

Study of dynamics of glass plasma induced by Nd:YAG laser in external magnetic field

R. QINDEEL, N. BIDIN, R. ZIA^a, Y. M. DAUD

Physics Department, Faculty of Science, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia

^aLahore College for Women University, Lahore, 54000, Pakistan

A Q-switched Nd:YAG laser (1064 nm, 8 ns) is focused on glass target to generate plasma in the presence of external magnetic field in air. The variable transverse magnetic field is applied by an assembly of electromagnetic poles to create uniform magnetic field in the range of 0.1 to 0.8 T. In the absence of external magnetic field the plasma plume expands almost spherical, perpendicular to the target surface. In the presence of transverse external magnetic field there is an increase in radial expansion and plume confines in a certain region within magnetic field. The dynamics of glass plasma is investigated by capturing plume images by charged-coupled device CCD video camera. The images are captured for different values of applied magnetic field strength. The irradiated glass material is collected on aluminum substrate and surface morphology is analyzed by scanning electron microscopy (SEM).

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1. Introduction

The presence of magnetic field (B) during the expansion of laser produce plasma has initiate several interesting physical phenomena [1] such as plume confinement, ion acceleration, radiation emission enhancement, plasma instabilities and conversion of plasma thermal energy into kinetic energy. Considerable-work has been performed previously on the interaction of an expanding plasma cloud in presence of external magnetic field. It has been postulated that a cloud of laser produced plasma has stopped by external magnetic field [2]. Mostovych et al. [3] observed, the collimation and instability in laser produced barium plasma in the presence of 0.5 – 1 T transverse magnetic fields and explained the narrowing of plasma jet in the plane perpendicular to magnetic field due to curvature of the polarization fields. Pisarczyk *et al.* [4] reported that an elongated and uniform plasma column along the axis of the magnetic coils in the presence of strong external magnetic field (20T), but the exact mechanism behind this process was not well understood. Peyser et al. [5] claimed, when high-energy plasma propagates through a high magnetic field, plasma jets arises due to an $E \times B$ drift and the plasma undergoes a dramatic instabilities.

Pulse laser induced plasma has very short temporal existence and transient in its nature with a fast evolution of the characteristic parameters that heavily depend on irradiation condition such as laser intensity, irradiation spot size, ambient gas composition and pressure. These parameters varied drastically with axial or radial distance from the target surface under the same irradiation conditions [6]. Thus high-speed photographic recording [7] is an important technique to investigate the dynamics and transient events of plasma plume. In spite of the extensive literature, expansion and dynamics of laser

produced plasma remains incompletely understood. The different processes such as laser absorption, ionization, recombination are rather complex and require further investigation.

The main aim of the present experiment is to study and get better understanding about laser induced plasma in free space with and without presence of external magnetic field. This paper reposts the observation of glass plasma expanding across an external magnetic field using high-speed imaging technique. An effect of variable magnetic field strength also has been discussed.

2. Methodology

A Lumonic HY200 Q-switched Nd:YAG laser of wavelength 1064 nm and pulse duration of 8 ns is employed as a source of energy to ablate glass target. The laser beam is focused using 300 mm focal length and the variable transverse magnetic field is applied by an assembly of electromagnetic pole to create uniform magnetic in the range of 0.1 to 0.8 T. A glass target material is placed at the end of the edges of magnetic poles. The plume imaging is accomplished using a Pulnix TM-6EX charged-coupled device CCD video camera, placed perpendicular to the plasma expansion direction. A zoom lens of 200 mm focal length is utilized to enlarge the activities in the focal region. A neutral density filter is used to avoid over exposure to the camera. The image is analyzed using Matrox Inspector version 2.1 software. The Laser and the camera are synchronized using a homemade external trigger unit. Both the targets and the bar magnets are held in free space. The thin film deposition of glass is done at 0.0 T on aluminium substrate. The whole experimental is performed in air and the set-up is shown in Fig. 1.

