Experimental Analysis of Micromachining Characteristics During Pulsed Nd:YAG laser Engraving Process of Sapphire

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Sapphire material is next to diamond in respect of hardness and is used mostly in semiconductor and electronic industries. For different applications, sapphire requires different surface roughness. Pulsed Nd:YAG laser beam has great ability for micro-machining ceramic materials because of high laser beam intensity at low mean beam power, good focusing characteristics due to very small pulse duration, small kerf widths and narrow heat effected zones. In this paper, pulsed Nd:YAG laser micro-machining of sapphire have been carried out. Influence of laser machining parameters like laser power, Frequency and Pulse duration on the surface roughness of sapphire substrate has been experimentally investigated. An interactive study of different laser parameters on surface roughness is studied by plotting graphs of surface roughness verses different laser parameters

Minimum surface roughness has been obtained as 49.20 microns when the pulse frequency, laser power and pulse width are set at optimal parametric setting i.e. 15.2 kHz, 2 watts and 6 micro seconds respectively.

Maximum surface roughness has been obtained as 886.04 microns when the pulse frequency, laser power and pulse width are set at optimal parametric setting i.e. 11.4 kHz, 8 watts and 6 micro seconds respectively

Keywords: *Nd:YAG laser, micromachining of Sapphire.*

1. Introduction

Sapphire is the non red variety of the mineral corundum and aluminium oxide and next to diamond for hardness. It can be used for variety of applications, including infrared optical components, watch faces, high-durability windows and wafers for the deposition of semiconductors and other electronic devices due to their superior properties like mechanical, electrical, low thermal expansion coefficient, stability at elevated temperature and corrosion resistance, etc. Despite its remarkable properties, it is facing a considerable challenge in micromachining, due to its extreme hardness, brittleness and corrosion resistance.

Micromachining such harder materials conventionally faces various problems. Q-switched DPSS Nd:YAG laser has been proved efficient for micro engraving steel and aluminium [1]. Alumina Ceramic plate can be micro grooved using fundamental pulsed Nd:YAG laser [2]. Surface profilometry of Ti irradiated with Nd:YAG laser with different intensities shows favourable results [3]. Barcodes were engraved on aluminium, galvanized steel and stainless steel and it was found that there are laser-scanner parameters that allow good contrast to be achieved. These barcodes were successfully read with an industrial barcode reader [4]. Three dimensional structures of Laser carving on ceramics are studied with Nd:YAG laser considering surface morphology, carving depth, material removal mechanism which has great potential industrial application in future due to its high precision and efficiency [5]. Semiconductor (Si) micromachining with DPSS Nd:YAG laser considering different laser parameters was performed and width, depth and roughness of groove are optimized [6]. Machining of hard materials like silicon, diamond etc with DPSS Nd:YAG laser at different wavelength is carried out considering thermal effects, HAZ, surface finish, cracks and showed favourable results [7]. A second harmonic 532 nm Q-Switched DPSS at different laser parameter is used to cut flexible PCBs which are very hard, brittle and non conductive. Kerf width, thermal aspects and cutting speed are considered as prime criteria [8].

In this paper we tried for experimental analysis of micromachining Sapphire material with fundamental Nd:YAG laser. Sapphire is next to diamond in respect of hardness and is used mostly in semiconductor and electronic industries. For different applications, sapphire requires different surface roughness. Experimental analysis of Nd:YAG laser marking at different laser parameters on sapphire was carried out. The surface roughness obtained with combinations of different laser parameters are measured by precise surface measuring instrument. Also an interactive study of different laser parameters on surface roughness is studied by plotting graphs of surface roughness verses different laser parameters.

2. Experimental Procedure

A pulse Nd:YAG laser with a maximum average power of 1 to 10 watts, a pulse width range from 1 to 10 µs and a repetition rate varying from 1 to 20 KHz is used in this experiment. The wavelength (1.064 µm), focal length (57 mm), number of pass (2), marking speed (2 mm/s) and nozzle air pressure are kept constant.

The varying laser parameters i.e. laser power, pulse width and repetition rate are divided in four levels of 2-4-6-8 watts, 2-4-6-8 µs and 3.8-7.6-11.4-15.2 KHz respectively. So considering Taguchi concept, it is a 3 factor-4 level experiment requiring full factorial trials of $4^3 = 64$. Squares of 2x2 mm^2 are marked on sapphire crystal with Machine Model ***Hallmark 007*** which is Nd:YAG Laser Marking Machine situated at Sahajanand Laser Technology Limited and is having an inbuilt company made software ***IMark 1.0.0*** which allows to change various laser parameters efficiently.

