

Laser etching rates of sapphire glass using metal targets

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Abstract. Q-switched Nd:YAG laser with an output power of 40 watts has been used to study LIPAA etch rates of Sapphire glass in air with different target materials including stainless steel, brass and mild steel. Experiments showed that an ablation depth of 50µm has been achieved in sapphire at a zero target-substrate gap at ambient pressure. The etch depth versus laser scan speed and laser power have also been studied. An etched depth of 200µm is achieved at a scan speed of 20mm/sec with stainless steel as target.

Keywords: Pulsed Nd:YAG Laser, LIPAA process, Laser Ablation, Sapphire glass

1. Introduction

Micro-fabrication on transparent materials such as quartz and sapphire glasses has been growing since last two decades due to various technological developments in optoelectronic industry. Specially, development of high brightness blue LED's has further accelerated the development of micro machining on sapphire substrates such as scribing, deep etching, dicing etc. Laser Induced Plasma Assisted Ablation (LIPAA) has emerged as an effective technique resulting in high etch rates (~ few hundreds of nanometers). This process has been studied by various scientific research groups. Y.Handa et al used single pulse second harmonic of Nd:YAG laser and femto second laser for dual pulse irradiation for LIPAA studies on soda glass[1-2]. The reported etch rate is around 10nm/pulse. Zhang, J et al used silver target for ablation of quartz and pyrex glasses using first, second and third harmonics of 1064nm laser to find etch rates of these glasses. The achieved ablation rate was 50nm/pulse at a laser fluence of 7J/cm²[3-4]. Zhang, J et al also reported ablation of quartz with stainless steel as target with fourth harmonic of Nd:YAG laser at 266nm[5]. The Laser Induced Back side Wet Etching (LIBWE) of sapphire glass has been reported by K.Zimmer et al [6]. Y.Handa has also reported LIPAA etching of sapphire using second harmonic of Nd:YAG laser[7]. However high etch rate LIPAA parameters for sapphire glass are still lacking.

We presented parametric study of LIPAA process for quartz in air and under vacuum in our prior works [8-9] with etch rates as high as 700nm/pulse. Now we present results of ablation depths in sapphire glass obtained during LIPAA with high fluence fundamental harmonic of Nd:YAG at 1064nm using different target materials. The high etch rates reported in this paper can be useful for fast dicing, engraving and scribing of sapphire substrates for various applications including thin film solar cell, blue LED manufacturing etc.

2. Experimental

The experimental setup for this study is shown in Figure 1 below. The laser source is an actively Q-switched 40W Nd:YAG laser (1.064µm) operating at 200Hz-50kHz with a galvano type laser scanning head.



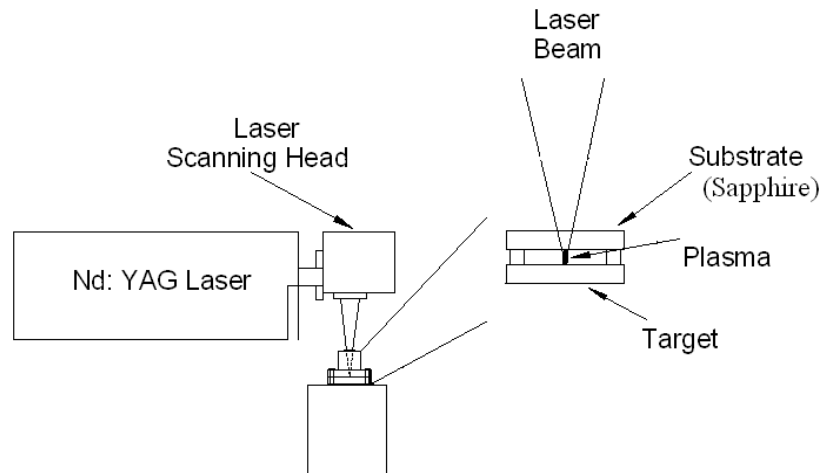


Figure 1. Experimental setup for LIPAA process

The laser is focused on target surface with a spot size of $225\mu\text{m}$ in a scan area of $3\times 4\text{mm}^2$ with varying scan speeds. The gap between target and substrate was varied from 0 to $540\mu\text{m}$ with an increment of $60\mu\text{m}$. The ablation depth was measured by a precision mechanical dial and averaged over 20 number of scans. The laser fluence was $65\text{J}/\text{cm}^2$ at focus spot for 40W output power.

3. Results and Discussion

Figure 2 shows the results of ablation depth for Sapphire glass using stainless steel as target material. It can be seen that a maximum ablation depth of $50\mu\text{m}$ is attained at a zero target-substrate gap at a scan speed of $100\text{mm}/\text{sec}$. The ablation depth drops to $5\mu\text{m}$ at maximum gap size of $540\mu\text{m}$. The maximum and minimum ablation rates are found to be $746\text{ nm}/\text{pulse}$ at zero gap and $74\text{nm}/\text{pulse}$ at maximum gap.

