

Study of Laser-Induced Plasma Using Two Focusing Techniques

Ahmad Hadi Ali* and Noriah Bidin

Centre of Science Study, Universiti Tun Hussein Onn Malaysia,

Tel : +607-4537975

Fax : +607-4536051

Laser Technology Laboratory, Physics Department, Science Faculty,
Universiti Teknologi Malaysia

**Corresponding email: ahadi@uthm.edu.my*

Abstract

Plasma plays an important role in laser fusion research. High power laser is used to drive the reaction. Hence the laser turns to become very crucial devices to form plasma. Generation of plasma can be done by various focusing techniques. Therefore the aim of this project is to determine the best focusing techniques in order to produce strong plasma. Two focusing techniques were considered, that are a single lens technique, and combination lenses technique. A high-speed photographic system was developed in conjunction with image processing system to visualize and record the plasma activities in the focus region. An electrical spark was observed at the focal region which indicates the existence of an optical breakdown. The results shown that the maximum plasma width was obtained correspond to the peak power of 22.21 MW using a combination lenses technique. In general, combination lenses technique produces more consistent plasma, although it size is small. A single lens technique induced large plasma but associated with turbulence condition as indicated by blurred image.

Keywords: Plasma, Q-switch laser, single lens technique, combination lenses technique, optical breakdown.

1 INTRODUCTION

Study of laser induced plasma becomes an interesting field since it is important for both the basic understanding of laser-material interactions and many practical applications (Motz, 1979). Plasma is an ionized state (Yaffa and Eliezer, 1989). Treumann and Baumjohann (1997) defined plasma as a special class of gases that include a large number of electrons and ionized atoms and molecules. Therefore plasma can be defined as a hot (up to keV) electrons and ions. One of the major difficulties in understanding of the physical nature of plasma formation is the fact that plasma formation is a high-speed phenomenon (Noriah Bidin, 1995). As well as to capture the ultrafast plasma formation, a high-speed photography technique must be applied (Mohd. Kamarulzaki Mustafa, 2000).

A high intensity light can create plasma. When a pulsed laser is focused into a medium and a certain pulse energy threshold is exceeded, a so-called breakdown is occurred (Ready, 1971). This phenomenon is characterized by the existence of bright luminous spark followed by an audible sound. The power density in this breakdown region is around 1010 – 1012 W/cm². Hence, the electric field strength E_0 of a focused laser beam of power density P_d is given by (Horisawa et. el, 2002),

$$E_0 = 2.74 \times 10^3 P_d^{1/2} \quad (1)$$

For a laser pulse with power density of $P_d = 1010 - 1012 \text{ W/cm}^2$, the corresponding electric field strength is 106 – 107 V/cm.

The important of this high power density is for generating breakdown which responsible to initiate plasma. At the focal region, for a start at least one atom is ionized resulting in a seed electron, which is accelerated by an inverse bremsstrahlung in the high electric field of the laser pulse (Ahmad Hadi Ali, 2004). After gaining sufficient energy additional atoms are ionized by collisions, thus multiplying the number of electrons. Hence, the density of free charge carriers increasing in avalanche after a few consecutive iterations and plasma is created.

In this present paper, a systematic study of the plasma formation in air produced by IR laser pulse was carried out. A single lens and combination lenses technique were employed to focus the laser beam. The results obtained could give a better understanding regarding the influence of plasma formation induced by laser.

2 EXPERIMENTAL SETUP

A Nd:YAG laser series HY200 manufactured by Lumonics with 1.06 μm fundamental wavelength and 8 ns pulse duration (FWHM) was employed as a source of energy. An external trigger delay unit was utilized to synchronize

the signal of Nd:YAG laser and the recording media. The laser beam was focused using two techniques. The first technique utilized a single lens and the second techniques consume a combination of positive and negative lenses. The whole experimental set up is shown in Figure 1. The plasma formation was visualized and recorded using a Pulnix TM-6EX CCD video camera. The CCD video camera was interfaced via frame grabber to the personal computer. Matrox Inspector version 2.1 software was utilized for image processing and analysis purposes.

