# IR Laser Plasma Interaction With Glass

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**Abstract:** The interaction of laser plasma with respect to glass surface is reported in this paper. A Q-switched Nd:YAG laser was used as ablation source. Glass material is utilized as target specimen. Aluminum plate is used as a rotating substrate. The dynamic expansion of the plasma was visualized by using CCD video camera and permanently recorded via image processing system. The exposed glass material was examined under photomicroscope and scanning electron microscope (SEM). The optical radiation from the plasma was observed by using spectrum analyzer. The results obtained show that the plasma is expanded linearly with laser energy. At low level energy symmetrical damage was found. Elongated hole is formed at high level energy. The progressive exposure on glass results in drilling process. The hole diameter is expanded non-linearly while the depth is increased linearly. The glass clusters were uniformly deposited on the aluminum substrate. The size of the glass clusters are in the range of nano and micro meter. The glass-plasma emitted radiation with majority lines of 390 and 450 nm.

**Keywords:** glass cluster, hole, plasma splashing, vaporize, damage.

## INTRODUCTION

Laser processing of optical materials is becoming increasingly important and may be considered a genuine alternative to standard mechanical and ultrasonic techniques for dicing or drilling. The formation and evaluation of plasma produced during the interaction of a high-power laser beam with solid dielectrics are topics of practical interest[1,2,3]. In the early stages of pulsed laser interaction with dielectrics, a number of processes contribute to the formation of free electrons: multiphoton absorption, absorption at lattice and surface defects, nonlinear absorption due to phase changes and chemical decomposition. If sufficient laser energy is provided avalanche process and thermal ionization lead to the formation of a dense plasma at the surface; the higher the laser intensity, the less in depth effects are stated.

Recently, considerable interest has arisen in laser-induced surface microstructure of dielectric material due to its potential application in optoelectronic[4,5,6,7,8,9]. Optical breakdown of dielectrics is rapid ionization and formation of plasma when the material is exposed to electric fields exceeding some critical value. High peak intensities associated with ultrashort laser pulses provide large photon fluxes necessary to initiate nonlinear absorption process (multiphoton initiated avalanche ionization)[10]. Ablation takes place when the density of the free conduction band electrons reaches a critical density[11].

This happens above a certain laser fluence threshold at which point the electrostatic forces are high enough to breakdown the material and to eject the ionized nuclei. The minimum laser fluence below which ablation cannot be initiated is defined as the ablation threshold or optical breakdown threshold. This shows that laser plasma interaction[12] occurs at the surface.

Optical breakdown of various dielectric materials such as fused silica, calcium fluoride ($CaF_2$) and barium aluminum borosilicate glass when exposed to ultrashort laser pulses had been reported[10,13,14,15,16,17]. In the short-pulse regime, the optical breakdown is a non-thermal process and various nonlinear ionization mechanisms (multiphoton, avalanche, tunneling) become important. An atmospheric pressure and gas condition at which the material is ablated has an effect on damage threshold. Glass is so common that most of us take it completely for granted. The transformation of the solid material into dense plasma is also interesting from a fundamental physics point of view.

The laser-induced damage process is believed to be associated with localized formation of plasma, heating of the material leading to melting and transient stresses

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that instigate mechanical damage. A damage site on the surface of an optical material generated using nanosecond laser sources usually appears as a crater with rough surfaces that strongly scatter the in coming laser beam. Most often cracks originating at the bottom of the damage crater are visible. It has been recently shown that damage growth is due to re-ignition of the damage process due to absorption of the laser light by the defect population formed at damage sites as well as a result to field intensification arising from cracks[18,19].