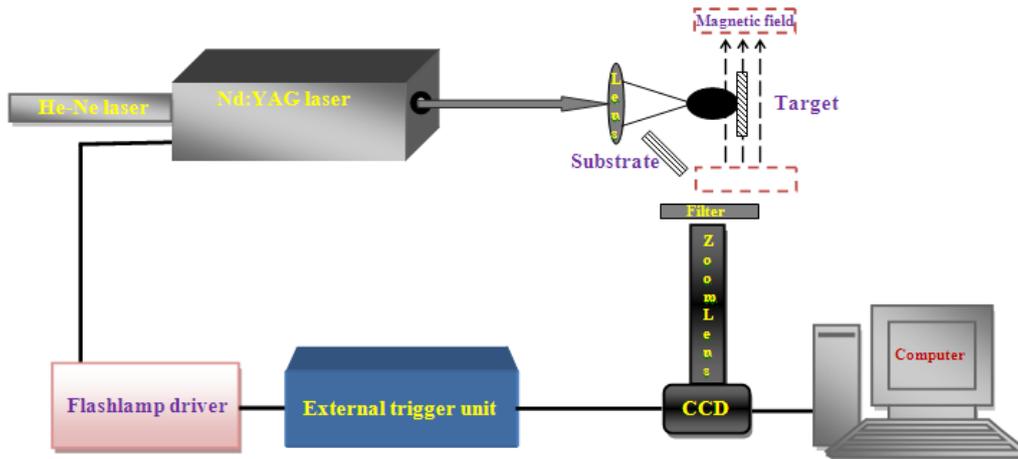


Fig. 1. The high-speed photography system and the optical arrangement of the experimental set-up.

3. Results and discussion

When laser pulse falls on the glass (target) surface, it produces ablation, evaporation and a luminous plasma plume that expands normal to the target surface. In the initial stage, the interaction of the laser beam with the target results in the evaporation of material from the surface of target. Followed by the interaction of the laser beam with the evaporating material leads to the formation of isothermally expanding plasma and this persists until the termination of the laser pulse. Due to forward peaking the plasma species moves along the normal to the target surface. An adiabatic expansion of the plasma can be

related to the dimensions of the plasma [1,8]. The thermal energy is rapidly converted into kinetic energy, with the plasma attaining extremely high expansion velocities.

Fig. 2 shows the typical CCD images of glass plasma plume for single laser pulse in the absence and presence of transverse external magnetic field. In the absence of external magnetic field the glass plasma plume is almost spherical in shape with contours along the propagation direction as shown in Fig. 2 (a). A significant change in the dynamics of plasma plume can be observed in the presence of transverse external magnetic field as shown in Fig. 2 (b). In the presence of external magnetic field the radial expansion of plume increases.

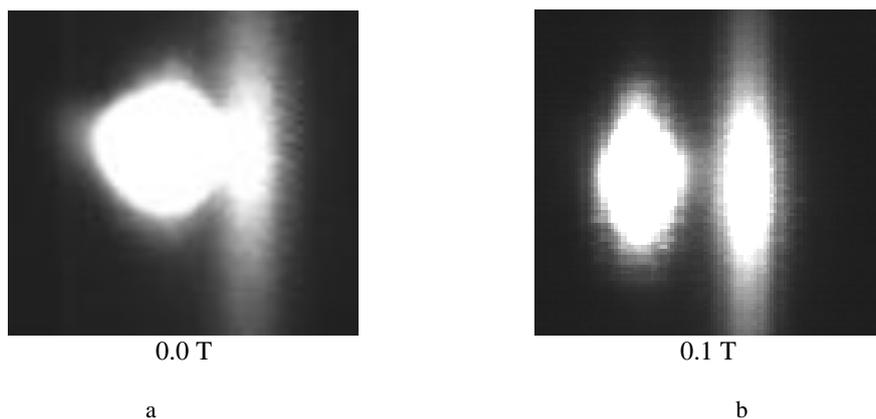


Fig. 2. Comparison the formation of plasma (a) without magnetic field (b) with magnetic field.

Fig. 3 shows the laser produced glass plasma images captured by CCD with different magnetic field strength from 0.1 to 0.8 T in air. Each image has been captured for single laser pulse for same time after laser shot triggered to the glass target. The CCD images in Fig. 3 illustrate as we increase the strength of external magnetic field, the radial expansion of plasma plume increases and forms an

elongated shape with contours along the magnetic field line. The plasma seems to be confine with in region, where magnetic field is applied. This is in agreement with results obtained by Pant et al. [9] and Harilal et al [10, 11]. The confinement of plasma plume in presence of external magnetic field causes increase in the collision frequency of charged species. Hence, the constraint of the cross-field

expansion by the magnetic field results in thermalization. The expansion of the plume is stopped when the magnetic pressure is balanced by the plasma pressure or β (plasma pressure/magnetic pressure) = 1. This is satisfied with the theory given by Bhadra [2] as well as the experimental result obtained by Rai *et al.* [12]. Glass plasma plume area is measured for different values of applied transverse external magnetic field as illustrated in Fig. 4. The graph in Fig. 4 shows an increase in plasma species in presence of external magnetic field (i.e. plasma plume confine within a certain region).

