An Investigation on Micro-via Drilling on Ceramic Substrates by a Picosecond Laser

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Abstract

Special ceramics are getting more attention as substrate materials for IC packaging, LED packaging and PC board. Certain ceramic materials have high mechanical strength, low thermal expansion, high electric barrier and high thermal conductivity. These properties are ideal for devices of designated purpose such as high power IC, LED and fast communication IC. For these applications via holes for signal and power connection are necessary. As the devices are miniaturized the sizes of via holes are forced to be reduced even down to tens of micrometers, thus, the drilling task can only be performed by laser. However, the ceramics are brittle and during the laser machining process the thermal stress and shock may easily cause defect in the heat affected zone. Also the debris generated in the thermal fusion-solidation process deteriorate the integrity of the via hole such as the in-out diameter, taper angle and roughness around the via. There is a trade-off between machining efficiency and quality has to be tuned. In this paper we apply a 12 picosecond 1033 nm wavelength laser to study the photo material interaction for drilling micro via in three thin plates of AlN, Al2O3 and Fe2O3 ceramic. AlN and Al2O3 are good heat dissipation material and Fe2O3 is idea for electronic noise immunity. A detail report of the results including machining parameters and inspection of via holes will be presented.

1. Introduction

Hole drilling is a very common machining process. In electronic industry such as PCB and IC packaging, different sizes of via holes are essential for electric connection. Thank to the fast development of optical and material technology, laser machining has replaced some outdated mechanical methods as the cost drops quickly. Laser can be used to drill holes in materials such as ceramics, copper, nickel, brass, aluminum, borosilicate glass, quartz, rubber and composite materials offer high-accuracy, repeatability and reproducibility for the medical device industry, semiconductor manufacturing and nano-technology support systems. For many brittle materials, edge chipping is a general problem while mechanical methods are applied. Laser drilling of micro holes offers alternatives to CNC, mechanical punching, wire EDM, broaching or other popular destructive hole drilling methods. Holes within 0.2 mm in diameter are difficult to drill by mechanical method, laser drilling offers an excellent solution for small hole drilling, especially in cases of hard and brittle materials, e.g., ceramics and glasses. General techniques in laser drilling include single shot, percussion, trepanning and helical [1,2]. Large holes can be “drilled” more efficiently by trepanning, namely, by lasering the circumference of a circle to form a hole.

The demand for high-aspect-ratio micro-holes in different materials, either transparent or opaque, is increasing in micro-manufacturing to obtain higher quality and performance. For micro-hole drilling, the current fabrication method still heavily relies on photolithography techniques, which require expensive facilities and elaborate process. They are usually limited by material and geometry. Laser drilling provides good consistency for manufacturing specifications under tight tolerances (diameters) and high depth-width ratios (small taper angle). Rapid “on-the-fly” prototyping is desirable in can provide dynamic, changing of hole diameter, hole depth and edge quality.

There are a few operating parameters to be tuned for best quality, i.e., wavelength, intensity, pulse width, pulse repetition rate for laser hole drilling. The quality of the laser beam, e.g. M2 value and pulse stability can be another factor too. Drilling and cutting with nanosecond (ns) or longer pulsed laser are always accompanied with the severe problem of melting and recast layer. Although the machining precision could be improved by using specific techniques such as helical drilling or wobbling, the edge quality and precision are still limited due to the heat-affected zone. Drilling and cutting with picosecond (ps) pulsed laser are much less affected by the heat effect due to the reaction between material and laser irritation is partially within molecules. Less heat is generated at shorter pulse length[3,4].

Alumina (Al2O3) and Aluminum nitride (AIN) are the most well-known and commonly used fine ceramic materials. Alumina has the same sintered crystal body as gem stone e.g., sapphire and ruby[5]. It has been used in electrical components for its high electrical insulation, and is in mechanical parts for its high strength, and free of corrosion and wear. It is especially ideal as substrate materials for packaging in IC and LED industries. Alumina substrate is the most popular ceramic substrate, with excellent heat resistance, high mechanical strength , abrasion resistance and small dielectric loss and suitable for thick film device application.

AIN has two special properties, namely, high thermal conductivity and matched thermal expansion coefficient with Silicon[6]. It is even more ideal as substrate material in the IC packaging and other electronics application than Alumina. However, Aluminum nitride is much more expensive than Alumina because of the higher melting temperature and difficulty of micro pore control during sintering process[7]. Another oxide ceramic substrate discussed in this paper is the Ferrosic Oxide (Fe2O3) ceramic. Ferrite has an excellent resistance to demagnetisation and can be magnetized before or after assembly without loss of performance. With mechanical properties similar to ceramics or porcelain, only grinding techniques can be used to machine these products[5]. Care is required during
handling due to their brittle nature though. Its special application in electronic devices is for EMI and RFI shielding.