Study of laser induced plasma is an interesting field since it is important for both the laser-material interaction and many practical applications, for example, in laser fusion research[20,21,22,23,24]. Laser matter interaction process involves in many applications including laser drilling, micro-matching and depth resolved chemical analysis[25,26,27]. The laser induced plasma from a deep down in the body of material has larger electron number density and to produce higher temperature compared to plasma formed on the surface. The deeper the depth, the higher the plasma temperature and more electron number density inside the cavity[28,29]. Other criteria have been used to define damage threshold such as volume of material ablated[17] and *in situ* scattering light technique to detect the surface damage[16].

In laser fusion research glass bubble was used to enclose fusion target. Fundamental study on glass plasma interaction will offer better understanding on fusion phenomenon. The motivation of this work arises from the need to detect and characterize laser induces defects in optical components to achieve fusion ignition in the laboratory. The purpose of this paper is to devise the expansion of laser generated plasmas into surrounding air at normal condition with pulses of comparable energy density in nanosecond (pulse duration $t_p$=8 ns) that can provide high resolution images of material modification including defect populations and subsurface cracks. The plasma expansion and its effect of interaction in terms of damaged area and penetration depth of glass are investigated.

## EXPERIMENTAL DETAILS

A Q-switched Nd:YAG laser model HY200 Lumonics was employed as a source of energy. The fundamental wavelength of the laser was 1064 nm with 8 ns pulse duration. The IR laser was focused using convex lens with focal length of 35 mm. The laser was operated in repetitive mode with frequency of 10 Hz.

He-Ne laser was coaxial with IR laser for an ease of alignment. Aluminum substrate was irradiated by glass particles. The substrate was rotated so the glass particles can be spread uniformly on it. The substrate placed opposite to the target at a distance of 5 cm. The activities at the focal region were visualized by using a Pulnix TM – 6EX CCD video camera. The camera was interfaced to the personal computer. The schematic diagram of experimental setup is shown in Figure 1.

The focused beam was targeted on glass material. The dimension of the rectangular glass is 25.4 x 76.2 mm². The glass material was identified by measuring the refractive index using Brewster angle method. The refractive index was obtained as 1.59 which means the glass material is Barium flint BaF. The thickness of the Barium flint glass sample is in the range of 0.8 – 1.0 mm. The Barium flint glass (BaF) was cleaned ultrasonically with methanol before the experiments. Incident laser radiation is absorbed in a narrow front layer expanding supersonically towards the laser source. In this stage some energy are still transferred to the workpiece by heat and radiation transfer.
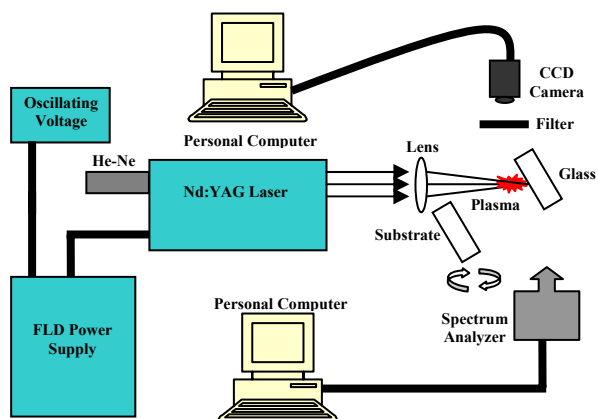


Fig. 1: Schematic of the experiment setup

Nd:YAG laser was focused on glass at variable duration of exposure while kept constant the laser power. The glass was also exposed by varying the laser energy but the time of exposure remained constant. Rotating aluminum substrate was placed at 6 cm from the target to deposit the glass cluster after 60 sec exposure.

The exposed glass was examined under photomicroscope and SEM. The depth was measured by Form tracer CS-500. The optical radiation of glass-plasma was observed through Ophir Wave Star

spectrometer, which placed at a distance of 20 cm from the target.

