Berkala Fisika **_ISSN : 1410 - 9662_**
Vol.8, No.1, Januari 2005, hal 11-14

The Role of Pulse Energy On Laser Induced Secondary Plasma Generation

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Abstract

An observation about the role of laser pulse energy on the secondary plasma generation has been point out. The plasma emission intensity as a function of laser pulse energy was detected by using a monochromator combined with photomultiplier tube. The Relationship between the plasma radius and laser pulse energy is in accordance with shock-wave theory. It is give additional support to the shock wave model in the secondary plasma excitation mechanism.

Introduction

It is well known when a high-power laser pulse is tightly focused on the surface of a solid target, bright plasma is usually formed [1-3]. At atmospheric pressure small bright plasma with high temperature and high-density generated gives rise to undesirably high intensity continuous emission and self-absorption effect. These become the major sources of obstacle in yielding the linearity and sensitivity required for an accurate spectroscopic applications.

When the pressure of the surrounding gas was reduced to around 1 Torr, the plasma invariably consists of two distinct parts. The first part is called the primary plasma, occupies a small area and gives off intense continuous emission spectra for a short time just above the surface of the target. The other part called secondary plasma, expands with time around the primary plasma with near hemispherical shape, emitting sharp atomic spectral lines with negligibly low background [4-10].

On the basis of time-resolved experiments series using TEA CO_2 laser [7], excimer laser [8], and Nd-YAG laser [9], it has demonstrated that this secondary plasma was excited by the shock wave, while the primary plasma acted as an initial explosion energy source. They have offered a theory with respect to the excitation mechanism of the secondary plasma as follows. Right after the cessation of the primary plasma, atoms gush out from the primary plasma at supersonic speed. It is assumed that the surrounding gas plays the role of damping material, impending the free expansion like a wall against which compression taking place. As a result of this compression, a blast wave is generated in the surrounding gas. The most important point of the shock wave model is that the energy required to produce the secondary plasma is supplied in the form of kinetic energy from the propelling atoms. By means of this compression, the kinetic energy of the propelling atoms is converted into thermal energy in the plasma, by which atoms are excited [9,10]. In general the generation of the laser induced shock wave plasma was largely determined by the laser power density incident on the target.

Previous experiment has provided an explanation about the role of surrounding gas on secondary plasma excitation mechanism. Another important issue regarding the shock-wave model is that the surrounding gas only plays the role as a damping material, impeding the free expansion of the propelling atoms, by forming something like a wall against which compression is taking place. As a result of this compression, a blast wave is generated in the surrounding gas [11] .

This study is undertaken substantiate the previous experiment in varied experimental conditions. For this purpose, the laser pulse energy is varied to allow a more comprehensive study about the excitation mechanism of secondary plasma. The main purpose of this study is to provide an explanation about the role of laser pulse energy on secondary plasma excitation mechanism by means of the relationship with the secondary plasma radius. Measurements were conducted on the secondary plasma radius for various laser pulse energies. A description about the plasma emission intensity for various laser pulse energies was also performed.

Experimental Procedure

The diagram of the experimental arrangement is shown in Fig.1. In this experiment, the laser radiation from a 1064 nm Nd:YAG (Quanta Ray, 400 mJ, pulse duration 8 ns) was operated in a Q-switched mode and the laser output was fixed at a certain energy. The laser beam was focused by a multi-coating lens (f = 100 mm) through a window onto the surface of the sample. The laser operation was conducted shot-by-shot manually. The shot-to-shot fluctuation of the laser was about 3 %.

In all of the experiments, a copper plate (Rare metallic Co., 99.99 %, 0.2 mm thickness) was used as a sample. The sample was placed in a small, vacuum-tight metal chamber (11 cm x 11 cm x 12.5 cm), which could be evacuated with a vacuum pump and filled with air at desired pressure. In this experiment surrounding air pressure was set at 2 Torr. The air flow through the chamber was regulated by a needle valve in the air line and another valve in the pumping line. The chamber pressure was measured and monitored with the use of a digital Pirani gauge (Diavac, PT-1DA). The sample, together with the whole chamber and multi-coating lens, could be moved in two dimensions, with the use of a step motor for movement in the laser beam direction and a micrometer for movement perpendicular to the laser beam direction. The sample was shifted after each laser irradiation to secure uniformity of the emission intensity.

The plasma radiation (reduced by using an aperture of 7 mm x 7 mm) was imaged 1:1 by a lens (f=150 mm) onto the entrance slit of the monochromator (SPEX M-270, Czerny Turner Configuration, f = 270 mm with 1200 grooves/mm). The slit was set at 1 mm in height and 100 μm in width so that only the observation could be restricted to the observation area. The electric signal output from the photomultiplier (Hamamatsu IP-28) was fed through a fast pre-amplifier (SRS 240) to a digital storage scope (HP 54600B). A part of a laser beam was detected by a positive-intrinsic-negative (PIN) photodiode, and the output was used as a trigger signal for the digital storage scope. Data collection of the emission intensity carried out by using a printer.

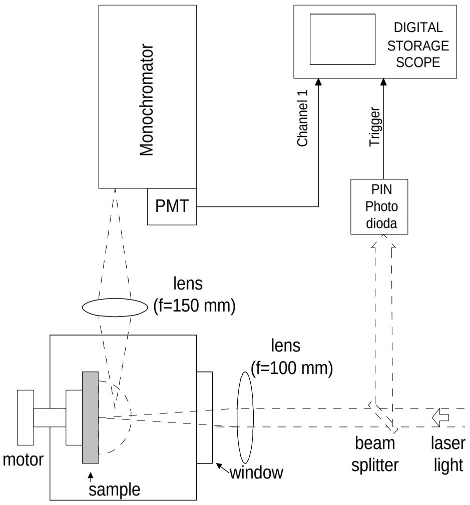

Fig. 1. The experimental set-up.

