

## Effect of Current on Substrates' Stability in LIPAA (Laser Induced Plasma Assisted Ablation) Process

**Muhammad Shahid**

Department of Materials Engineering,  
School of Chemical & Materials Engineering,  
National University of Sciences & Technology, Islamabad, Pakistan.  
mshahid@scme.nust.edu.pk

### Abstract

Three types of hard materials Borosilicate glass, Soda lime glass and Quartz have been ablated using stainless steel, copper, brass and silver as target materials. Various combinations of substrates and target materials have been investigated to study effects of current on an ablated depth of the substrate and to find optimum values of current and ablated depth without formation of crack on the substrate; the damage to the glass surface was due to a high absorption after the first few pulses. Optimization of LIPAA (Laser Induced Plasma Assisted Ablation) process parameters have been investigated using a 50 watt acoustic-optic Q-switched Nd:YAG solid laser.

**Keywords:** laser, hard glass, Q-switched Nd-YAG laser, micro-fabrication, LIPAA

### Introduction

LIPAA (Laser Induced Plasma Assisted Ablation) was developed in Japan, using a single conventional pulsed laser, thus enabling high-quality and high-speed micro-fabrication of transparent materials like glass. This technique has been widely applied for micro machining of a variety of soft and hard materials possessing wide transparency from UV to IR. This process can be obtained by a single-pulse irradiation, when an adequate pulse width laser i.e. several tens nanoseconds (ns) and an adequate distance between the target and the substrate i.e. several hundreds micrometers) are used [1,3]; principle of LIPAA has been shown in Fig.1. A series of complex interactions between the target plasma, glass surface, and incident laser occur in a time frame of nano-seconds. The resulting etch on the glass surface is assumed to be the result of the kinetic energy from the plasma particles flying toward the glass surface at high speed. Early LIPAA techniques used a vacuum ultra-violet (VUV) laser that required the material to be kept in a vacuum. Later experiments using a pulsed, Q-switched Nd:YAG laser successfully produced ablation on the lower surface of the glass at ambient conditions.

Hanada et al [2] also developed a practical system for LIPAA for micro machining of glass using 2<sup>nd</sup> harmonic Nd:YAG laser for use in industry. The use of the

encapsulated film was very effective to plate the metal film only on the ablated region [7]. Zhang et al [3] achieved high quality ablation of quartz using the fourth harmonic of a Nd:YAG lasers.

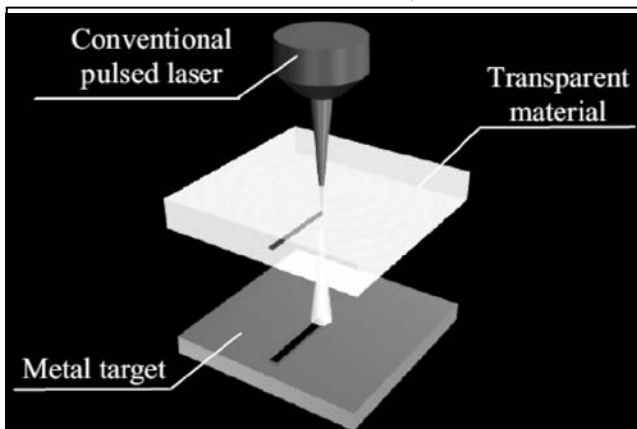
Hong et al [4] worked on laser micro fabrication of transparent hard materials and signal diagnostics. They concluded that glass ablation results from target ablation and dynamic interactions among target plasma, incident laser light and glass back side surface. Additionally, this technique can be also accessible to micro machining of the wide-band-gap and transparent materials such as quartz and Teflon, etc [5]. The researchers also demonstrated that the quality of the surface structuring of both fused quartz and Pyrex glass is independent of laser wavelength at 266 nm, 532 nm, and 1064 nm. However, the ablation rate and ablation threshold of the laser, strongly depend on the laser wavelength and current. The shorter laser wavelength is suitable for surface structuring, whereas, longer laser wavelengths are suitable for channel drilling. The surface structuring and channel drilling appear to use different ablation mechanisms [6,7]. Another application of the LIPAA process is colored marking of the substrate material by using different target materials [8].

This paper summarizes the effect of current variation on substrate's ablated depth during LIPAA process. Various substrate materials (Borosilicate, Soda lime (BK-7) and Quartz), were irradiated with different target materials (e.g. stainless steel, copper, brass and silver) for a best compromise of ablated depth and current keeping their intactness.

### Experimental methodology

#### The Laser System

The Laser used in this work was 50 watt acoustic-optic Q-switched Nd:YAG solid laser; its specifications are given in Table-1. A small X-Y stage Model No. Starrett M-263 was used for linear movements of the work piece in X-Y directions with laser work station. This stage had a



**Fig. 1** Principle of laser induced plasma assisted ablation [3].

**Table-1.** Technical Specifications of the Laser System

Sr. No.	Functioning	Tech Parameter
1	Scanning range	100 × 100 mm
2	Marking speed	7000 mm/s
3	Line width range	0.04—0.3 mm
6	Positioning error	± 0.01 mm

resolution of 10  $\mu\text{m}$ . Important specifications are given in Table-1.

