Abstract LTCC material is introduced as an excellent alternative to silicon, glass or plastic materials for the fabrication of miniaturised analytical devices, though it is most widely used in the automotive industry and microwave industry. Laser ablation of LTCC material was studied in this report. This kind of green tape material is mechanised by excimer laser (KrF, 248 nm) and UV laser (Nd:YAG, 355 nm) and, for the first time, by infrared laser (1,090 nm). The optical photos and the SEM photos of the LTCC ablated by different kinds of laser sources are given in this paper. For the first time, we discuss the laser ablation of LTCC by optical fibre sources. When using the excimer laser, the tapered structure can be easily seen from the SEM photo. However, a kind of clear and perfect ablation of LTCC can be seen for the first time by the 1,090-nm infrared laser ablation.

Keywords Laser ablation · LTCC · Microfluidic chip

1 Introduction

The microanalysis system is nowadays one of the most active areas in the analytical chemistry research field. It will dramatically reduce reagents, sample consumption and analysis time and provide a kind of portable system allowing in situ and in time analysis. There is a lot of research done on lab-on-chip system including the substrate selection, the microfabrication method, the microfluidic mechanism, the microsensor and actuator, the integrated system, etc., which can be seen in the related reviews and papers [1–5]. Silicon is a common substrate material compatible with IC standard process but expensive instruments are needed when silicon is used. The polymer is another usually used substrate material. Some methods such as micromoulding, microinjection, lamination, LIGA and laser technology [6, 7] are usually used to achieve the polymer microfluidic parts. However, the excellent sealing and packaging of polymer microfluidic chip is still a challenge. Thus, low temperature co-fired ceramics (LTCC), which have been widely chosen by researchers as electronic substrate due to some of their material properties, are proposed as an alternative material for the construction of microfluidic systems. The main advantage of LTCC to be used as a miniaturisation technology of microfluidic chip system is the ease of constructing multiplayer devices. Thus, complex three-dimensional structures, such as channels or cavities, can be easily achieved by means of an appropriate design of the component layers. Moreover, not only can a complex structure be accomplished, but also different materials or devices can be embedded and co-fired at the same time. A lot of LTCC-based micro/mesofluidic chip systems have been done for the microfluidic analysis system [8–15]. Several works discuss the fabrication of LTCC material [10, 14]. Excimer, CO2 and Nd:YAG lasers can be used to ablate the fired tapes with precision [10, 16–19]. However, the detailed research of manufacturing of LTCC devices is seldom done on the manufacturing process of the LTCC material, especially using the laser ablation method for the unfired and fired LTCC green tape [17 and its references, 19]. Jaroslaw Kita et al. presented the possibility of laser
application for fabrication of 3D elements and structures of LTCC [17]. K. Kordas et al. reported a method based on laser-assisted processing by which even 3D thin/thick post-metallisation can be accomplished, which opens new routes towards advanced novel applications in RF/microwave technology, MEMS and chemical catalysis [19]. A laser can be used in thick film and LTCC technology. Fine-line patterning, trimming and cutting are examples of the possible applications. Vias for the fired and unfired tape are reported by using Nd:YAG laser system.

In the present work, we first study the vias of the unfired and fired LTCC tape by both the excimer laser (KrF, 248 nm) and Nd:YAG (355 nm). At the same time, we compared the laser-treatment mechanism of the two laser systems by Scanning Electron Microscope. At the same time, the microseparator design with our previous work is also manufactured in the present work.

2 Materials and methods

2.1 Material

The LTCC green tape with thickness 250 μm is from the DuPont Company.

2.2 Excimer laser ablation

The surface of the LTCC unfired and fired tape is ablated using a kind of KrF excimer laser beam (248 nm, 20 ns per impulse) coupled with an optical device that projects a beam through a metal photo mask consisting of a slot of 100–300 μm width (and 15 mm long) or square holes with 200×200,2000×2000,4000×4000 microns. The Excimer laser ablation system used for this work is a PM848 Excimer laser system that generates KrF laser pulses of 12–25 ns duration at a wavelength of 248 nm and with a maximal output of power 80 W. Beam dimension of the laser is (8–12)×25 mm² as tested by the sensitive paper. A stainless steel stencil was employed to define and project the geometry of the ablation spot, which was made using our Nd:YAG laser drilling system. The projected beam of the laser system is passed through a continuously optical homogeniser and tunable attenuator that adjusts the fluence of output laser and applies uniformity to the beam. The attenuated laser then projects onto our stainless steel mask that is positioned in a mask holder. The beam passes through the mask and proceeds on to pass through an object that condenses the beam down by a factor of 10. The substrate material is secured down onto a microcontrolled computer-interfaced ultra-precision 2D scanning stage. The maximum travel distances are 75 mm×75 mm (X and Y), the linear resolutions are 1 μm (X and Y) and the position accuracy is ±1 μm. A kind of CCD device connected to the CRT is also used to control the laser ablation process during manufacturing.

During the pulsed ablation process, the substrate was moved horizontally with an X, Y stepper motor between 0.05 and 0.2 mm/s in order to generate linear micro-channels with final dimensions needed for the experiment. The speed of the substrate movement and the laser pulse frequency were used to control the total number of pulses impinging on any given substrate area and, therefore, the resulting microchannel depth.

According to the following equations: \( F/F_0 = S_0/S \), \( F_0 = E_0/S_0 \) (\( F \), the fluence at the workpiece; \( S \), the area of the mask pattern on the workpiece; \( F_0 \), the light source fluence; \( S_0 \), the area of the original facular size; \( E_0 \), the source light energy), we can calculate the fluence of our experiment. In our experiment, we set the original size as \( 8 \times 25 = 200 \text{ mm}^2 \) = 2 cm² (which is decided by the laser shape of our instrument measured by the sensitive paper experiment, not shown in this article); thus, the fluence is \( E_0/2 \)

![Fig. 1 Setup of the infrared wave laser with a wavelength of 1090 nm](image)

Table 1 Parameters of 248-nm laser ablation experiments

| Parameter                        | Value          |
|----------------------------------|----------------|
| Fluence (m J cm⁻¹)              | 400            |
| Repeat rate (Hz)                 | 1              |
| Attenuate angle (degree)         | 0, 30, 60, 90, 120, 150, 180, 210, 240, 270 |
| Pulse number                     | 100            |
| Mask diameter (μm)               | 200            |

Table 2 Parameters of 355-nm laser ablation experiments

| Parameter                        | Value            |
|----------------------------------|------------------|
| Power (W)                        | 0.15–1.1         |
| Repeat rate (KHz)                | 1, 5, 10         |
| Pulse number                     | 10, 100, 500, 1,000, 5,000 |