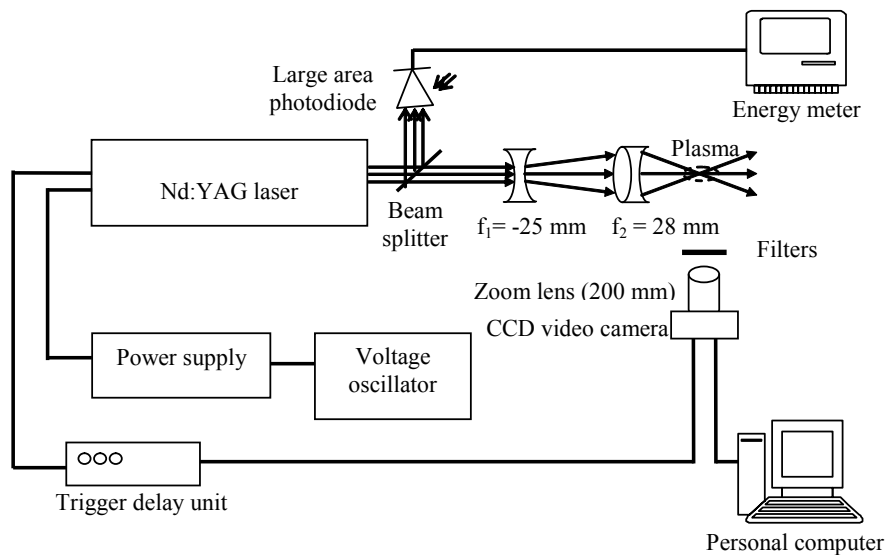


Figure 1 Experimental setup to generate plasma using infrared laser.

Prior to any measurement, magnification factor was calibrated as discussed in other text (Ahmad Hadi Ali and Noriah Bidin, 2003). The plasma formation were studied at various peak powers by changing the voltage oscillator of the Nd:YAG laser. The generation of optical breakdown was identified by the appearance of electrical spark at the focal point.

3 RESULTS

The activities generated at the focal point was visualized and recorded in conjunction with a high-speed photographic technique. The typical results obtained from a single lens technique are shown in Figure 2. These pictures were arranged in the increasing order of the laser peak power.

The configuration of the plasma produced by focusing the laser using a single lens technique is in the ellipsoid form. The plasmas were captured

in the dark room. Consequently, the grabbed images consist of a bright area which corresponds to the appearance of ellipsoidal plasma with a dark background. The brightness of the plasma gives more than enough light to CCD video camera, in fact a filter was employed to avoid over exposure. Thus a very clear image can be recorded. The ellipsoidal plasmas were observed expanded as the laser peak power delivered at the focal point was increasing in the range of 21.61 MW to 21.93 MW. However as the peak power gets higher within 22.00 MW to 22.25 MW, the size of the plasma unstably changed. In certain case, it reducing, expanding and reducing again within that region.

In average, the plasma is comprised of two stages. One is the inner part in which the degree of brightness is illustrated as totally white. While the external part of the plasma comprised of a very blurred image. The existing of a blurring part creates a difficulty in measurement. The precise measurement of plasma becomes skeptical. This is lead to a large of uncertainty. The blurring part is observed getting thicker upon the peak power.

The typical results obtained from combination lenses technique are shown in Figure 3. In the same manner as previous picture of Figure 2, the frames are arranged in the increasing order of the laser peak power. Focusing the laser beam using a combination lenses technique produced broadly-ellipsoid plasma. This particular configuration becomes longer and wider unstably as the laser peak power increases within the range of 21.61 MW to 22.21 MW. The size of plasma was slightly dropped at the highest laser peak power of 22.25 MW.

In average the size of plasma is relatively small. Obviously the blurred part of the plasma induced using combination technique is observed thinner than the previous Figure 2. This leads to a high accuracy of plasma size measurement. This kind of image is referring as significant plasma. The existing of plasma is very clear and concentrated. This quality of plasma promises a good mechanism for damaging and interaction with target material. Cutting edge for example will be smoother and explosion or implosion will take place in uniform distribution.