An optical microscope “CMC model FOIC JX6” with a resolution of 10  $\mu\text{m}$  both in X-Y directions was used for measurement of induced spot size. CCD colour camera by Minitron Model MTV-8055 MK-II was used for the photography of ablated samples. This camera was integrated with X100 magnification microscope and a computer.

### Experimental Setup

A special jig was designed to hold the target on the work station of the laser below the laser beam. Target was machined in the form of a disc having a diameter of 37mm and thickness of 7mm. Target and substrate were thoroughly cleaned with ethanol. Substrate was firmly secured above the target. A total of 10 readings were taken with varying gaps between substrate and target starting from 0 to 540 microns with an increment of 60 $\mu\text{m}$ . A total of 195 experimental readings were taken.

### Materials investigated

Substrate materials: (1) Borosilicate glass, (2) Soda lime glass (BK-7) and (3) quartz.

Target materials: (1) Stainless steel, (2) Copper, (3) Brass and (4) Silver.

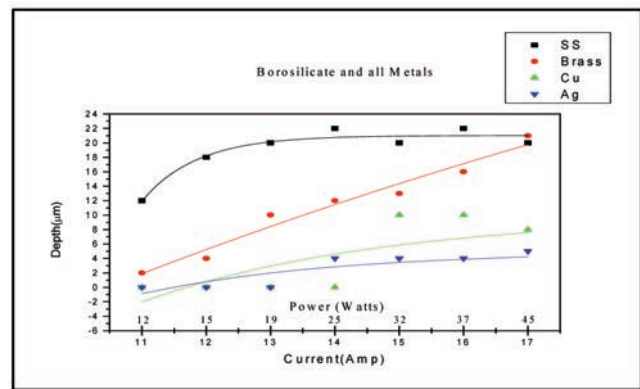
Frequency: 1.5 KHz Speed:100 mm/s.

A feature of the size of 3.5×3.5 mm square was generated with the help of Ez CAD the integral software of this laser set up. The feature was hatched with the hatch distance kept as 0.01mm and hatch angle was 90°. This hatching resulted in more than 95% overlap between successive laser induced lines. The substrate and target were cleaned with ethanol prior to experiments where as substrates were cleaned with HCl after ablation to remove deposited metal.

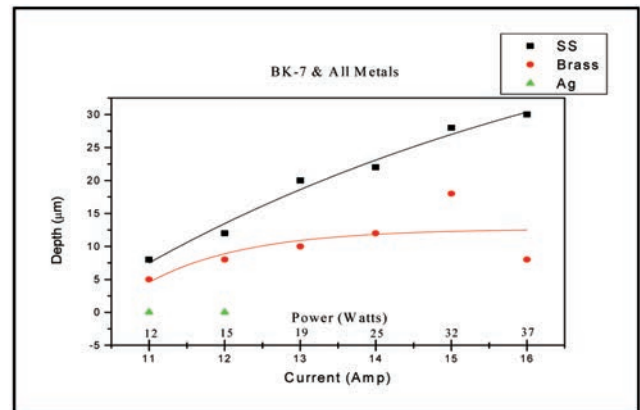
Depth of the feature ablated was measured and results were plotted against the varying gaps between the substrate and target. Experiments were also repeated for varying currents starting from 11 Amperes to 17 Amperes with an increment of 1 Ampere. Depths obtained were measured and graphs were plotted.

### Results and Discussion

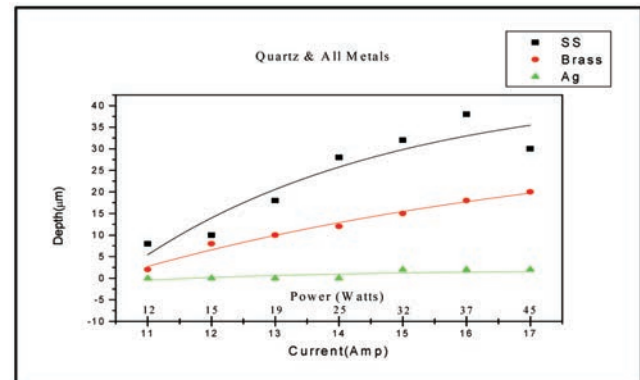
Figs. 2(a-c) show graphs between current and ablated depths for various combinations of substrate and target. Currents varied from 11—17 A with an increment of 1 A (corresponding to powers of 12 W to 45 W). Gap between target and substrate was kept constant as 60  $\mu\text{m}$ . Depth obtained was measured and graphs were plotted.



(a)



(b)



(c)

**Fig. 2** Ablated depths Vs current using various metallic target materials for: (a) borosilicate; (b) BK-7; (c) quartz.

