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Experimental study of laser drilling on LTCC with ultra-short pulsed laser

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Abstract

Low Temperature Co-Fired Ceramics (LTCC) is being widely used as a circuit substrate material for microwave devices and electronic equipment. This paper presents experimental results of the picosecond laser drilling technology for LTCC under different conditions. The laser has a maximum power of 30 W with a spot size of 3 mm, pulse width of 10 ps, maximum repetition of 1000 kHz, and wavelength of 355 nm. By optimizing the parameters, a series of drilled holes with an aperture of 200 µm and an accuracy of less than ±5 % are achieved. When the frequency, scanning speed, and pulse energy are 200 KHz, 1000 mm/s, and 15 µJ, respectively, the heat-affected zone is weakly visible and the hole edge has good surface finish. The experiments demonstrate that currently available ultra-short pulsed lasers are suitable for drilling LTCC materials which opens up new opportunities in this field.

Keywords: picosecond UV laser; laser drilling; LTCC

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1. Introduction

Modern mobile communication, wireless local area network, and military radar devices are developing towards small, light, high frequency, multi-function, and low cost, which puts forward the requirements of lightweight, small, high frequency, high reliability, low price and improved integration of components. The most effective way to realize the above-mentioned requirements is to manufacture multi-layer substrate, multi-layer chip components, and multi-layer modules by using the technology of Low Temperature Co-Fired Ceramic (LTCC) well-known for its excellent thermal and high frequency electrical performance. Drilling on

LTCC is one of the key techniques in the manufacturing process, because the through-hole aperture and position accuracy directly affect the yield and final electrical performance of the substrate.

Drilling of micro-holes with well-defined geometries is gaining significance in a wide variety of industries. At present, the most commonly used mothed is mechanical drill or punch, of which the resulted size and the ability to drill non-standard holes are limited by the mold. In addition, direct contact of the tool with the substrate leads to a short tool life. Laser drilling in turn is replacing conventional drilling processes, which is attributed to that it is a noncontact, precise, flexible, and reproducible technique and can be used to produce holes of any shape in almost all types of materials, such as diamonds, ceramics, and composites without tool wearing. With this technique, a focused laser beam is repeatedly pulsed at the layer along the edge, and the laser energy vaporizes the material layer by layer and ultimately creates a through hole.

Currently, three kinds of laser sources have been reported for LTCC laser drilling, namely CO_2, Nd-YAG, and Ultra Violet (UV). Compared with CO_2 and Nd-YAG, the beam of UV laser can be focused to a smaller diameter due to its shorter wavelength. In addition, in the infrared range (longer wavelength), the dominant mechanism is thermal reaction due to low photon energy. In short-range/UV lasers, cold ablation dominates over thermal interaction. And the ultrashort pulsed picosecond laser with short pulse duration makes machining possible with improved quality. It has been proved that the picosecond laser with high peak power density, low pulse energy, and high repetition rate helps in drafting small features and drilling miniatured holes of good quality for different materials. Therefore, the UV picosecond laser is used in this study to drill micro-holes in LTCC material. By optimizing the process parameters, including pulse energy, repetition rate, and scanning speeds, a series of drilled holes with an aperture of 200 μm and an accuracy of less than ±5 % are achieved. The laser entry side and exit side of hole with and without plastic backing was compared at 200 KHz. The results indicate that UV picosend laser has the ability to process LTCC material, and circular holes with a good surface finish and small taper can be obtained.

2. Materials and methods

2.1. LTCC material

Table 1. Physical parameters of LTCC (FST06)

Physical parameters	Values
Thickness (μm)	130
Dimension (inch)	8
Density (g/cm^3)	1.66
Tensile strength (Mpa)	4.2
Adhesion (g)	130
Dielectric constant (@10 GHz)	6.06
Loss angle tangent (@10 GHz)	0.0012

FST06 is a low-temperature co-fired ceramic ribbon capable of embedding multiple passive components and co-firing with existing Au electrode paste. The product has advantages of low dielectric loss, high mechanical strength, excellent reliability, machinability, and high precision dimension controllability, easy achieving high-density precision wiring, which is widely used in RF modules, high-density circuit packages, ceramic printed circuit boards, and other chip components. The physical parameters of LTCC (FST06) used in this experiment are listed in Table 1.

