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Temperature effects on the geometry during the formation of micro-holes fabricated by femtosecond laser in PMMA

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ABSTRACT

In this study, the temperature effects on hole geometry of the PMMA during micro-holes drilling by femtosecond laser has been studied under various pulse energy and number of pulse. The laser-induced hole's diameter is considerably increased by 73% as the temperature rises from 20 °C to 90 °C. Remarkable enhancement in the removal volume of micro-hole is also observed under high temperature. The possible mechanism for such changes is discussed in detail on account of optical absorption enhancement and higher density of surface plasma. The atomic percentage of oxygen obviously increases with the increase of temperature, which is beneficial to femtosecond laser fabrication of PMMA micro-hole. The spatter area of micro-hole has been found to tremendously extend with the increase of temperature, which is due to recoil pressure effect. These results demonstrate that temperature plays a crucial role to tailor micro-hole fabrication by femtosecond laser.

1. Introduction

Recently, due to its non-contact nature, reduced recast/microcracks, minimal heat-affected-zones and the absence of plasma-shielding effects [1–5], femtosecond lasers (fs) with peak power in the range of gigawatts are becoming an efficient tool in precision machining of transparent materials. The direct femtosecond laser surface processing has distinguished itself from other conventional laser ablation methods. And it has become one of the best ways to create surface structures at nano- and micro-scale, which are suitable for a wide range of applications [6,7]. As compared with other transparent materials, polymethyl methacrylate (PMMA) has high transmission in the visible region and a lower ablation threshold because of a low glass-transition temperature, which makes it suitable for a micro-hole drilling study [8–11]. Nevertheless, the spatter of the laser-induced materials around the micro-hole and the hole taper angle still unclear [12,13]. Moreover, the optical absorption coefficient during laser-material interactions, as a function of environmental temperature, is a significant factor that determines the ablation efficiency. Some works have focused on the influence of environmental temperature on ablation efficiency, laser-induced surface roughness, laser threshold and micro/nanostructures formation [14–16]. Hence, we use a heating device to pre-heat the sample during the micro-hole drilling procedure. This implies that studying the hole geometry and spatter area of the drilled hole for PMMA during femtosecond laser processing at different temperature can provide a new approach to understanding the laser-material interactions.

In this work, the temperature effects on micro-hole geometry formed on PMMA surface by femtosecond laser irradiation are systematically studied. The dependence of holes' diameter and removal volume on temperature from 20 °C to 90 °C with different pulse energy and number of pulse are discussed. In addition, the spatter area diameter at different temperature has been presented and explained in detail by recoil pressure effect. The mechanism for such temperature dependence phenomenon is also discussed by optical absorption enhancement and higher density of surface plasma.

2. Experimental

Fig. 1 presents the experimental set-up of femtosecond laser system with a heater. An amplified femtosecond laser (Spectra Physics Spitfire) consisted of a mode-locked Ti:Sapphire oscillator and a regenerative amplifier that generates 120 fs linearly polarized pulses at a 1 kHz repetition rate with a central wavelength of 800 nm has been used in this study. The pulse numbers were controlled by an electromechanical shutter. And the pulse energy attenuated by a neutral density attenuator was measured using a

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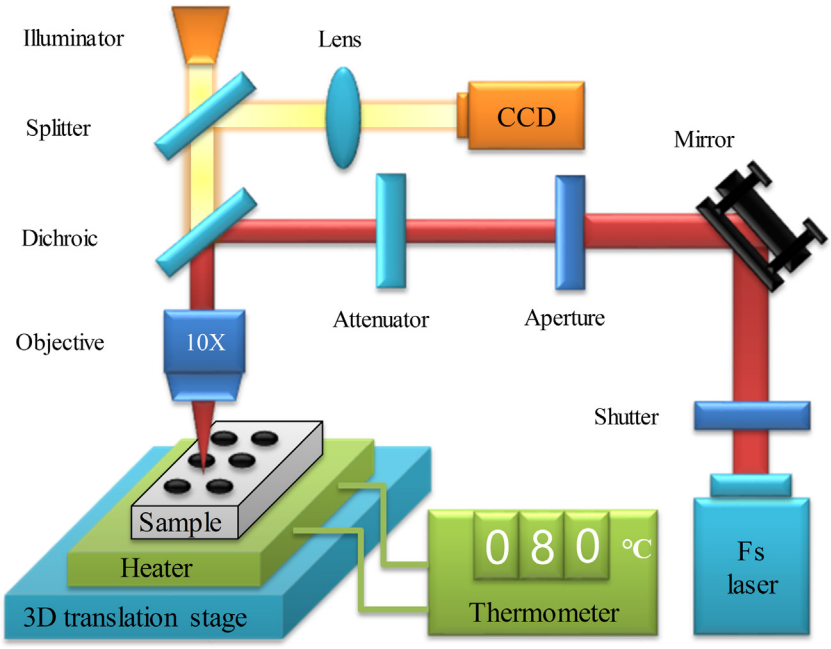