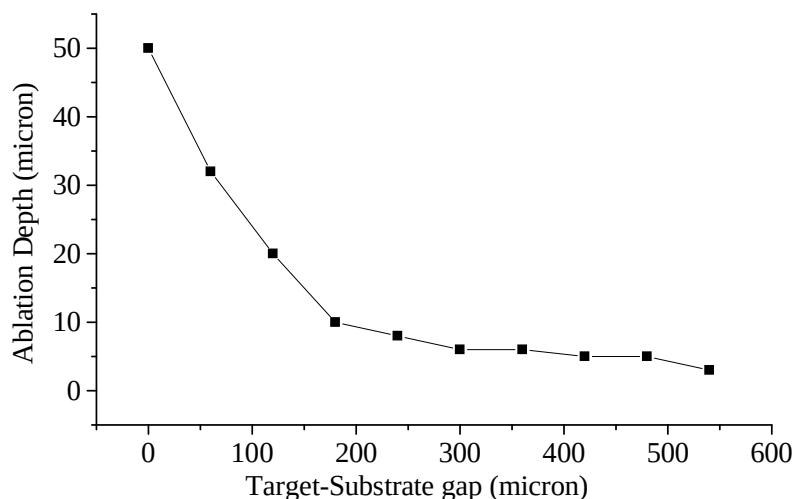


Figure 2. Ablated depth of Sapphire for stainless steel target

Figure 3 shows the results of ablation depth for Sapphire using mild steel target. The maximum ablation depth of $40\mu\text{m}$ is produced at zero gap which gives a maximum ablation rate of $595\text{ nm}/\text{pulse}$ and a minimum of $45\text{nm}/\text{pulse}$ at a gap size of 0 and $540\mu\text{m}$, respectively.

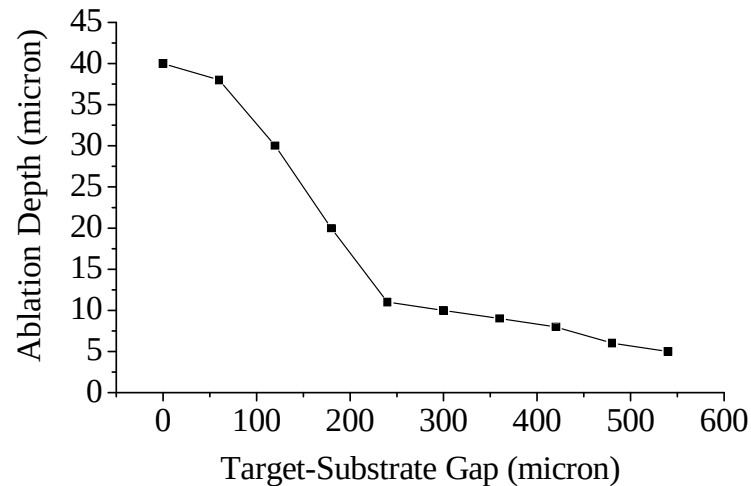


Figure 3. Ablated depth of Sapphire with mild steel target at varying gaps

The results for ablation depth in Sapphire glass using non ferrous material such as brass are shown in Figure 4. The maximum ablation depth of 30 μm is attained with brass target at zero gap which corresponds to a maximum ablation rate of 446nm/pulse and a minimum of 74nm/pulse at a gap size of 0 and 540 μm respectively.

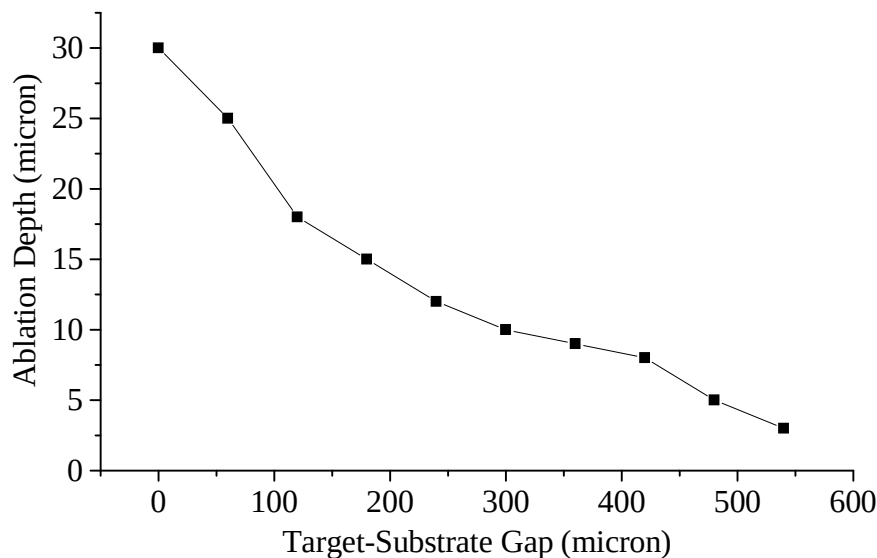


Figure 4. Ablated depth of Sapphire with brass target at varying gaps

The comparison of Figure 2, Figure 3 and Figure 4 shows that overall ablation depths are higher in case of ferrous metals. This can be attributed to the fact that laser absorption of ferrous material at 1.064 μm is higher as compared to non-ferrous materials. The amount and energy of the plasma generated at the surface of ferrous materials is significantly higher than that formed on non-ferrous metals. The healthy plasma imparts more kinetic energy on the glass surface resulting in deeper etching.