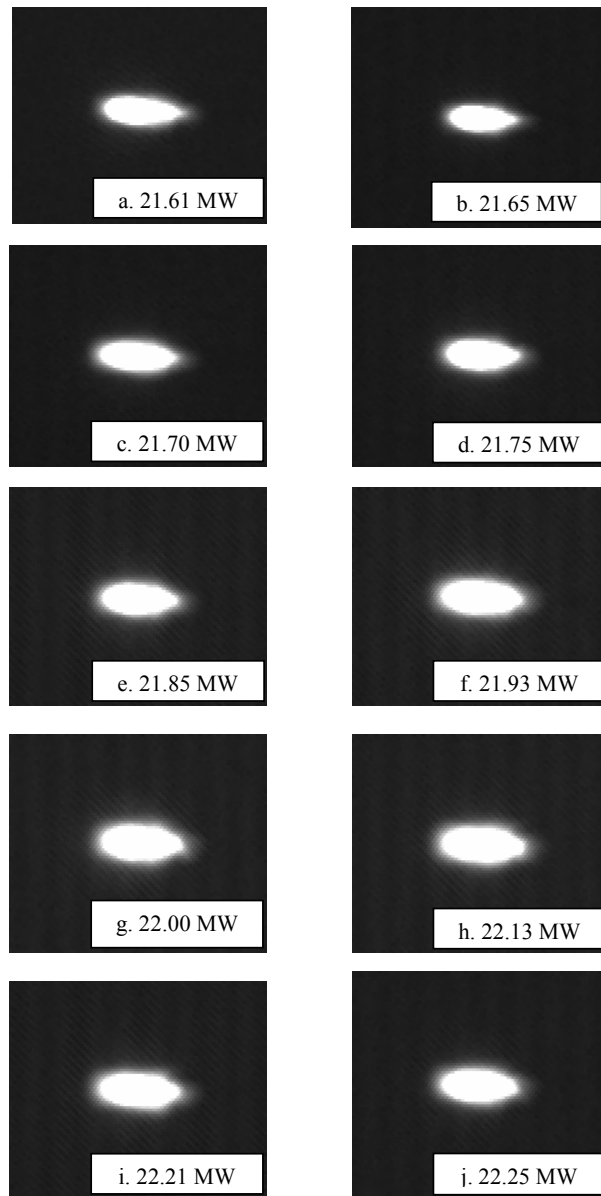


Figure 2 Plasma formation produced using a single lens technique consisting of 28 mm focal length lens. Magnification factor is $10\times$.