Microscopic observations were made to watch integrity of the specimens. Development of cracks as a result of increased current above a threshold value was set as benchmark for maximum allowable current. Fig.4 shows cracked surfaces as a result of current increase for various substrates using different targets.

All substrate materials were found to be best ablated with stainless steel as target material compared to other materials. This phenomenon is supported by the fact that stainless steel has strong absorption of 35 to 40% at a wavelength of 1064 nm as compared to copper and silver with less than 5% absorption at the same wavelength. This strong absorption results in strong plasma formation with high kinetic energy of species consequently resulting in good ablation [8,9]. Quartz produced good ablation results

with all target materials, which can be attributed to high hardness value of 7 Mohs, greater Young's modulus and low coefficient of expansion as compared to borosilicate and soda lime glasses. Similar parametric study has been mentioned in an earlier work done by other members of our group [10]. Other researchers also used similar parameters and the results are in close proximity with their findings [11-13].

During experimental work while using borosilicate glass as substrate and silver as target metal, some cracks developed in the substrate. This behaviour is supported by scientific reasoning that silver has a low absorption of about 2% at 1064 nm wavelength which means it has a reflectivity of 98%. So the laser after striking the target is reflected towards the substrate, hence transferring the maximum energy to substrate. Borosilicate having high coefficient of expansion and comparatively low hardness could not sustain the energy and developed cracks [14]. Cases of cracks in soda lime glass were also recorded while using stainless steel, brass, and silver as target metals. In the case of silver and brass the reason is low absorption and high reflectivity of laser light, where as in the case of stainless steel the reason of damaging the substrate is the formation of strong plasma with high kinetic energy species striking the soda lime substrate having high coefficient of expansion and comparatively low hardness.

### Conclusions

- Stainless steel has proved to be the best target material compared to brass and silver, giving the highest ablation depth, for all substrate materials investigated.
- Silver was not found suitable to get adequate ablation depth as it cracked borosilicate and BK-7 glasses due to its high reflectivity.
- LIPAA process can be applied for the micro feature fabrication. An optimized line width of 50  $\mu\text{m}$  was achieved with the laser parameters of 14 A current, 1.5 KHz frequency and 50 mm/s speed, using a Q-switched Nd-YAG laser.

### REFERENCES

1. Y Hanada, K. Sugioka et al, "Double-pulse irradiation by LIPAA and mechanisms study", *Applied Surface Science*, 248(2005), pp. 279 – 280.
2. Y. Hanada, et al "Development of practical systems for laser-induced plasma-assisted ablation (LIPAA) for micro machining of glass materials", *Applied Phys. A*, 79(2004), pp. 1001–1003.
3. J. Zhang, et al, "Laser-induced plasma-assisted ablation of fused quartz using fourth harmonic of a Nd:YAG laser", *Applied Phys. A*, 67(1998), pp. 545-549.
4. M. Hong, et al, "Laser microfabrication of transparent hard materials and signal diagnostics", *Applied Surface Science*, 186(2002), pp. 556-561.
5. J. Zhang, et al. "High-speed machining of glass materials by laser-induced plasma-assisted ablation using 532-nm laser", *Applied Phys. A*, 67(1998), pp. 499-501.
6. J. Zhang, et al, "High-quality and high-efficiency machining of glass materials by laser-induced plasma-assisted ablation using conventional nanosecond UV, visible, and infrared lasers", *Applied Phys. A*, 69(1999), pp. S879-S882.
7. Y. Hanada, et al "Selective metallization of polyimide by laser-induced plasma-assisted ablation (LIPAA)" *Applied Phys. A*, 80,(2005), pp. 111-115.
8. Y. Hanada, et al "Development of practical systems for laser-induced plasma-assisted ablation (LIPAA) for micro machining of glass materials", *Applied Phys. A*, 79(2004), pp. 1001 – 1003.
9. Y. Hanada, et al, "Colour marking of transparent materials by LIPAA", *Journal of Physics: Conf. Ser.*, 59(2007), p.687.
10. A H Hamdani, W Ahmed et al, "Parametric study of ablation depths for different optical glasses using influence laser LIPAA process", *Key Engineering Materials*, Vol.442 (2010), pp.172-177.
11. A H Hamdani, A Ansar et al, 'Laser induced backside dry etching of BK-7 and quartz in vacuum', *Key Engineering Materials*, Vol.510-511, 2012, pp.261-264.
12. Zheng Huang & Cai-ling Feng, Study of machining microchannel on quartz by laser induced plasma, *Adv Mat Res*, Vol.154-155, 2011, pp.1655-1658.
13. Jürgen Ihlemann, *Laser Processing of Materials*, Springer series in Materials Science, 2012, Vol.139, 169-187.
14. R. E. Hummel "Understanding Materials Science, History, Properties, Applications" ed.2, Springer-Verlag, New York, 2004.