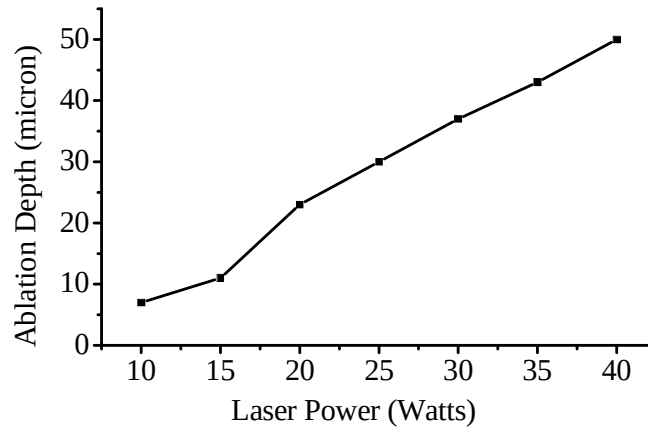


Figure 5. Ablation depth versus laser power at zero target-substrate gap for Sapphire-stainless steel

Since the maximum ablation depth and etch rates were obtained for Sapphire with stainless steel target, hence variation of ablation depth with laser power was studied for this case.

Figure 5 shows that ablated depth increases with laser power which can be attributed to increased plasma formation at target surface and hence more ablation at substrate surface. A maximum ablation depth of $50\mu\text{m}$ is obtained at 40Watts of average power at $0\mu\text{m}$ gap size.

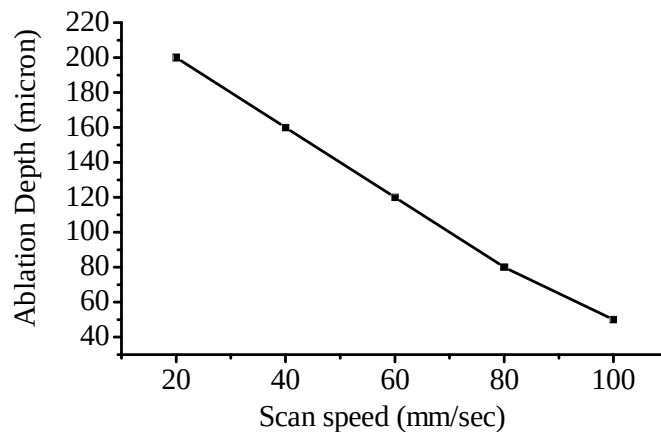


Figure 6. Ablation depth in Sapphire with varying scan speed

The etched depth in Sapphire glass was also studied as a function of scan speed at zero gap and stainless steel target. The results are shown in Figure 6 where lower the scan speed results in higher etch depths. The 0.2 mm thick sapphire plate was cut at a scan speed of 20m/sec in 20 scans.

4. Conclusion

The present studies on ablation rates of sapphire glass using different target materials have shown that ferrous metals such as stainless steel and mild steel produce maximum etch depths at zero target-substrate gap. The maximum ablation depth of $50\mu\text{m}$ at an etch rate of 744nm/pulse has been measured in stainless steel. The ablation depth at different scan speeds has also been measured for practical substrate cutting applications. Sapphire has shown a near linear relationship between laser power and ablated depth in

available laser power regime (0-40Watts) which shows that further increase in cutting rates are expected at higher fluence.

Acknowledgement

Authors are grateful to management and staff of Pakistan Institute of Laser and Optics for their continued support during completion of this work.

References

1. Lee J M et al, 2000 *Appl. Phys. A* **70** 561
2. Sugioka K and Midorikawa K, 2001 *RIKEN Review* **32** 36
3. Jie Z et al. 1998 *Applied Phys. A.* **67** 499
4. Hanada Y et al. 2004 *Applied Phys. A.* **79** 1001
5. Z. Jie et al. 1999 *Applied Phys. A.* **69** S879
6. Zimmer K et al. 2008 *Laser Chemistry*, 2008 (article ID170632)
7. Hanada et al 2005 *Journal of High Temperature Society*, **30(2)** 105
8. Hamdani A H et al. 2010 *Key Engineering Materials*, **442** 172
9. Hamdani A H et al. 2012 *Key Engineering Materials*, **261** 510-511