characteristic. The linear part of the graph has a slope of 0.45. The space potential or plasma potential from the graph is 16.5 V, whereas the floating potential where LP potential is zero, calculated as 0.5 V. The floating potential of laser produced copper plasma is experimentally found to be positive which is in accordance with theoretical prediction. Ion current saturation occur when probe potential is greater than - 17 V, while electron saturation of graph of Figure 3 occur after plasma potential achieved more than 16.5 V. The temperature of plasma measured in air is high due to ionization of air particles. In air, the kinetic energy of electrons increase due to increased electron temperature which then cause expansion of plasma plume and in turn decrease electron density. The calculated results by Langmuir probe are tabulated in Table 1.

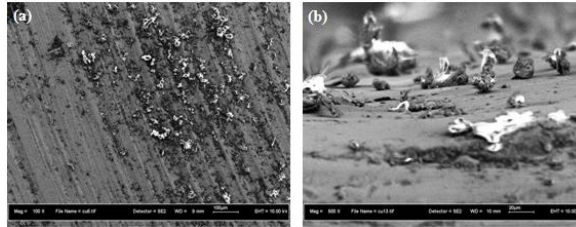


**Figure 3:** Langmuir probe I-V characteristic of copper plasma

**Table 1:** Calculations of copper Plasma parameters

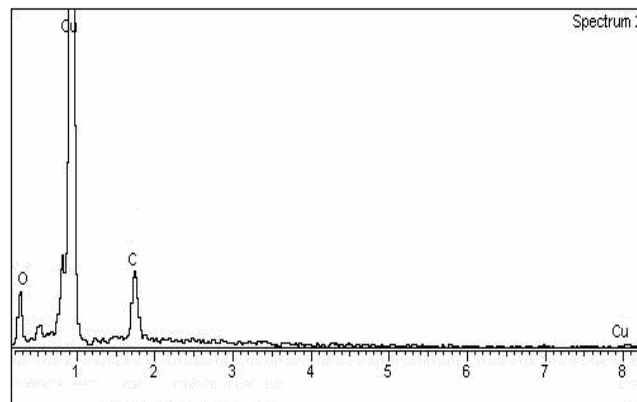
Plasma Parameters	Quantity
Floating Potential ( $V_f$ )	0.5 (V)
Plasma Potential ( $V_p$ )	16.5 (V)
Electron Temperature ( $kT_e$ )	7.91 (eV)
Electron Density ( $n_e$ )	$3.814 \times 10^{14} \text{ (cm)}^{-3}$
Debye Length ( $\lambda_D$ )	$1.07 \times 10^{-3} \text{ (cm)}$

The exposed Faraday Cup was then examined under Scanning Electron Microscope (SEM). The typical observation results are shown in Figure 4.



**Figure. 4:** SEM Micrograph of copper cluster on Faraday Cup.

The pictures in Figure 4 are taken at different measured area with different magnification and positions. The copper clusters are found distributed heavily in Figure 4 (a). Picture in Figure 4(b) has been enlarged from the same picture of Figure 4(a) in order to view the clusters more clearly. The clusters comprised of various state and configuration including molten and solid state. The appearance of copper cluster is confirmed by using EDX. The typical observation from EDX result is shown in Figure 5.



**Figure 5:** Spectrum of ablated particles of Cu under measured area.

The major line in the spectrum of Figure 5 is copper. The other associated lines indicate the carbon and oxygen element. The existence of impurities of oxygen and carbon elements are possibly due to the exposure is carried out in open air and involvement of contamination during ablation. The flatten structure of cluster is associated with copper molten.

As summarization the maximum collection of copper ions by Faraday cup is found almost along the normal line of the target. The minimum collection occurs at an angle of  $90^\circ$ . Hence the angular distribution of copper ion was maximum at the axial direction and minimum at the radial direction. The concentration of copper ions is found reducing at larger angle of distribution. Initially higher concentration of copper ions was formed near the target surface. However due to adiabatic expansion of plasma, the copper ions are accelerated away from the target. During their flight to reach the Faraday cup, ion concentration decreases due to diffusion and scattering. Plasma was distributed angularly because of this phenomenon. In additional, the copper ions also subject to involve in

mutual interaction or the Cu ions might collide with electrons or atoms during their journey to reach the Faraday cups. This also contributed to angular distribution of copper ion.

## CONCLUSION

On the basis of results and discussions it can be concluded that the rate of arrival of copper ions is maximum along the normal of the target. The value of this flux decreases with the increasing angle with respect to the target normal. The investigation of angular distribution shows that the flux is maximum in axial direction and decreases in radial direction. The number of peaks in the signal represents the charge states in the plasma plume. With the help of Faraday cup the charge states of plasma ions are  $\text{Cu}^{+4}$ ,  $\text{Cu}^{+3}$ ,  $\text{Cu}^{+2}$  and  $\text{Cu}^{+1}$ . The temperature of plasma is measured as 7.91 (eV) and density of copper plasma is  $3.814 \times 10^{14} \text{ (cm)}^{-3}$ .

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