Groove in Sapphire Machined by CO_2 Laser Under Water

Leilin Huang, Lei Xiao, Fufei Pang, Huanhuan Liu, Xianglong Zeng, and Tingyun Wang

Abstract We have demonstrated a method for crack-free machining of groove in sapphire by using a CO_2 continuous-wave (CW) laser under water. A sapphire wafer with a thickness of 1 mm is immersed into the water with 1 mm beneath the water surface. The effect of laser processing parameters on the jagged edge size and groove depth has been analyzed by tuning line-to-line spacing ranging from 0.006 to 0.1 mm as well as scanning speeds from 5 to 80 mm/s. As the decreasing of line-to-line spacing and the increasing of scanning speed, the jagged edge size reduces. The groove depth is deeper as the increasing of line-to-line spacing and scanning speed. Since underwater laser machining reduces substrate defects originated from heat accumulation from the laser, a groove without recast layer and cracking could be formed in sapphire wafer. The achieved groove in sapphire shows potential application for optical fiber sensing in harsh environments and microfluidic channels in corrosive solutions.

Keywords Groove · Sapphire · CO_2 laser

1 Introduction

The machining of groove in sapphire has broad application prospects in many fields [1]. Particularly, in optical fiber sensing, the formation of groove can be used as a Fabry–Perot cavity that has been shown to be highly sensitive to temperature and pressure [2], especially in high temperature environments. Since sapphire is an extremely hard and corrosion-resistant crystal with a melting point of over 2000 °C, the machining of groove in sapphire shows great potential in harsh environments and provides the possibility for the application of microfluidic channels in corrosive solutions. The processing of such material by picosecond and femtosecond

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ultrashort pulse lasers shows high photon loss and low material removal [3]. In contrast, sapphire has a high absorption coefficient of 95% for a CO_2 laser emitted at 10.6 μm [4]. Meanwhile, CO_2 laser underwater machining has been found to result in reducing substrate defects such as recast layer and cracking that are typically found in machining in air [5].

In this paper, the effect of laser processing parameters on the jagged edge size and groove depth is analyzed by laser machining in sapphire wafer with different line-to-line spacing and scanning speeds. The achieved groove in sapphire shows potential application for optical fiber sensing in harsh environments and microfluidic channels in corrosive solutions.

2 Experimental Investigation

The experiment setup for CO_2 laser underwater machining system is shown in Figure 1a. It consists of a computer-controlled CO_2 CW laser associated with an *x-y* galvanometer beam scanner and a sample container with water. A 53 × 25 × 1 mm sapphire wafer is immersed into the water with 1 mm beneath the water surface. A groove with a diameter of 3 mm is machined into the sapphire. Figure 1b illustrates the interaction between CO_2 laser, water and sapphire wafer.

Figure 2 shows the micrographs of the jagged edge morphology with line-to-line spacing ranging from 0.006 to 0.1 mm. As the distance between the lines decreases,

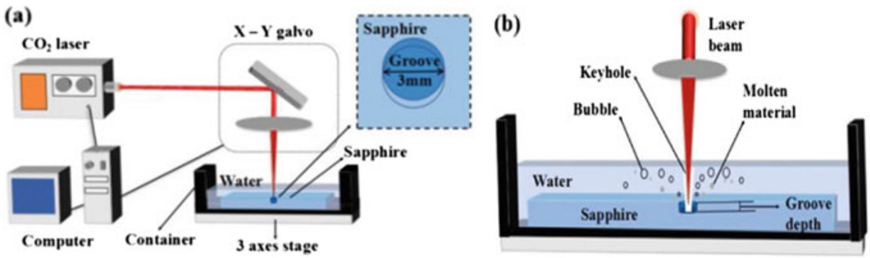

Fig. 1 **a** Schematic diagram of experimental setup for underwater machining of sapphire, **b** interaction between CO_2 laser, water and sapphire

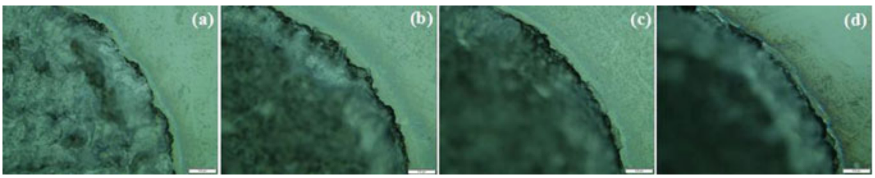

Fig. 2 Micrographs of jagged edge morphology at a line-to-line spacing of **a** 0.1 mm, **b** 0.04 mm, **c** 0.01 mm, **d** 0.006 mm. Scale bars are 100 μm

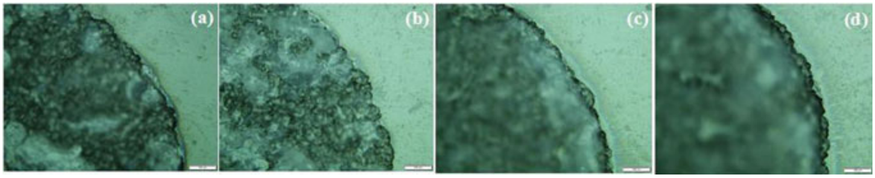

Fig. 3 Micrographs of jagged edge morphology at a scanning speed of **a** 80 mm/s, **b** 50 mm/s, **c** 10 mm/s, **d** 5 mm/s. Scale bars are 100 μm

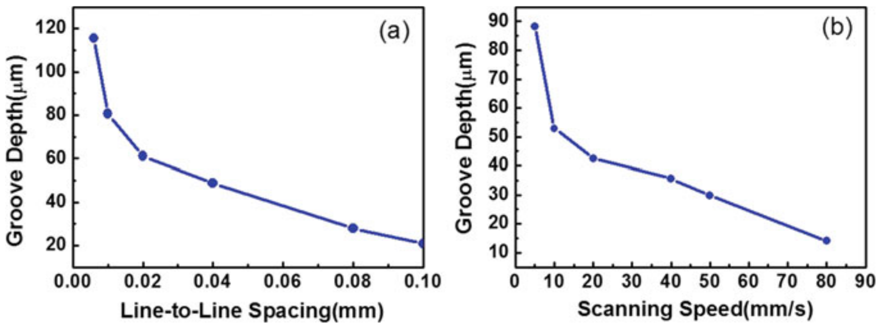

Fig. 4 Groove depth under different **a** line-to-line spacing, **b** scanning speed

the overlap rate of the spots on the edge increases and the jagged edge reduce. The jagged edge morphology with scanning speed ranging from 5 to 80 mm/s is shown in Fig. 3, which indicates that the jagged edge size reduces along with the decreasing heat accumulation induced by speed increasing.

Figure 4a plots the groove depth measured by 3D Optical Profiler (S neox) under different spacing. As the spacing becomes smaller, the thermal accumulation in unit is higher so that and the depth of groove is deeper. The groove depth under different scanning speeds is shown in Fig. 4b. The increase of the material's removal rate caused by the extension of the machining time which is resulted from the speed decreasing, deepen the groove depth eventually.

3 Conclusion

In summary, we realize the CO_2 laser underwater machining of grooves in sapphire and investigate the influence of line-to-line spacing and scanning speed on jagged edge size and groove depth. The achieved groove in sapphire shows potential application for optical fiber sensing in harsh environments and microfluidic channels in corrosive solutions.

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