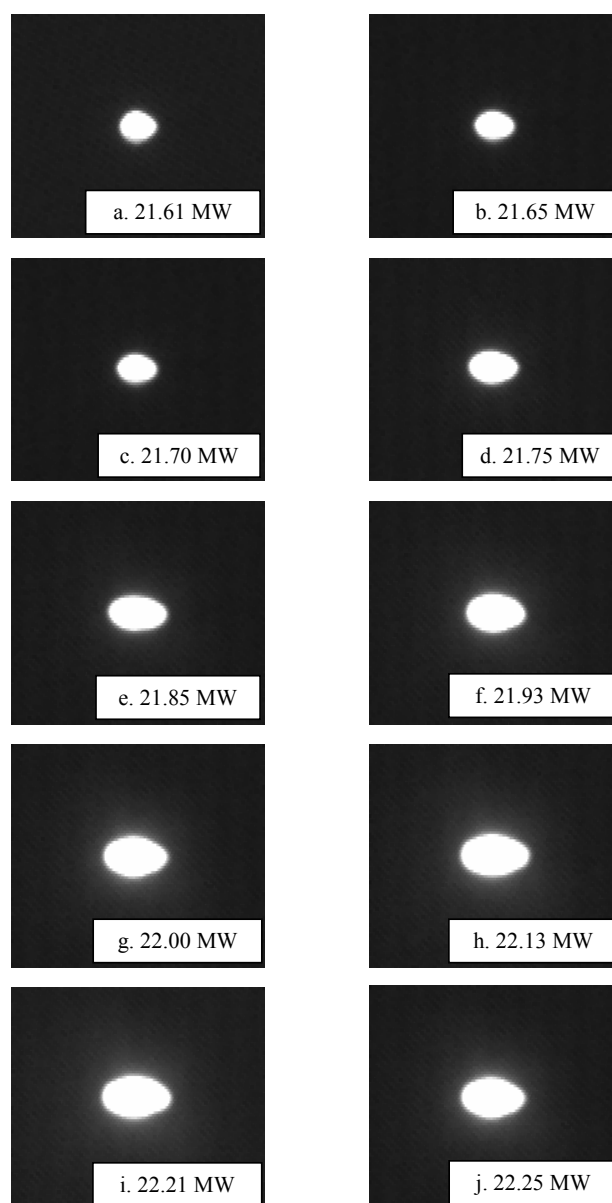


Figure 3 Plasma formation produced using a combination lenses system. Magnification factor is 10x.

The characteristics of the plasma were determined based on the recorded images obtained in Figure 2 and Figure 3. They were described in terms of plasma length as well as plasma width.

The graph of plasma width against laser peak power is shown in Figure 4. Two curves are drawn together on the same graph for comparison purposes. Generally the peak power which is in the range of 21.70 MW to 22.13 MW indicates that the plasma width obtained from a single lens technique is greater than the one by using a combination lenses technique. Both plasma width curves are increases nonlinearly upon the given laser peak power. However the changes of plasma width due to single lens technique is found drastically increases in compared with the plasma width from a combination lenses technique. At higher peak power, the plasma width curves produced from a single lens technique dropped and remained almost constant. In contrast, the plasma width curves produced from a combination lenses technique decreasing at highest peak power.

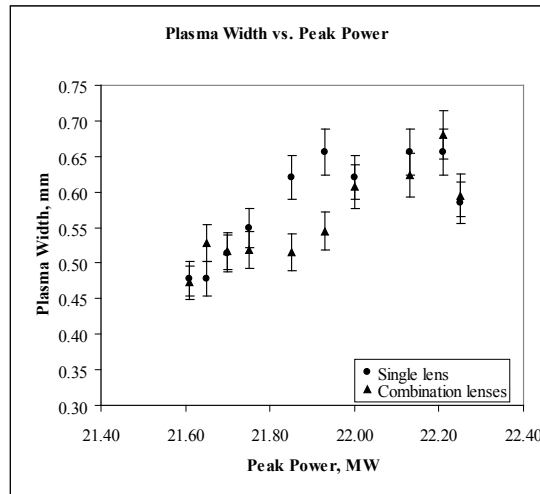


Figure 4 Plasma width profile with respect to peak power of laser beam.

Figure 5 shows the graph of plasma length as a function of peak power. The length of plasma obtained from combination lenses technique obviously shorter than the single lens technique. Initially the curve for combination lenses technique is found nonlinearly increases. After achieving a maximum point of 22.21 MW, the plasma length is drop slightly and remains constant throughout the end.

The results obtained from a single lens technique indicates that the plasma length is increasing to the given peak power of 22.13 MW. However, as the laser peak power gets higher, apparently the plasma length drop slightly and stay almost constant throughout the end of experiment. In general, the plasma length produced from a single lens technique was found much greater than the combination lenses technique.

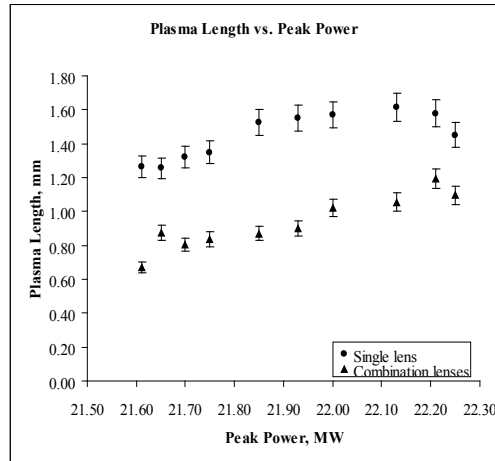


Figure 5 Plasma length profile as a function of peak power.