2.2. Experimental setups

Ultrafast laser has a short pulse width, which is benefical for reducing the heat-affected zone. Compared with the traditional CO_2 laser drilling technology, it can improve the situation of slag and blackening at the edge of the through hole. Therefore, in this experiment, a UV picosecond laser with a high repetition rate and high-speed 2D scanning galvanometer from Scanlab GmbH is chosen. The PINE2-355-30 laser produced by Wuhan Huaray Precision Laser Co.,Ltd. is used. Its pulse width is less than 10 ps, the maximum output power is 30 W, and the base frequency range is adjustable from 400 KHz to 1 MHz. The laser beam with a spot size of 3 mm emitted by the laser source enters the scanning galvanometer after 3-fold beam expansion and is focused through the field lens with a focal length of 160 mm. The spot diameter at the laser focus is about 14 µm. The laser beam is scanned by a computer under the control of the galvanometer control unit according to the predetermined trajectory, as shown in Fig 1.

By changing the repetition rate, pulse energy, and scanning speed, LTCC samples with small holes with different processing parameter combinations were obtained. Then the holes were observed by optical microscopy. In order to ensure data reliability, each process is repeated for five times.

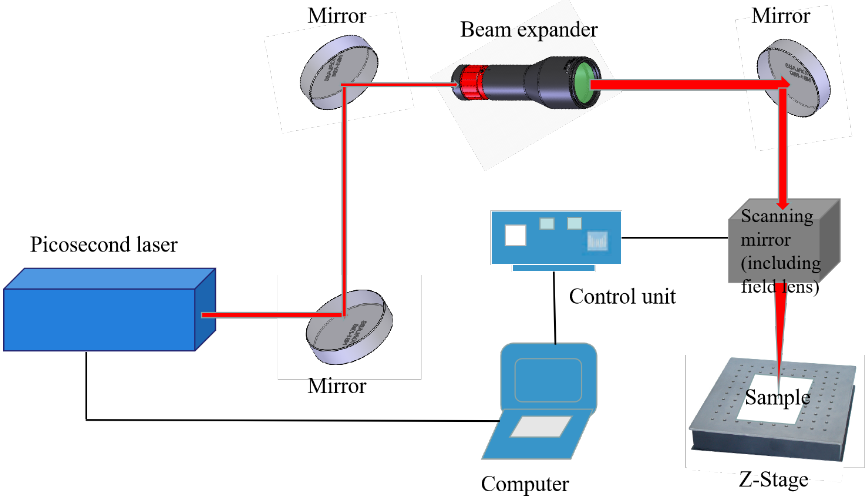

Fig. 1. Setup of laser drilling for LTCC samples with a picosecond laser

3. Results and discussion

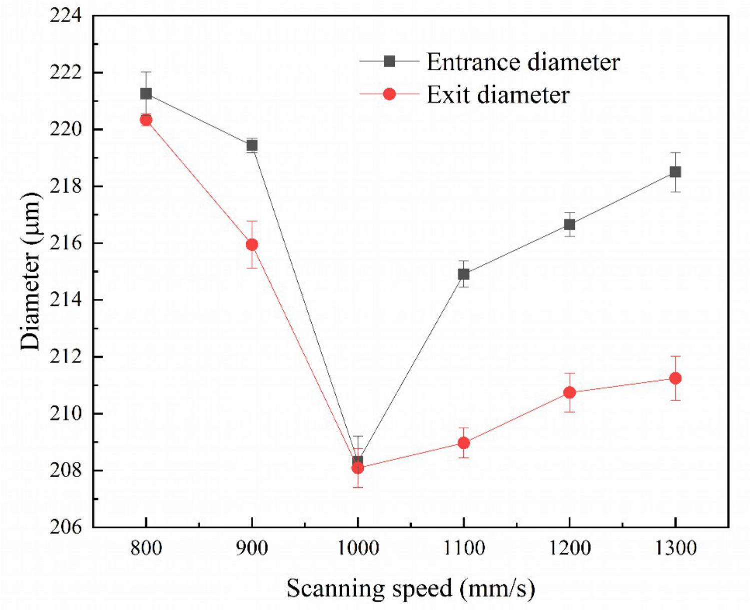

Fig. 2. The effect of scanning speed on entrance and exit diameters at 15 uJ and 200 KHz

To laser-drill a via in a piece of LTCC tape layer, a focused laser beam is repeatedly pulsed at the tape layer along the edge of a via. The white tape is covered with plastic backing to protect the surface. In order to avoid plastic residue around the edge, the vias were drilled with removing this plastic backing.