## RESULTS AND DISCUSSION

The typical results obtained from plasma glass interaction are shown in Figure 2(a). The frames are increased in ascending order of the laser energy. The vertical line at the right hand side of the frame shows the position of glass slide. The bright image of the dark background shows the formation of plasma plume. The plasma was appeared in contact with glass surface. The direction of laser is from left to the right of each frame. Incident laser radiation was absorbed in narrow front layer of the glass surface. The plasma was expanding supersonically towards the laser beam. Some of the laser energies are still transfer to the workpiece by heating and radiation. The area of the plasma was measured and plotted against laser energy. The graph is shown in Figure 2 (b). The plasma is expanded linearly with respect to the laser energy. Obviously the higher the laser energy deliver to the glass target the bigger the size of plasma. The size of the plasma demonstrated the
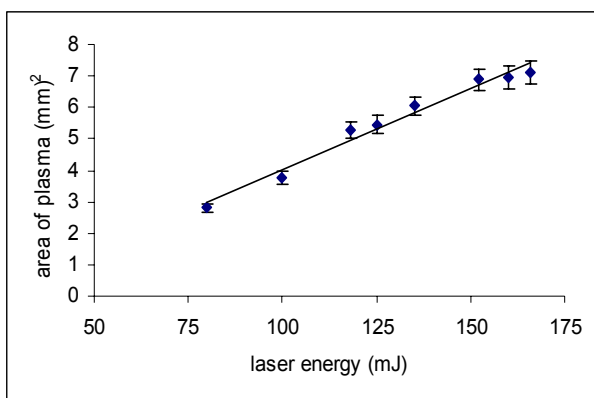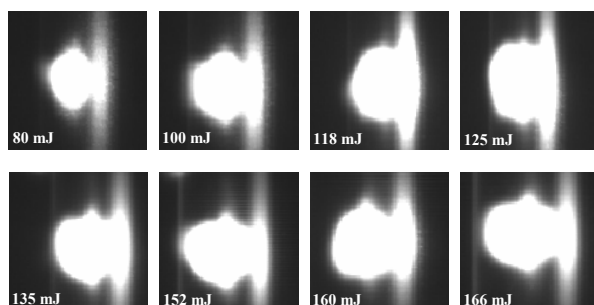




Fig. 2: (a) Dynamic expansion of plasma with laser energy. Magnified 10 x. (b) Plasma area profile

ions contain inside it. Of course the bigger the configuration of the plasma involves more number of charges including positive ions and electron. The kinetic energy of the electron, the collision of the charges, and the ejection of particles from the target surface encouraged the expansion of plasma in space. Thus laser ablation on glass produced plume of plasma which is highly dynamic and linearly expanded.

The exposed glass materials then observed under photomicroscope. The typical results obtained are shown in Figure 3. Various damage patterns are observed when the glass interacted with laser-plasma at different level of energy as shown in Figure 3. In low level energy most of the damages are comprised of circular pattern with peculiar configuration of holes at the centre. The damage pattern was started after 5 seconds exposure corresponding to 80 mJ of laser energy. The damage is perfectly circular with small symmetrical hole at the center as shown in Figure 3 (a). After exceeded the damage threshold energy the ring deformation is shrunk and the holes at the center become enlarge.
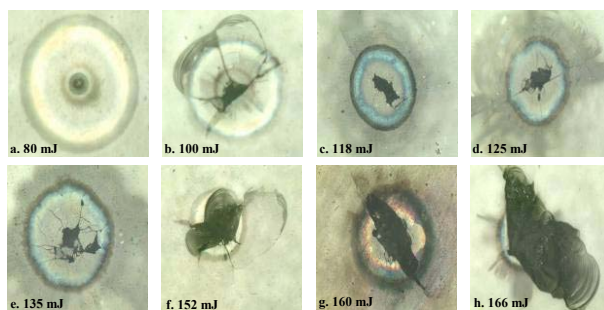


Fig. 3: Photomicroscope of damaged glass with energies variation. Magnified 5 x

The size of the ring deformation again become fluctuated and associated with crack formation at higher energy level. When the laser energy is greater than 152 mJ, the hole is become obviously larger than the ring deformation. This is apparently seen at Figure 3 (h), whereby the hole is dominating rather than ring damage. The laser ablation at this stage involve mass explosion without phase change. By increasing the laser energy it is causing immediate damage. The vaporization of the glass when interact with plasma associated with thermal shock waves which responsible on the losses, crack and ring deformation. The area of the damage and the depthness of the hole were measured.