The surface roughness (Ra) of all 64 squares engraved with different laser parameters is measured twice with profilometer named as ***Dektak IIA*** which is an instrument for measuring the thickness of thin films. It works by gently dragging a mechanical stylus across a surface. *Dektak IIA* acquires data by moving the sample beneath the diamond tipped stylus. Vertical movements of the stylus are sensed by an LVDT, digitalized, and stored in the instruments memory. Its output is a graph of stylus height v. position, from which we can determine step height, surface roughness, and other features.

The effect of different laser parameters on surface roughness of sapphire crystal is examined by plotting various graphs family like (1) pulse duration vs. surface roughness with constant laser power at different laser frequencies, (2) laser power vs. surface roughness with constant pulse duration at different laser frequencies and (3) pulse duration vs. surface roughness with constant laser frequency at different laser power. All graphs are then examined critically and concluded accordingly.

3 Results

3.1 Graph of pulse duration vs. surface roughness with constant laser power

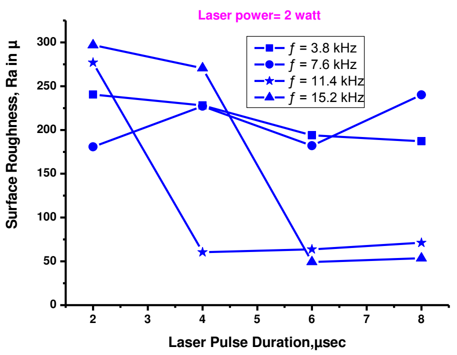

Figure 1. Pulse duration vs. Ra with laser power constant at 2 watt

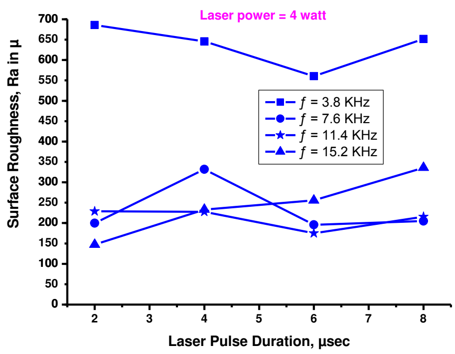

Figure 2. Pulse duration vs. Ra with laser power constant at 4 watt

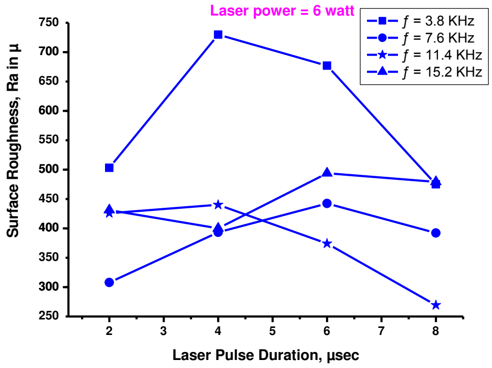

Figure 3. Pulse duration vs. Ra with laser power constant at 6 watt

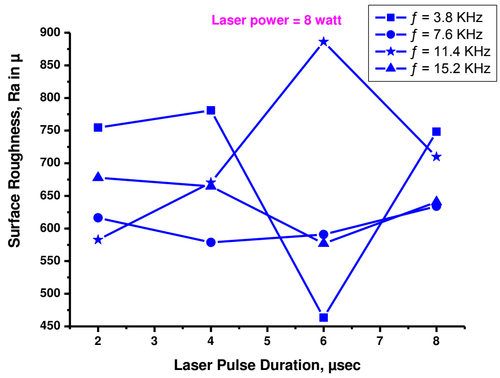

Figure 4. Pulse duration vs. Ra with laser power constant at 8 watt

Examining the graph of figure 1 reveals the trend of decreasing surface finish with increase of pulse duration particularly for 11.4 kHz and 15.2 kHz frequency. Examining the graph of figure 2 reveals the trend of increasing surface finish value with increase of pulse duration with very low slope. At 3.8 kHz the surface finish value is quite high. Examining the graph of figure 3 reveals the trend of increasing surface finish with increase of pulse duration up to the value of 6 µsec pulse duration with exception for 11.4 kHz frequency where surface roughness increases up to 4 µsec pulse duration. Thereafter a decrement in surface finish is easily noticed. Examining the graph of figure 4 reveals the trend of increasing-decreasing surface finish value with large slope for 3.8 kHz and 11.4 kHz and with small slope for 7.6 kHz and 15.2 kHz frequency. Above all the surface finish values for all four frequencies are quite high as compared to laser power of 2, 4 and 6 watts.