4 DISCUSSION

It should be noted that the power delivered at the focal point also determined by the oscillator voltage. It is known that the voltage oscillator controls the output of the laser beam. The laser output was found unstable at higher voltage, hence influence the plasma formation. Consequently, the plasma formation in air is dependent on the laser output. If the laser output is fluctuated, the breakdown as well as the plasma formation is also affected.

The size of the plasma depends on the focusing technique of the laser beam. As shown in Figure 6, when the laser is focused using a single lens technique, a long focal length was introduced. As a result, elongated plasma was produced. The experimental spot area or the width of plasma was found almost constant. This result is in a good agreement with the theory of Gaussian beam profile. When the elongated plasma was formed there is a possibility of multiple breakdowns to occur. This is subjected to the occurrence of gross explosion at the focal point. Normally the formation of plasma will associated with the generation of acoustic shock waves. If multiple breakdowns occur, a gross multiple shock waves also involved. The gross explosion will creates turbulence in the surrounding area. This is the possible reason why the capturing event at the focal point became blurred.

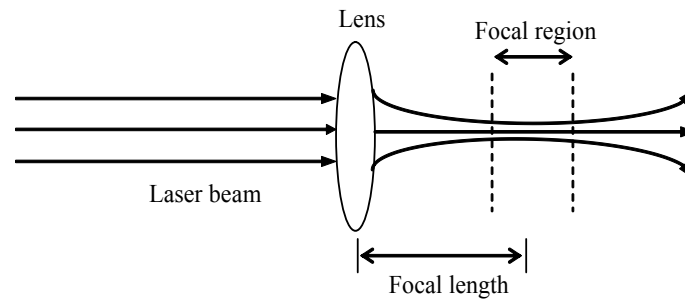


Figure 6 Focused laser beam by using a single lens.

The optical geometry of the combination lenses technique is shown in Figure 7. When the laser is focused, a short plasma length is induced with a smaller beam waist. This experimental result is in good agreement with the theory of Gaussian beam. When the beam waist is small, meaning that the power density is large thus emitted brighter sparkling or huge breakdown. Under this circumstance more atoms were ionized and spreading through the focal region, thus generated stronger plasma. Apparently the width of plasma was found greater especially when the peak power is high.

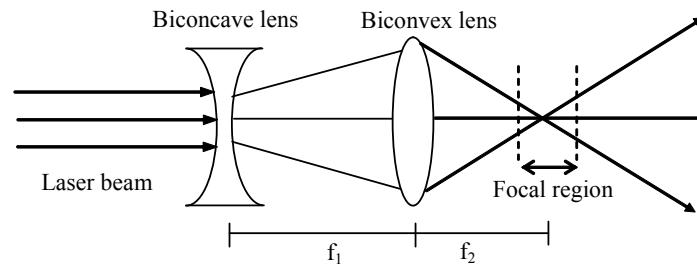


Figure 7 Combination of two lenses to focus the laser beam. The focal region is quite small, thus there is a small spot compared with single lens technique.

Another advantage offered with this combination lenses technique is that it produces a point source of breakdown. It indicates that only a single explosion is created at the focal point accompanied with a very energetic and symmetrical distribution of acoustic shock wave. Such mechanism offers a lot of advantages in application either in material processing or for fusion reaction. Hence this type of plasma became preferable in many applications such as in laser machining and laser fusion research.

5 CONCLUSION

Plasma was successfully generated in air by focusing a Q-switched Nd:YAG laser. Two techniques were employed to focus the laser beam that is a single lens and combination lenses. The plasma formation was grabbed by using a high-speed photography technique and analyzed with the aid of image processing system. Ellipsoidal plasma was obtained from a single lens technique, whereas broadly-ellipsoidal plasma was obtained from combination lenses technique. The length of ellipsoidal plasma was found greater than the broadly-ellipsoidal one. However the plasma width from both techniques does not appeared so much different, in fact the width of plasma from a single lens was found bigger compared to the result from combination lenses technique at higher power. Overall, the combination lenses are preferable technique for producing more energetic plasma.

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