Fig. 1. Experimental set-up of the laser systems with a heater.

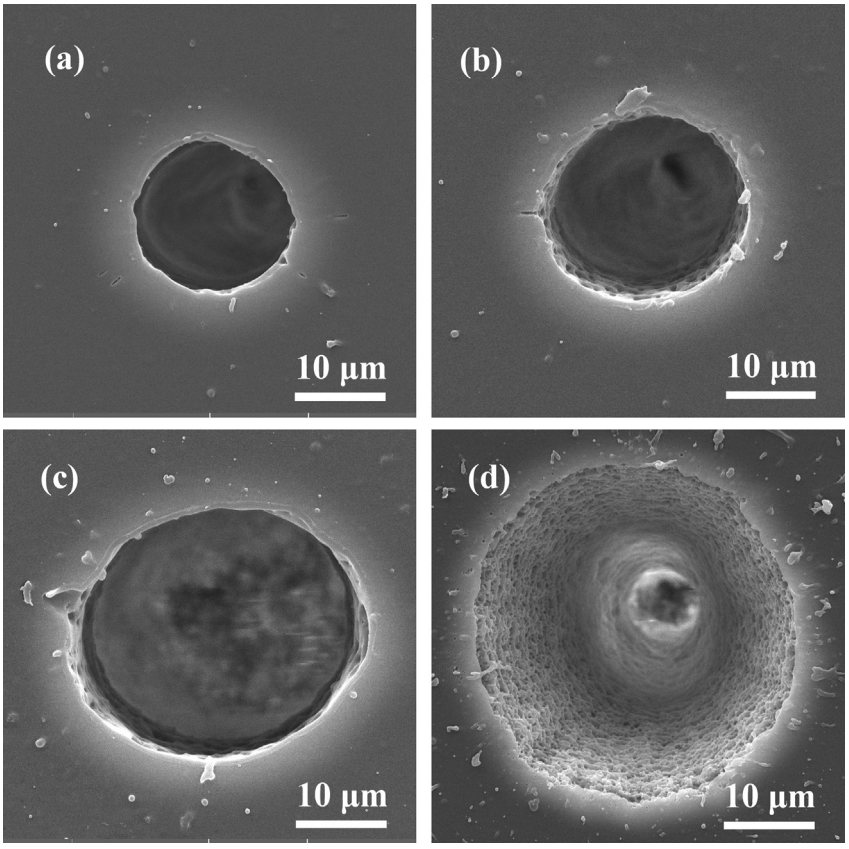

Fig. 2. SEM images of the micro-hole fabricated by femtosecond laser with different temperature (a) 20 °C; (b) 40 °C; (c) 60 °C; (d) 80 °C. The irradiation energy and number of pulse are fixed at 35 μJ and 500 shots, respectively.

power meter. The laser beam was statically focused onto the surface of a polished PMMA with thickness of 2 mm via a 10× objective lens (N.A. = 0.2). The sample was fixed onto an electric heater, which was mounted onto a three-axis translation stage. The temperature of PMMA sample ranging from room temperature 20 °C to 90 °C in a step of 10 °C was monitored real-time by a thermocouple. The CCD camera was linked to the computer for real-time observation on PMMA surface in the fabrication procedure. After irradiation, the morphology of PMMA sample was analyzed by using laser confocal microscopy (LCM) and scanning electron