3.2 Graph of laser power vs. surface roughness with constant pulse duration

Examining the graph of figure 5 reveals the trend of increasing surface finish with increase of laser power with exception for 11.4 kHz and 15.2 kHz frequency where surface roughness decreases up to 4 watt laser power and thereafter an increment in surface finish is easily noticed. Examining the graph of figure 6 reveals the trend of increasing surface finish with increase of laser power with greater slope for 3.8 kHz, 11.4 kHz and 15.2 kHz and with lesser slope for 7.6 kHz frequencies respectively. Examining the graph of figure 7 and figure 8 reveals the trend of increasing surface finish with increase of laser power.

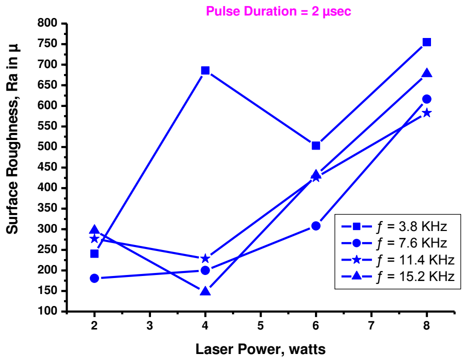

Figure 5. Laser power vs. Ra with pulse duration at 2 µsec

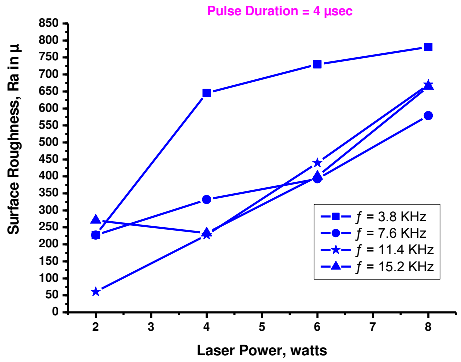

Figure 6. Laser power vs. Ra with pulse duration at 4 µsec

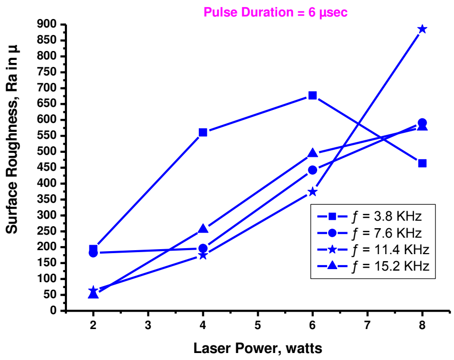

Figure 7. Laser power vs. Ra with pulse duration at 6 µsec

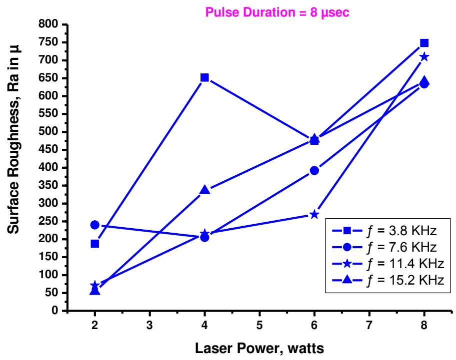

Figure 8. Laser power vs. Ra with pulse duration at 8 µsec

3.3 Graph of pulse duration vs. surface roughness with constant laser frequency

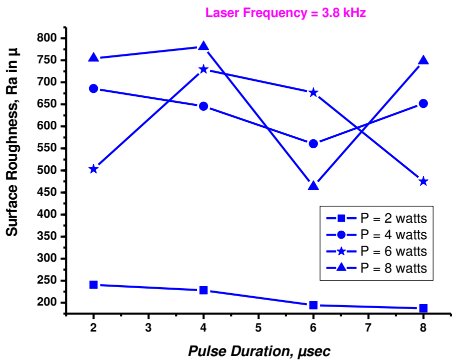

Figure 9. Pulse duration vs. Ra with laser frequency 3.8 kHz

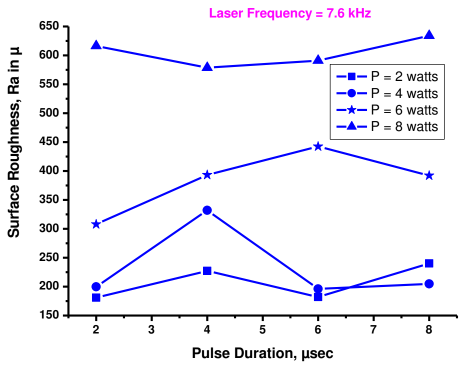

Figure 10. Pulse duration vs. Ra with laser frequency 7.6 kHz

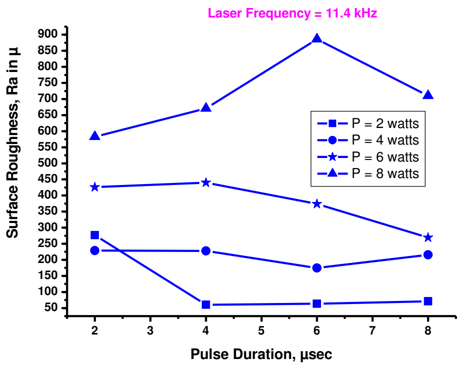

Figure 11. Pulse duration vs. Ra with laser frequency 11.4 kHz

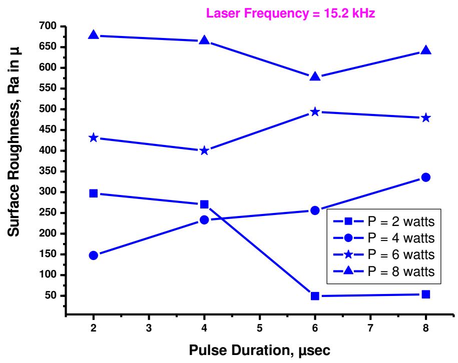

Figure 12. Pulse duration vs. Ra with laser frequency 15.2 kHz

Examining the graph of figure 9, 10, 11 and 12 reveals the trend of increasing surface finish with increase of laser power.

4. Discussion

4.1 Influence of laser power on surface roughness

It is noticed that surface roughness is approximately proportional to average laser power or power density as we have not changed the lens and the laser spot diameter is kept constant throughout the experiment. With high power, the depth of ablated material increases increasing surface roughness accordingly. The growth of the surface roughness with depth arises partly due to debris re-deposition at random, which affects the developing surface relief.