The measurements are used to plot graph such as shown in Figure 4. The damage area is found nonlinearly increases against the laser energy as depicted in Figure 4 (a). However the depthness is almost proportional to the laser energy as shown in Figure 4 (b). Thus the laser ablation involves absorption on the glass surface causing stress from shock wave mechanism and produced ring deformation. The heat from the plasma interaction causing vaporization results in peculiar hole. The enlongation of the holes formation demonstrates the energetic of the plasma, which created by multiple breakdowns consequently and multilobe of plasma was created. Such configuration contribute to large and enlongate of plasma.
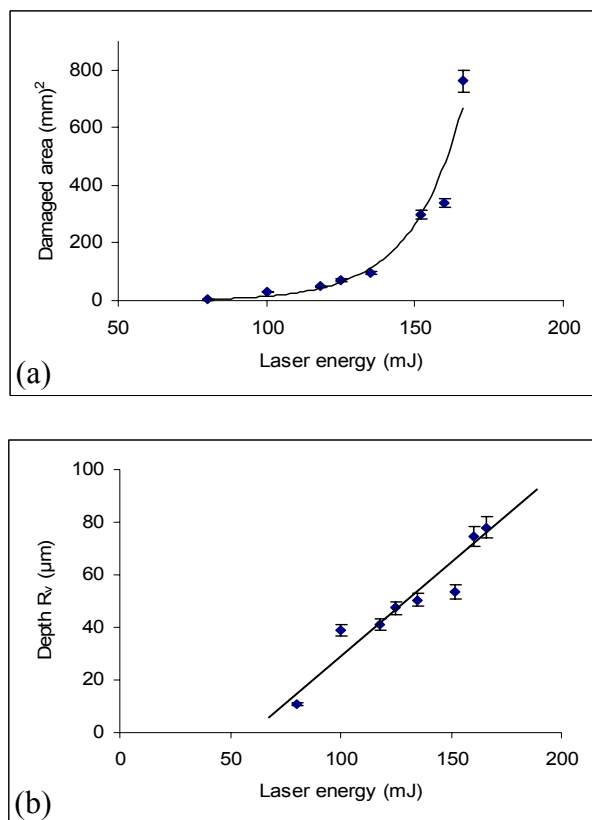


(a)



(b)

Fig. 4:   Effect of laser energy. (a) Damaged area profile. (b) Depth profile

The interaction of plasma with glass surface was also studied based on time variation. The typical results obtained in this study are shown in Figure 5. Entirely different structure of damage is observed. This is because of the picture is magnified to a bigger scale. The damage structure is examined under the scanning electron microscope (SEM). The structure was enlarged up to 200 magnifications. The first two frames indicate the erosion without the hole in the center region. As the time of exposure increases the damage is accompanied with the creation of holes. Meanings that the glass material has been drilled as the duration of exposure get longer. Variation of exposure time while keeping the energy of laser constant, subjected the glass been experienced drilling process. From time to time the hole gets deeper and deeper. This is illustrated by the dynamic expansion of the hole. After 60 seconds exposure, a clear, big and deep hole was realized. Along the process, the laser ablation caused the glass surface experiences the phase changes both in liquid and vapor state. This is obviously since in Figure 5 (k). The repetition plasma impact on the glass surface is subjected to vaporize and particle removal. As shown in the same Figure 5 (k), a droplet can be seen still left in the hole. The mass explosion and losses due to the particle removal causing the hole get deeper and bigger. In general the result obtain in this particular experiment is in good agreement with the other researchers[18,19].
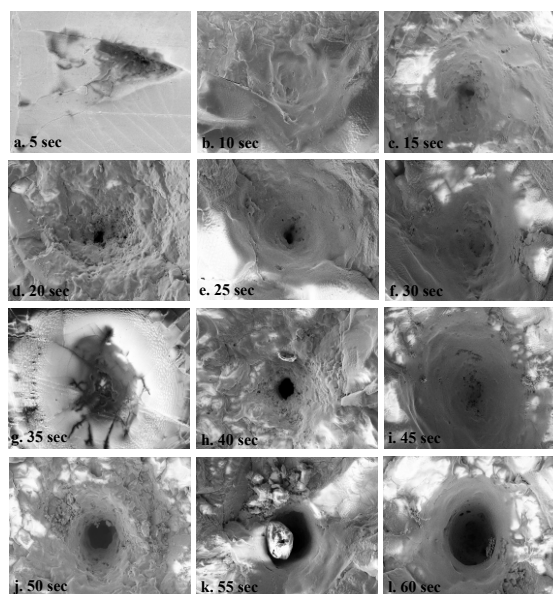