In this paper we apply a 12 picosecond 1033 nm wavelength laser to study the interaction between laser and material for drilling micro via in three substrates of AlN, Al₂O₃ and Fe₂O₃ ceramic.

2. Materials and Methods

The sample is mounted on a precision X-Y stage. The optical path of the high quality (M²=1.3) 150 W 12 picosecond 1033 nm wavelength laser is controlled by a galvanometer system as shown in Fig. 1. The A F-theta lens is used to maintain perpendicular irradiation into the material within the range of scanning. This is very important that as the laser beam sways from perpendicular angle there will be a difference in drilling results. The laser beam is driven in helical fashion as shown in Fig.2.

Three thin plates of Al₂O₃, AlN and Fe₂O₃ ceramic in 0.38mm standard substrate thickness are prepared for drilling.

3. Results and Discussion

The via hole in Al₂O₃ ceramic substrate is drilled at optimal condition after trials, at speed=500mm/sec, power=45W and pulse frequency=360kHz. The optical microscopic photo of the via hole is as shown in Fig.3. The In/Out diameter ratio (72 and 61µm) is about 1.2. The geometric property is generally acceptable. However, there is a serious accumulation of debris deposition at the cutting boundary of the wall. This will cause a problem for later process, i.e., fill-in of metal conductive. The results of EDS assessment is as shown in Fig. 4. In the area not exposed to laser irration the chemical content consists purely of aluminum and oxygen. In the area of the debris deposition there is a significant carbonate content.
For ease of separation breaking, a trench is cut in V-shape. The machine parameter is set at: speed=780mm/sec, Power=60W, and pulse frequency: 300kHz. The machining is performed by straight line scans at different depth sequentially. The optical microscopic photo of a trench in Al₂O₃ ceramic is shown in Fig. 5, and the width of the trench is about 60 μm.

The via hole in AlN ceramic substrate is drilled at optimal condition after trials, at speed=450mm/sec, power=135W and pulse frequency=1000kHz. The optical microscopic photo of the via hole is as shown in Fig. 6. The melting temperature of AlN is much higher than Al₂O₃ ceramic, thus more laser power is needed for machining. However, the edge quality is better than in Al₂O₃ ceramic without deposition of debris. The In/Out diameter ratio (54 and 50μm) is about 1.1. A cross-pattern is grubbed in AlN ceramic and the optical microscopic photo is shown in Fig. 7. The corners are difficult to maintain a perfect shape while the rest of the edges are satisfactory.

The via hole in Fe₂O₃ ceramic substrate is drilled at optimal condition after trials, at speed=600mm/sec, power=30W and pulse frequency=600kHz. The optical microscopic photo of the via hole is as shown in Fig. 8. The melting temperature of Fe₂O₃ is lower than AlN and Al₂O₃ ceramic, thus less laser power is needed for machining. However, Fe₂O₃ is very easy to dissolved even at low temperature, and the quality of the via is the worst of the three ceramic substrates. Not only In/Out diameter ratio is poor but also the build-up of debris is significant.
Fig. 7 The optical microscopic photo of a cross-pattern in AlN ceramic.

Fig. 8 The optical microscopic photo of the via hole in Fe$_2$O$_3$ ceramic, (a) frontal view (b) cross-section view.

4. Conclusions

Application of functional ceramic substrate for different purpose will get more popularity in electronic industry. Drilling micro via holes will get more important for interconnection in either packaging or circuit board lay-out. In this study, we successfully apply picosecond laser to drill via holes of diameter less than 100 micrometer in three popular ceramic substrate, i.e., Al$_2$O$_3$, AlN and Fe$_2$O$_3$ at good speed. The results from AlN ceramic is excellent in terms of the geometric parameters and clean edge since it’s the most stable of the three. As for the Al$_2$O$_3$ ceramic, although the via hole maintains a satisfactory geometry the heat effect still induces undesired debris deposition. This has to be eliminated though acid cleaning after laser machining. Fe$_2$O$_3$ ceramic is the most difficult to process by laser. The via holes are successfully drilled through for basic functional requirement but serious tapering and debris accumulation is still a problem. Overall, one advantage of using picosecond laser in this study is that in all the cases, the drilling process proceeds at good speed.

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