Pulse Laser Ablation of Ground Glass Surface and Application to Ignition of High Explosives

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ABSTRACT

We discovered burst of small fragments of glass, when ground glass surface is laser ablated. Production of macro particles by laser ablation is an inherent characteristic of ground glass, and no similar phenomena have been observed in case of metal or polymer ablation. In this case, no additional metal coating has been made to further enhance absorption of laser pulse. Pulse laser shadowgraph has been taken to study the details of the phenomena. Particle burst is found almost normal to the surface. By using ns-duration Nd:YAG laser of 100 mJ/pulse, observed particle velocity ranges 0.5 km/s to 1.0 km/s. SEM observation of the ground surface reveals that glass surface is covered with micro cracks with several microns deep, which might attribute to macro particle production. In this sense, not surface roughness but also surface structure will be important in the ablation phenomena of glass. It is plausible that absorption of laser beam at the glass surface causes spallation like phenomena as well as production of an amount of plasma, and the plasma production might be responsible for the acceleration of broken fragments of glass. We applied the phenomena to ignite PETN powder explosive. It is found that only by glass particle motion, PETN powder can be ignited, although the required laser fluence for ignition is somewhat higher than that for roughened and metallized polymer surface. It is suggested from this study that moving small glass particles gives significant effect not only on the ignition but inside the detonating explosives.

1. INTRODUCTION

Enhanced absorption of the laser pulse has been studied by our group, when the surface of the target material is intentionally roughened.\(^1,2\) Threshold fluence of laser ablation for plasma production decreases by this treatment. The phenomena were evidenced by pulse laser shadowgraphy. Thin metal coating on the roughened surface further enhances the laser absorption. However, too thick metal layer leads to the appearance of granular structure behind the region of ablation-induced shock wave. This is explained by the insufficient laser energy to evaporate and ionize thicker layer to form plasma plume. In this sense, appropriate metal layer thickness should be chosen for efficient use of laser energy.

Absorption enhancement by roughness has scale dependence. It is also noted that ex-
tremely tiny roughness of nanometer scale still has an ability to reduce the threshold for ablation but the effect is limited compared with the roughness of micrometer scale.

The phenomena have been successfully applied to basically two purposes\cite{1,6}: (i) micro-surgery tool as an alternative of laser mess by producing repetitive short pressure pulses in bio-tissue, (ii) initiation of PETN powder by laser ablation induced high temperature plasma flow. Small amount of PETN powder of 10 mg with loading density of 0.7-1.2 g/cm$^3$ has been initiated by focusing pulse laser beam through PMMA plate with changing the surface roughness of the focused surface of PMMA, aluminum layer thickness, focused beam diameter, laser energy, etc. Even in the case of 1mm diameter columnar PETN charge embedded in PMMA casing could be initiated and the streak recording of the self-luminous front velocity showed almost steady detonation.

Enhanced absorption of laser pulse depends on various experimental parameters including material. As described later, it is found that laser ablation of glass, especially ground glass surface is quite different from that of other materials. In this paper, we will present the evidence of particle production from glass surface by laser ablation and describe the application of the phenomena to the initiation of PETN powder without any metal coating.

2. LASER ABLATION AT GROUND GLASS SURFACE

We first noticed self-luminosity when pulse laser beam is irradiated on the ground glass surface. The phenomena occurred even in case laser irradiation is not focused. Typical experimental condition of this kind of experiment is as follows:

- Pulse laser : Nd:YAG or KGW laser
- Pulse duration : 10 or 7 ns
- Pulse energy : 150 or 50 mJ/pulse
- Beam diameter : 6 or 3 mm
- Wavelength : 1064 or 1062 nm

![Fig. 1 Video frames of luminous spot at laser irradiation: (a) before irradiation, (b) instant of first irradiation of laser pulse, (c) and (d) instant of second and third irradiation, respectively.](image)

Figure 1 shows typical video frame pictures for the glass surface luminosity. Comparison of Fig. 1(a) and (b) showed that white spot in (b) appears only in a frame at the laser irradiation. Luminosity decreases with multiple laser irradiation as seen in Fig. 1(b)-(d). This phenomenon can be seen also for a naked eye. A noise is also heard at ablation. In some cases, mist-like materials emanating from the laser-irradiated area has been observed.
These phenomena are found to be quite common for any ground glass surface. However, no indication of the same phenomenon was observed in case of polymer surface even if the surface is roughened.