Fig. 5:   Optical micrograph of laser induced glass holes at different exposure time. Magnified 200 x

The diameter and depthness of the hole were measured and the results are represented in Figure 6. The diameter of the hole is found to be nonlinearly increases as the time progress. However similar results are obtained as in previous studied based on energy

variation. The depthness of the hole is obtained linearly increases upon the exposure time. The variation of exposure duration causes the glass surface experience drilling process. The longer the time of exposure the bigger the size and the deeper the holes.

The removal of glass particles due to the plasma interaction are deposited on the aluminum substrate. The typical results of deposition are shown in Figure 7. All frames in the Figure are the same picture but taken with different magnifications. Figure 7 (a) is magnified to 2500 times. We can see the glass particles are distributed almost uniformly on the aluminum substrate. Figure 7 (b) is the enlarge picture of Figure 7 (a), to 5000 times.
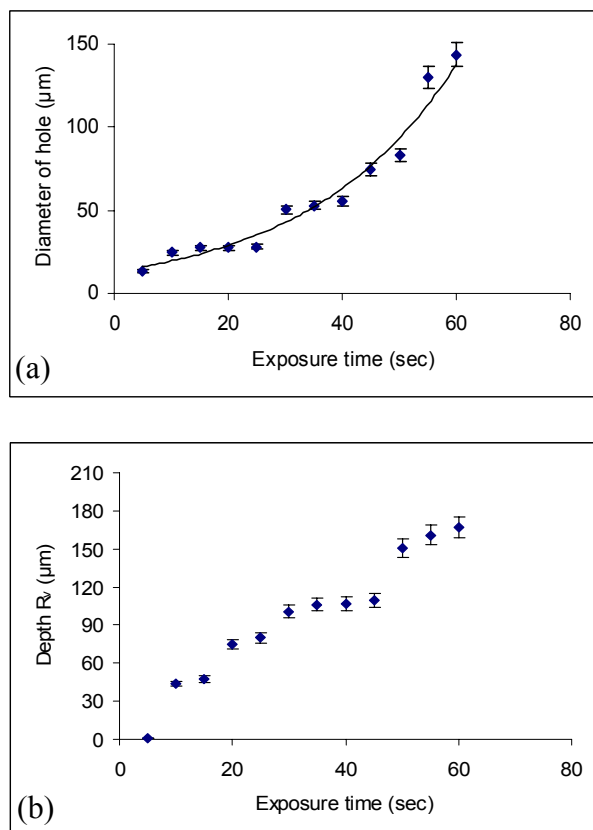


(a)



(b)

Fig. 6:   Effect of exposure. (a) Diameter of holes profile. (b) Depth profile

Each individual particle can be seen clearly. The same picture is further enlarged to 10,000 times. The glass cluster is even larger such as shown in Figure 7 (c). Figure 7 (d) using the same magnification of 10,000 times but observed at different measured area. Overall

the clusters have different sizes. Some are in nano meter and the other are in micron size. Large clusters are interesting for coating applications because they are large enough for economical coating processes. However the different size of clusters depends on impact condition, splash and disintegrates into many small satellite droplets. As laser plasma interacts with glass surface, it will produce solid deposits by impingements and solidification of molten droplets on to substrate. When a liquid droplet hits a solid surface it spreading and experience coating process.