It is observed that the plume is confined within applied magnetic field region and also expel from the surface of target. Several authors have reported the same phenomenon of plume expel in vacuum or with the control of gas pressure without magnetic field [13-15]. It is observed that plume expel due to the manipulation of magnetic field. The splitting of plasma plume is due to the reduction of shock wave velocity and the losses in kinetic energy of the ablated species after colliding with the background gas. Chen *et al* [15] claimed that the ionization of the vapor due to temperature near the shock wave front also can result in an acceleration of the plasma flow.

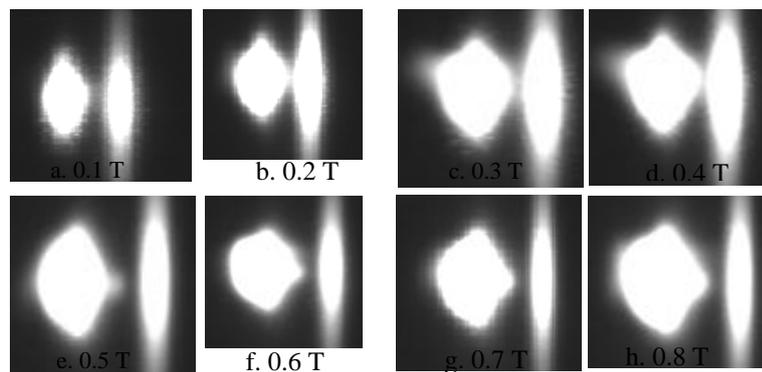


Fig. 3. Plasma expansion in variable magnetic fields.

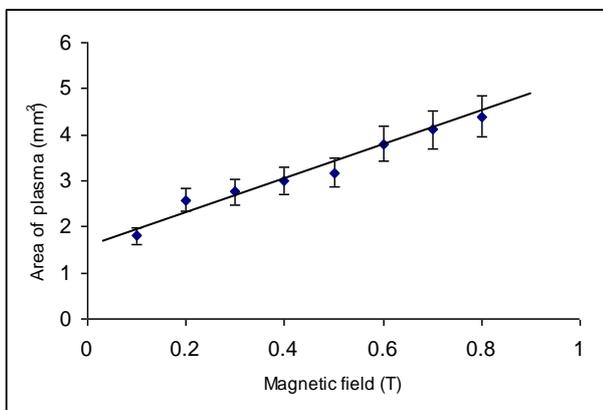


Fig. 4. Size of plasma as a function of magnetic field.

The increase in kinetic energy of the laser induced plasma through absorption of incident laser energy, decrease the shock wave velocity. Simultaneously, the

parts of the ablated species that collide with background gas also lose their kinetic energy. In the case of applied transverse magnetic field the magnetic force confine the charge species in certain region and cause the splitting of plasma plume from the target surface. Hence the splitting of plasma plume from target in air also enhance by the magnetic field as compared to the plasma plume with the absence of applied magnetic field.

Specification of the laser beam makes it able to apply in the glass damage as compared to ordinary light. Mechanism of laser glass interaction is shown in Fig. 5. The removal of glass particles due to the plasma interaction are deposited on the aluminum substrate. Surface morphology of deposited substrate is analyzed by Scanning Electron Microscopy (SEM). The typical results of deposition are shown in Fig. 6 with different magnifications. Large clusters are cluster size are observed and have interesting applications in thin film coating processes. The different size of clusters depends on impact condition and splash.

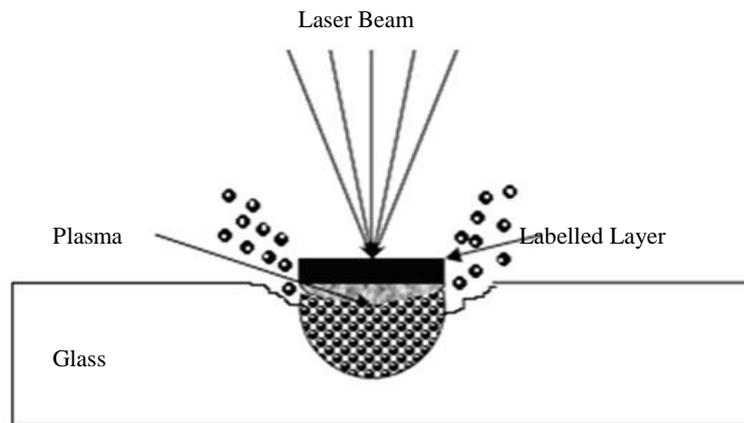


Fig. 5. Mechanism of laser and glass interaction.