Laser drilling was performed with the scanning speed range of 800-1300 mm/s, and the pulse energy and repetition rate remained the same, which were 15 uJ and 200 KHz, respectively. It can be observed that the scanning speed would influence the entrance and exit diameters, as shown in Fig 2. In this experiment, a circle with a diameter of 200 µm was drawn. However, due to the effect of the beam diameter, the hole diameter obtained is larger than the set diameter. As can be seen from the figure, when the scanning speed is less than 1000 mm/s, the exit diameter tends to decrease with the acceleration of the scanning speed. This is because when the speed is low, the energy per unit area of the laser pulse on the surface of the material is high, which can cause adhesion and melting. When the speed is greater than 1000 mm/s, the energy per unit area on the surface of the material is low, and the taper of the hole is large. Under the scanning speed of 1000 mm/s, vias with diameters down to 208.69 µm (laser beam entry side) and 208.55 µm (laser beam exit side) have been fabricated. It can be observed that the drilling micro vias have a similar opening size at the front and back sides of the LTCC tape layers. Laser machining generally results in conical through-hole shapes, where the shape and through-hole diameter are strongly dependent on material-specific laser parameters.

To compare the visual difference, vias drilled with and without plastic backing at the same condition are shown in Fig 3. It can be observed that the vias drilled without plastic backing have a less dark area on the surface on the entry side and the aperture is clean and circular. With the plastic backing, the diameter of the via is larger on the entry side. It could be concluded that the plastic used for protection has higher absorption than tape so it melts on the edges, leaving a small residue behind on the surface of the tape.

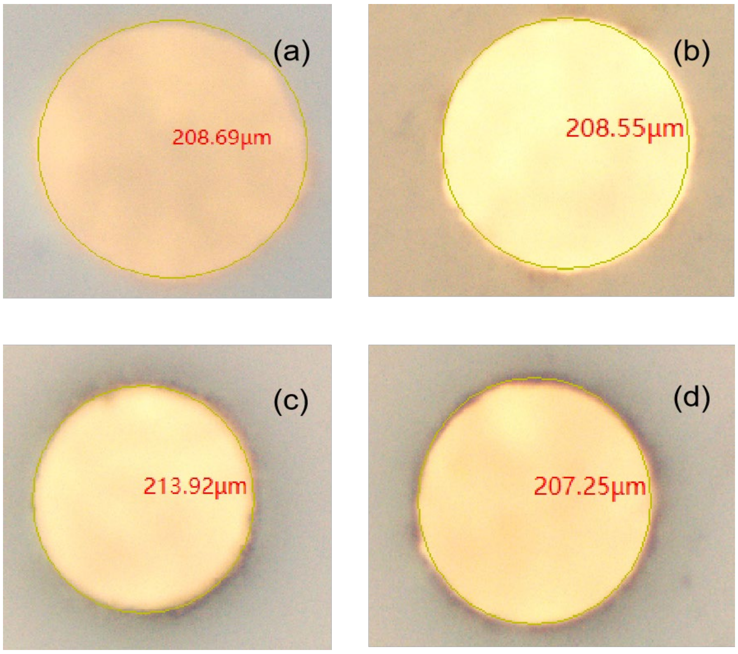

Fig. 3. Laser drilled via, entry side (a) with, (c) without plastic backing; Laser drilled via, exit side (b) with, (d) without plastic backing

The laser repetition rate refers to the number of pulses emitted by the laser source in a unit of time. In order to study the influence of the repetition rate on the drilling effect of LTCC, the laser single pulse energy was selected as 15 µJ and the scanning speed was 1000 mm/s, and the dependence of the entrance and exit diameter of the hole was obtained under different repetition rate, as shown in Fig 4. It can be seen that with increasing repetition rate, both the entrance diameter and exit diameter of the hole are increased. This is because the number of pulses acting on the surface of the material in unit time is increased, and the unit area of the material receives more laser energy. Consequently, the surface heat accumulation effect increases significantly, resulting in the increase of the aperture.

In addition, the effect of laser pulse energy on the entrance and exit diameter of LTCC was studied. The laser scanning speed was selected as 1000 mm/s, and the laser repetition rate was 200 KHz. The input of pulse energy is tuned by changing the laser input power, and the result is shown in Fig 5. When the pulse energy is 10 uJ, the aperture and taper are the smallest. With increasing the pulse energy, the aperture also increases, and especially the entrance diameter increases rapidly. That is because when the power is too high, the laser processing area melts the adhesion again while removing the material, resulting in the increase of the taper of the hole.