Optical emission of the glass-plasma was also analyzed using spectrum analyzer. The typical spectrum is shown in Figure 8. The emission bands are in the range of 360 to 600 nm with majority line of 390 nm and 450 nm respectively. Each line indicates the compounds existing in the glass material. Compare each of the line with calibration curve, one can identified the elements contain in the tested material.
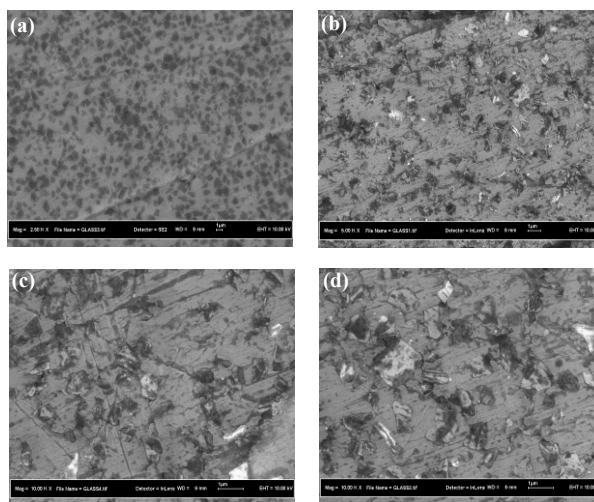


Fig. 7:   SEM Micrograph of irradiated glass target on aluminum substrate: Magnified (a) 2.50 Kx, (b) 5.00 Kx, (c,d) 10.00 Kx.

The detail components are not provided since it is out of the scope of study. However the important of this observation just to show that the plasma interaction with matter can also be used to analyze material for spectroscopy field. Thus the plasma interaction with glass produce spectrum in the range of ultraviolet (UV) to visible light.
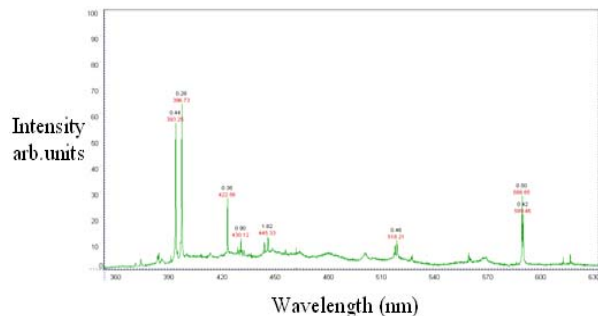
Fig. 8: Spectrum of plasma beam from glass

## CONCLUSION

When laser was focused on glass surface a plume of plasma was created. The plasma was linearly expanded with respect to the laser energy. The plasma interaction with glass surface was studied in two aspects, first by varying energy of laser and second by the variation of period of exposure. Energy variation produced symmetrical damage in low level energy and elongation hole at high level energy. Damaged area was found nonlinearly increases with energy. However the depth of the hole is linearly increased with energy.

In variation exposure, entirely different structure of damage is found, in fact glass experience drilling process. In this case diameter of the holes nonlinearly increases with the time, but the depthness is increases linearly. The vaporization of the glass surface was deposited on the aluminum substrate. This is also known as coating process. The examination under SEM indicates that the glass clusters were found in the nano and micron size. The optical radiation of glass-plasma was also detected and the spectrum produced is in the range of UV to visible light.

## ACKNOWLEDGEMENT

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