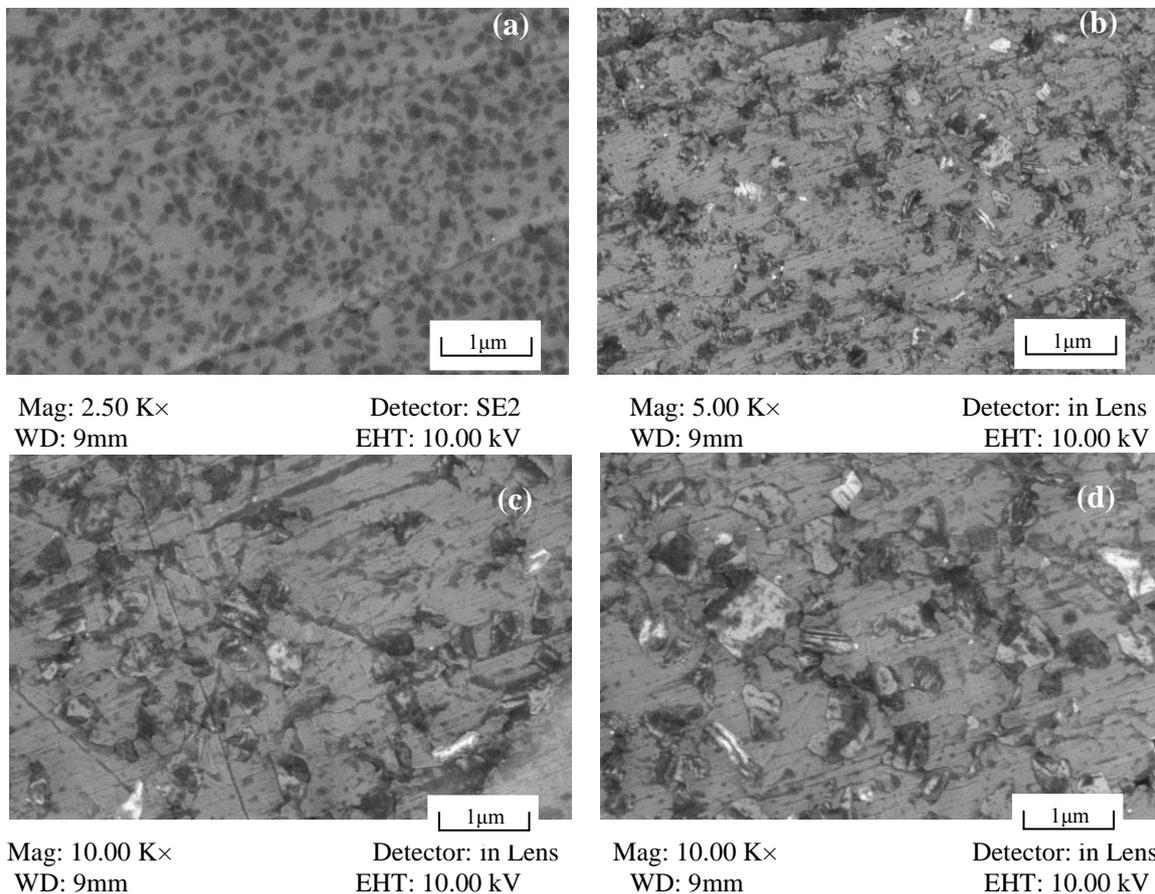


Fig. 6. SEM Micrograph of irradiated glass target on aluminum substrate: Magnified (a) 2.50 Kx, (b) 5.00 Kx, (c,d) 10.00 Kx.

4. Conclusions

Glass laser induced plasma was studied under two conditions, with and without presence of external magnetic field in free space. The plasma expand freely and perpendicular to the surface without magnetic field. In contrast the plasma has been confined and expelled to the longitudinal line when magnetic field was introduced. The confinement and radiation emission increased with the

increase in the value of applied transverse external magnetic field.

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*Corresponding author: plasma_qindeel@yahoo.com