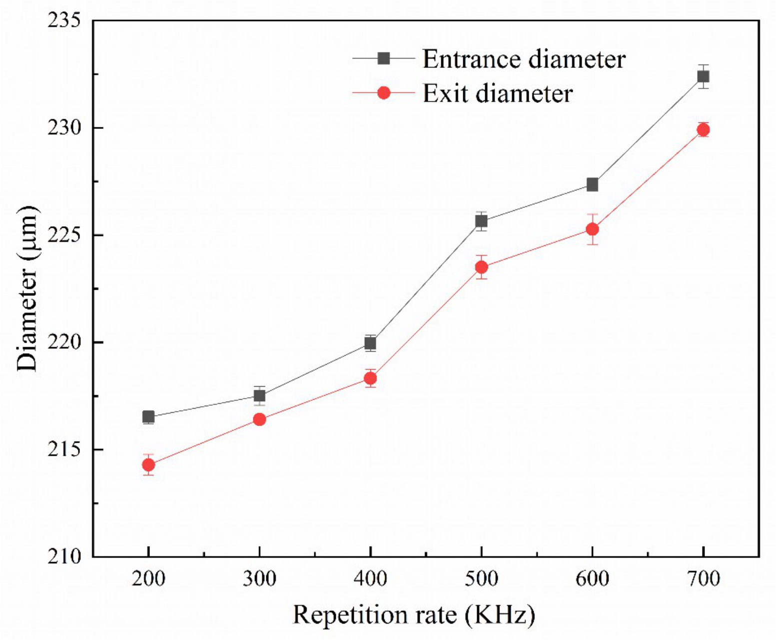

Fig. 4. The effect of repetition rate on entrance and exit diameters at 15 µJ and the scanning speed of 1000 mm/s

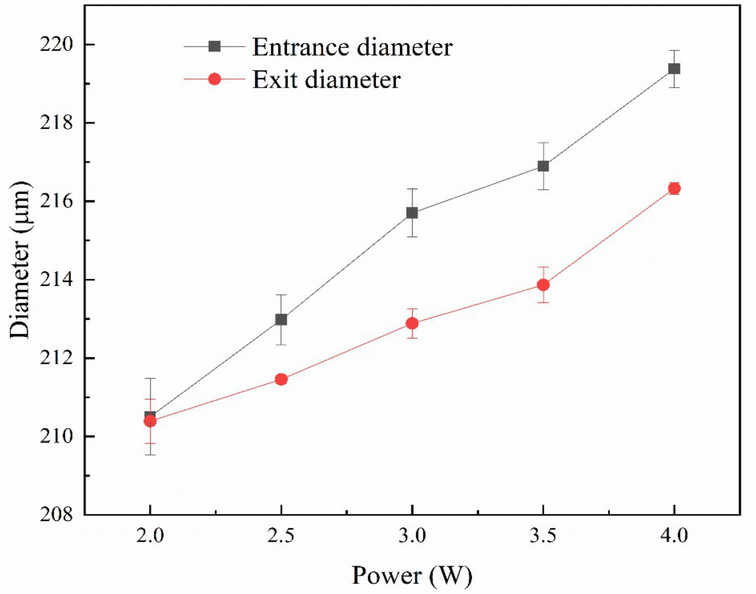

Fig. 5 The effect of power on entrance and exit diameters at 200 KHz and the scanning speed of 1000 mm/s

4. Conclusion

Multilayer co-fired ceramics is an advanced technology to manufacture modern microelectronic multilayer electrical interconnection substrates and packaging shells, including LTCC. Laser plays a key role in cutting, drilling, marking, and so on in the production process. In this paper, the through hole was successfully drilled on the LTCC with a UV picosecond laser. When the frequency, scanning speed, and pulse energy are 200 kHz, 1000 mm/s, and 15 μJ, respectively, holes with small taper are obtained and there is very small heat-affected zone at the hole edge. In addition, the effects of laser pulse energy, scanning speed, and repetition rate on the entrance and exit diameters of LTCC were analyzed. All the results demonstrate that picosecond laser processing is very promising for the application in the LTCC ceramics industry.

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