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Characterization of the drilling alumina ceramic using Nd:YAG pulsed laser

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ABSTRACT

Laser micromachining can replace mechanical removal methods in many industrial applications, particularly in the processing of difficult-to-machine materials such as hardened metals, ceramics, and composites. It is being applied across many industries like semiconductor, electronics, medical, automotive, aerospace, instrumentation and communications. Laser machining is a thermal process. The effectiveness of this process depends on thermal and optical properties of the material. Therefore, laser machining is suitable for materials that exhibit a high degree of brittleness, or hardness, and have favourable thermal properties, such as low thermal diffusivity and conductivity. Ceramics which have the mentioned properties are used extensively in the microelectronics industry for scribing and hole drilling.

Rapid improvement of laser technology in recent years gave us facility to control laser parameters such as wavelength, pulse duration, energy and frequency of laser. In this study, Nd:YAG pulsed laser (with minimum pulse duration of 0.5 ms) is used in order to determine the effects of the peak power and the pulse duration on the holes of the alumina ceramic plates. The thicknesses of the alumina ceramic plates drilled by laser are 10 mm. Average hole diameters are measured between 500 μm and 1000 μm at different drilling parameters. The morphologies of the drilled materials are analyzed using optical microscope. Effects of the laser pulse duration and the peak power on the average taper angles of the holes are investigated.

1. Introduction

Laser drilling has rapidly become an inexpensive and controllable alternative to conventional hole drilling methods such as punching, wire EDM, broaching or other popular destructive methods. Laser hole drilling in materials such as polyimide, ceramic, copper, nickel, brass, aluminium, borosilicate glass, quartz, rubber and composite materials offer high-accuracy, repeatability and reproducibility for the medical device industry, semiconductor manufacturing and nanotechnology support systems (Corcoran et al., 2002; Dhar et al., 2006).

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Laser drilling has many controlling parameters to obtain desired hole characteristics such as depth, entrance and exit diameters, circularities. Drilling characteristics are determined by exit hole diameter as a function of material thickness and pulse energy for the single pulse drilling of the material (Rodden et al., 2002). Rodden et al. also give information on the laser parameters required the holes of required dimensions with a single pulse, or, in the case of multiple pulses drilling, allows the number of pulses to drill a required thickness to be estimated.

The machining of ceramics to their final dimensions by conventional methods is extremely laborious and time-consuming. While laser machining is a non-contacting, abrasionless technique, which eliminates tool wear, machine-tool deflections, vibrations and cutting forces, reduce limitations to shape formation and inflicts less sub-surface damage. Therefore laser machining of ceramics is used extensively in the microelectronics industry for scribing and hole drilling (Lumpp and Allen, 1997).

However, laser drilled holes are inherently associated with spatter deposition due to the incomplete expulsion of the ejected material from the drilling site, which subsequently resolidifies and adheres on the material surface around the hole periphery. The high hardness and brittleness lead to fracture (microcracks) of the ceramic material during laser machining. In order to prevent spatter and microcracks during the laser machining, many techniques based on either chemical or physical mechanisms have been developed (Guo et al., 2003; Orita, 1988). Also the influence of the temporal pulse train shaping is investigated on the material ejection (Low et al., 2001b). Low et al. (2001a) performed spatter-free laser percussion drilling closely spaced array holes. Also Sharp et al. (1997) applied another antispatter technique for laser drilling.

Depending on the laser drilling application there are three common methods used for laser hole drilling; single pulse, percussion and trepanning (or conventional laser cutting). Each method depends on depth requirement, hole diameter, number of holes, edge quality and production quantity. Mechanical hole drilling is difficult as the hole size decreases, furthermore laser drilling is limited because of the optical resolution and absorption of the wavelength to provide material ablation.

In literature, different ceramic drilling studies have been done using different laser wavelengths. Alumina ceramic and green alumina ceramic sheets with approximately 1 mm thickness were drilled using 9.5 μm and 10.6 μm wavelengths (Imen and Allen, 1999). Excimer laser (KrF, 248 nm) was used to drill Aluminium nitride (AlN) ceramics with 635 μm thickness applying different design of the experiment providing with or without a metallization layer deposited on the hole walls (Lumpp and Allen, 1997).

The main aim of the present study is drilling the alumina ceramic with a thickness of 10 mm, which is remarkably thicker than the previous studies as presented above. In order to drill thick alumina ceramic, percussion laser drilling method is used. Percussion laser drilling uses a “rapid-fire burst-of-pulses” micromachining method. Varying the laser pulse energy, duration, spot size, optics and beam characteristics in percussion laser drilling produces a high-quality hole with minimal residue and consistent edge quality from entry to exit point. Percussion laser drilling (by using Nd:YAG laser) evaporates the machined substrates layer by layer without noticeable strata or striations, which enable us to drill highly thick alumina ceramic with a desired geometry and quality.

Table 1 – Fundamental parameters of the JK 760 TR GSI Lumonics Nd:YAG Pulsed used in this work

Wavelength (μm)	1064
Average power (W)	600
Pulse repetition rate (Hz)	500
Pulse duration (ms)	0.3–50
Focus diameter (μm)	480

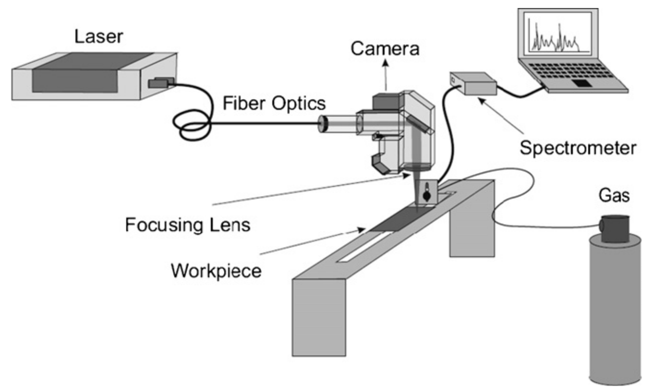

Fig. 1 – Experimental setup.

2. Experimental method

From the large range of the solid-state lasers, the flash lamp-pumped Nd:YAG laser is used in this paper. Fundamental parameters of the pulsed Nd:YAG laser are tabulated in Table 1. Beam quality of the laser is 28 mm mrads. The experimental setup is shown in Fig. 1. The fibre optic cable is used to transfer the light around the 1.06-μm range from the laser to the lens at the focus unit. Workpiece is infixed on the CNC table. The camera placed the top of the focus unit provide monitoring of the best focalization coupling with the CNC table. UV–vis spectrometer is used to record the visible light emitted from the plasma produced by laser during the drilling processes.

In this study, 10-mm thick alumina ceramic block is drilled by using Nd:YAG laser system. The alumina which is used in this study is produced from Alcoa A16SG without any additives. Alumina content is over 99% and used as ballistic tiles or substrate in microelectronic industry. Surface can be tailored for fabricating microelectronic thin film circuitry. Absorption features of Al_2O_3 are given in Table 2.

Table 2 – Absorption features of the alumina ceramic (Al_2O_3) used in this work

Irradiation wavelength, λ (μm)	1.064
Fraction of deposited energy (%)	98.7
Absorption coefficient, α (cm^{-1})	4700
Absorption depth, δ (μm)	2.1