From this experiment, we can say that the phenomenon is inherent to glass surface. Absorption of laser energy by surface roughening, therefore, has material dependence. In the experiment, laser beam is irradiated from the transparent surface to the ground surface through the glass material. Similar phenomenon was observed when the irradiation direction is reversed.

Figure 2 shows the typical SEM photographs of the ground glass surface after laser ablation. The top photograph is the overall view of the surface. Laser beam was focused into the central circular region with the diameter of about 1 mm. Point B belongs to this region. One may note that much larger circular area is influenced by laser beam. This might be due to the weak laser beam diffracted from long-pass optics from the laser system. Point C represents a typical point in this area. We chose the point A typical of the uninfluenced region of the surface. Bottom three photographs are the close up of the regions around points A, B and C. We may call three figures also by A, B and C.

From Fig. 2A, it is seen that virgin surface of the ground glass has a lot of sharp edges or peaks and valleys. Many white lines will correspond to these peaks. It also has many cleavage surfaces. In other words, surface structure of ground glass surface is described not only by the surface form function but also plenty of micro cracks appearing on the surface. These cracks are some \( \mu \text{m} \) deep into the glass material.

From Fig. 2B and 2C, one can see that laser ablation took these sharp peaks away from the surface. One may also note that apparent cleavage surfaces are recognized, and surface
roughness or the characteristic length of the rough surface is longer than that before ablation. Comparison of Fig. 2B and 2C suggests that intense laser focus gives sharper cleavage of the surface.

3. SHADOWGRAPH OBSERVATION

In this study, two Nd:YAG lasers are used to study the ablation process of ground glass surface. Specification of the lasers are

- Pulse width: 12 ns and 4 ns
- Wavelength: 1064 nm
- Energy: 80-150 mJ/pulse.

Laser beam is focused onto the ground surface through the specimen. Ablation of ground glass plate was observed by high speed framing camera (Cordin 220) with the exposure time of 10 ns up to 6 frames with arbitrary delay time.

Figure 3 shows typical photographs taken with successive time delay. Pulse was focused from right side through the glass. Glass plate is seen as a black region in the picture in Fig. 4. One may clearly note from these photographs that a spray-like dark region is extended from the ground glass surface, which could drive air shock wave front ahead of it. This burst of materials is seen to be ejected normal to the surface.

Ablation threshold fluence for ground glass surface is much lower than that for flat glass surface. Air shock is produced in both surface of the glass plate when the laser fluence at the glass surface is close to the value of 20 J/cm². Dark region consists of glass particles, which
was evidenced by direct capturing of them by PMMA plates ahead of the particle stream. Glass particles are ejected normal to the surface at their production, and gradually spread to the mushroom shape to drive a shock wave. They must also be decelerated by air flow velocity with time. It is obvious that size of initially ejected glass particles has some definite distribution. Larger and heavier particles may not be decelerated less, and they are responsible for the shock drive, while lighter particles are fully decelerated with time. In some photographs at longer delay time, shock wave front is not observed smooth by the reason that some of heavier particle overrides the initially generated shock front. In this case, a small conical shock wave is seen almost attached to these particles. This phenomenon is observed when the focused laser fluence was about 20J/cm².

Similar phenomena have not been observed for ablation of polymer material such as PMMA. Therefore, the phenomenon is characteristic of glass material. In case of polymer materials, laser energy absorption may cause the scission of molecular bonds, but not produce macro sized polymer particles. Ablation phenomena of polymer are known to resemble to that of heating. Relatively longer stress relaxation time inherent to polymer materials might explain the difference of ablation behavior from glass. In case of ground glass, SEM image suggests large number of cleavage sites on the surface. Laser energy could be absorbed at various surface including cleavage sites producing small-scale ablation plasma plume at each site and the produced plasma might make the cleavage open to generate a broken pieces of glass. Similar scenario might be expected for various brittle materials with ground surfaces. Further study is desirable to examine the physical mechanisms of the phenomena.