For measuring the time-integrated signals, a 1 MΩ resistor (its resistance-capacitance (RC) time constant was about 600 μs) was attached to the photomultiplier instead of the 50 Ω (RC time constant about 30 ns) resistor normally used for time-resolved. The plasma radius was observed by reading the end of emission intensity at a certain slit positions, micrometer or shadowgraph for each laser pulse energy. From the results of these measurements, one can derive the relationship between the plasma radius as a function of various laser pulse energies. The laser pulse energy proportional to laser power density.

Results and Discussion

The secondary plasma of copper sample shows a hemispherical shape with green color associated with the emission from the constituent atoms was clearly distinguished from the bright primary plasma. The radius of primary plasma is around of one mm but the radius of secondary plasma in order of cm. The shape of the secondary plasma is similar with the expansion of a shock wave reported by Taylor [11]. In generating shock-wave plasma, the power density is a key factor. It is generally thought that adiabatic compression of the surrounding gas induced by the action of atoms gushing from the target creates a blast wave. As a result, a shock wave initiated by a point explosion is generated. In order for this to occur, the speed of the propelling atoms must be high enough to cause sufficient compression of the surrounding gas [9,10]. The speed of the gushing atoms in largely determined by the power density which is proportional with pulse energy. When laser energy 86 mJ the laser pulse power density is 40 GW/ cm^2

In order to understand the excitation mechanism of the secondary plasma, one need to know further, how the relationship of the secondary plasma characteristics with laser pulse energy. This information was provided by the data of the secondary plasma radius as a function of laser pulse energy. Figure 2 shows the relationship between the radius of secondary plasma and laser pulse energy at 2 Torr air pressure. The graphs presented is consisting of a linear line, with the slopes of around 0.2. This result in accordance theoretical equation about shock-wave by point explosion derived by Sedov [12], indicated that the secondary plasma was excited by shock-wave.

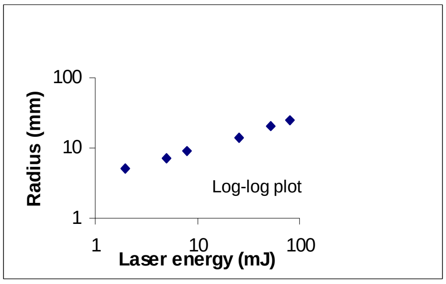

Fig. 2. Relationship of plasma radius with various laser pulse energy.

The most important point of the shock wave model is that the energy required to produce the secondary plasma is supplied in the form of kinetic energy from the propelling atoms. By means of this compression, the kinetic energy of the propelling atoms is converted into thermal energy in the plasma, by which atoms are excited.

Figure 3 shows the relationship between the spatially and time-integrated total emission intensity of the secondary plasma and laser pulse energy at 2 Torr. For this purpose the emission of Cu I 521.8 nm was used. These data show that total emission intensity increases linearly with the laser power after threshold. Similar results were obtain for the experiment using XeCl laser [8], TEA CO$_2$ laser [7] and long pulse Nd-YAG laser [13].

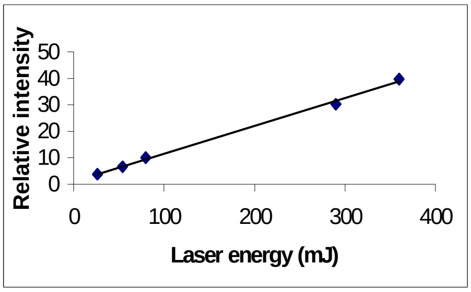

Fig. 3. Temporally and spatially integrated total emission intensity of Cu (I) 521.8 nm of secondary plasma as a function of laser pulse energy.

The total emission intensities obtained by time and spatially integrated emission intensity of Cu I 521.8 nm rises with laser power. Namely, the steep climb is related to the process of continuing compression of the gushed atoms. With time the compression proceeds and intensifies. Consequently, the plasma temperature rises to enhance the atomic emission. The total emission intensity of the atomic emission line is determined mainly by the amount of propelling atoms and the total amount of kinetic energy carried by them. This fact confirms, that surrounding gas only plays the role as a dumping material in the secondary plasma excitation mechanism.

The excitation mechanism of the secondary plasma has been considered as follows. Right after the cessation of the primary plasma, atoms gush out from the primary plasma at supersonic speed. It is supposed that the surrounding gas plays the role of damping material, impending the free expansion of the propelling atoms, by forming something like a wall against which compression is taking place. As a result of this compression, a blast wave is generated in the surrounding gas. The most important point of the shock wave model is that the energy required to produce the secondary plasma is supplied in the form of kinetic energy from the propelling atoms. By means of this compression, the kinetic energy of the propelling atoms is converted into thermal energy in the plasma, by which atoms are excited.

Conclusions

The data of the secondary plasma radius as a function of laser pulse energy, which is proportional with laser power density with the slope of 0.2 in accordance with the theoretical shock-wave by point explosion derived by Sedov. This result gives additional support that the secondary plasma was excited by shock-wave mechanism and the radius of the secondary plasma depends on the pulse energy. Another fact, about the emission intensity of the secondary plasma increases with laser power density at certain pressure, confirms that surrounding gas only plays the role as a dumping material in the secondary plasma excitation mechanism.

Acknowledgment

Grateful thanks to Dr Hendrik Kurniawan Head of Laser Spectroscopy Laboratory and Indonesia University and Maju Mandiri Research Center for the permission to use the research facilities.

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