4.2 Influence of laser frequency on surface roughness

As laser gain is inversely proportional to the square of frequency, pulses of q-switched solid-state lasers become longer and less energetic with increasing frequency. So the pulse energy decreases and pulse duration increases with frequency, so the irradiance decreases even more quickly giving low value of Ra at high frequency. Sapphire gives high roughness at least laser pulse repetition frequency of 3.8 kHz. At this frequency, the laser gain and consequently the irradiance is very high giving high value of Ra. Low value of Ra at high frequency is also partly due to effect of plasma shielding which blocks the laser irradiance impinging on sapphire crystal.

4.2 Influence of pulse duration on surface roughness

There is no direct dependence of laser pulse duration on surface roughness of sapphire crystal. It affects in conjunction with the values of laser power and laser frequency.

5. Conclusion

The surface roughness Ra of sapphire crystal engraved by Q-switched, diode pumped solid state Nd:YAG laser mainly depends on incident laser power/power density and laser frequency. The pulse duration alone is not much effective to surface roughness. Minimum surface roughness with the average roughness from 49 µ to 200 µ is obtained with the laser power of 2 to 4 watts. Maximum surface roughness with the average roughness from 616 µ to 886 µ is obtained with the maximum laser power of 6 to 8 watts.

6. Further scope

In this experimental analysis only three laser parameters namely laser power, frequency and pulse duration were considered for surface roughness of sapphire crystal. Other laser parameters such as laser wavelength, spot diameter, number of passes, air/gas pressure and engraving speed were kept constant here. These variables could be varied to explore their effect for surface roughness.

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