4. IGNITION OF PETN POWDER BY LASER ABLATION OF GROUND GLASS

If one side of a transparent substrate, e.g., PMMA is intentionally roughened with water resistant paper and then aluminized by vacuum evaporation method, appreciable enhancement of laser energy absorption was recognized. A very intense air shock wave is produced by ablation. By utilizing high temperature high pressure state of the ablation plasma, initiation of PETN powder of very small amount has been studied.

On the contrary, energy conversion of laser energy for ground glass ablation is different from that for thin metal layer on roughened surface. In case of ground glass ablation, part of the laser energy is converted to high velocity glass particle kinetic energy. Feasibility of initiating high explosive by this kinetic energy has been examined in this study. Instead of using PMMA plate as a substrate one of the surfaces of which is roughened and put on the PETN powder, a glass plate with one ground surface was used. Effect of aluminum coating on the ground surface was also studied. We have used a commercially available ground glass plate with a thickness of 2.8 mm in experiments. Figure 5 shows the schematic illustration of experimental setup. Image converter camera (IMACON 790) of the streak mode is used to record the light emission caused by detonation of PETN.
Typical experimental conditions and results are shown in Table 1. Among cited, we have examined the cases of aluminum thickness of 200 nm and 300 nm on ground glass. It is found that in all the cases of thicker aluminum layer, detonation of PETN powder was recognized. In these cases, mechanism of energy conversion to metal plasma should be similar for both substrate material of PMMA and glass.

From the results of # 5-8 in Table 1, it is seen that PETN powder can be ignited by laser ablation of ground glass surface without help of high temperature plasma. This means the initiation is induced simply by the collision of glass particles at the PETN powder grains. It is, therefore, evidenced that kinetic energy of glass particle cloud is large enough to ignite high explosive. Threshold laser fluence for PETN is found to be higher than the value for plasma-assisted initiation. In this study, initiation by glass ablation was observed in the case of laser fluence 11 J/cm² or more.

<table>
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<th>#</th>
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Table 1 Summary of experimental conditions and results.

Among tested, it is found that plasma-assisted method only fails in #9 case with 100 nm Al thickness and low fluence 5.4 J/cm². This result, however, is not reproducible and the fluence might be near the threshold value for this experimental condition.
Fig. 6  Streak photographs of light emission associated with detonation of PETN powder for two cases. (a) only ground glass, #7 in Table 1, (b) aluminum layer thickness 300 nm on ground glass, #12 in Table 1.

Figure 6 shows examples of streak photographs taken with the image converter camera. The earliest intense flash is the one by emission caused by laser ablation of ground glass surface. Long streak of luminescence after some break indicates emission caused by detonation of PETN powder. Bright region is seen to spread to the direction of camera slit gradually. Since the slope of this bright region corresponds to the propagation velocity of detonation, gradual change in slope indicates the acceleration of reaction front approaching the steady state detonation.

Break in time between laser irradiation and onset of detonation emission is called here the ignition delay time. Value of it is also shown in Table 1 only for the case when detonation takes place.

Figure 7 shows the dependence of the ignition delay time on the laser fluence and aluminum layer thickness. Although ignition delay time in the present experiment is not very reproducible, it is obvious that the thicker aluminum layer and higher laser fluence shortens the delay time.

Fig.7  Dependence of ignition delay time against laser fluence.

5. CONCLUSION

Ground glass ablation has been studied experimentally in detail to give evidence on the production of small glass particles by ablation. This explains the flash observed for ablation of relatively low laser fluence. Physical mechanisms of ablation of ground glass is suggested to be quite different from those of other kinds of materials. Similarity and non-similarity of the phenomena of laser interaction of small glass spheres prepared on the other substrate surfaces might be interesting further topics. From the results of the present study, behavior of glass particles might be an important role even in the detonating explosive charge, because they have ability to ignite the adjacent unreacted explosive grains.
ACKNOWLEDGEMENTS

Authors wish to thank Asahi Chemical Industry for providing PETN powder.

REFERENCES


