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Transient response of fish cornea towards a single femtosecond pulse

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Abstract

Nonlinear interaction of fs-laser and soft tissues like cornea and elastomers like PMMA (Contact lens) and PDMS is a dynamic process where the biomechanical properties might be perturbed by the laser beam during the time-course of the processing. Here we demonstrate the time-resolved response of focused single fs-laser pulse on soft-tissues like Cornea, elastomers like PDMS and PMMA (Contact lens) near ablation threshold where the energy is nonlinearly absorbed by the target. Using high speed photography and single shot selection from the pulse train, we observe long exponential relaxation dynamics of crater diameter. Moreover, the single pulse response could be useful to quantify the residual effects of multiple pulses on material surface while using high repetition rate (several MHz) lasers.

1 Introduction

Femtosecond laser pulses have been used in the field of eye surgery, particularly corneal flapping procedure namely LASIK, providing the advantages of combined high precision and minimized collateral tissue damage [1, 2]. While prominent side-effects after LASIK are relatively rare, fs-laser flap-creation results in creation abnormal roughened corneal surfaces, vision defects such as irregular astigmatism, interface haze, and transient light sensitivity syndrome caused by increased light scattering [3, 4]. The challenge in femtosecond laser dissection is to optimize clinical operating conditions for maximal precision and minimal damage to surrounding corneal tissues. Thus, it is vital to understand the single pulse response of soft materials. Since, when the surgery systems are operating at several MHz repetition rates, the interaction time of pulses with material plays a significant role in increasing or decreasing the surface roughness.

2 Material and Methods

Fig. 1 demonstrate the schematic of the experimental setup [5].The CEP amplified femtosecond laser system (FEMTOLASER, AUSTRIA) with 2 mJ energy at the wavelength of 800 nm with a repetition rate of 1 kHz was used to modify the soft surfaces. The pulse duration of the laser is about 25 fs. The laser energy could be attenuated with variable neutral density filter (Thorlabs). The laser beams are focused on the sample surface by using an objective lens (10X). The laser beam spot size at sample surface was determined to be about 2.5 μm in diameter. The laser polarization is set to be perpendicular to the processing direction. The two high speed mechanical shutters was synchronized with input pulse and the high-speed charge-coupled device (CCD, FASTCAM, Photron, Japan) to capture the time resolved video after exposing to a single femtosecond pulse[2]. The video was converted to time resolved optical images using home built LABVIEW software to analyze the change in crater diameter of ablated surface as a function of time. To study the transient response of single fs- pulse on polymer samples, the commercial contact lens (bosh and Lomb, US) made of PMMA and PDMS was used. Details for the preparation and mounting of Polymer samples was explained elsewhere [6]. In order to prepare the fish cornea samples,the fish heads were procured from local abattoir and maintained at wet lab facility, IISER Mohali at 4 ^{o}C). The eyes were cleaned, enucleated and incised with proper surgical care to extract the transparent cornea sample. Finally, the samples were kept in 0.9 percent normal saline at

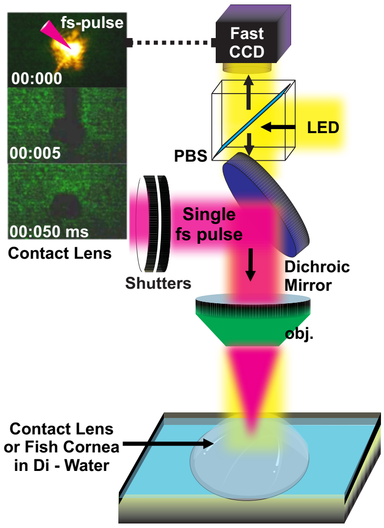

Figure 1. Schematic of experimental setup illustrating single femtosecond pulse exposure on polymers (PDMS, PMMA) and fish cornea.

4 ^oC before the laser exposure.

3 Results and Discussion

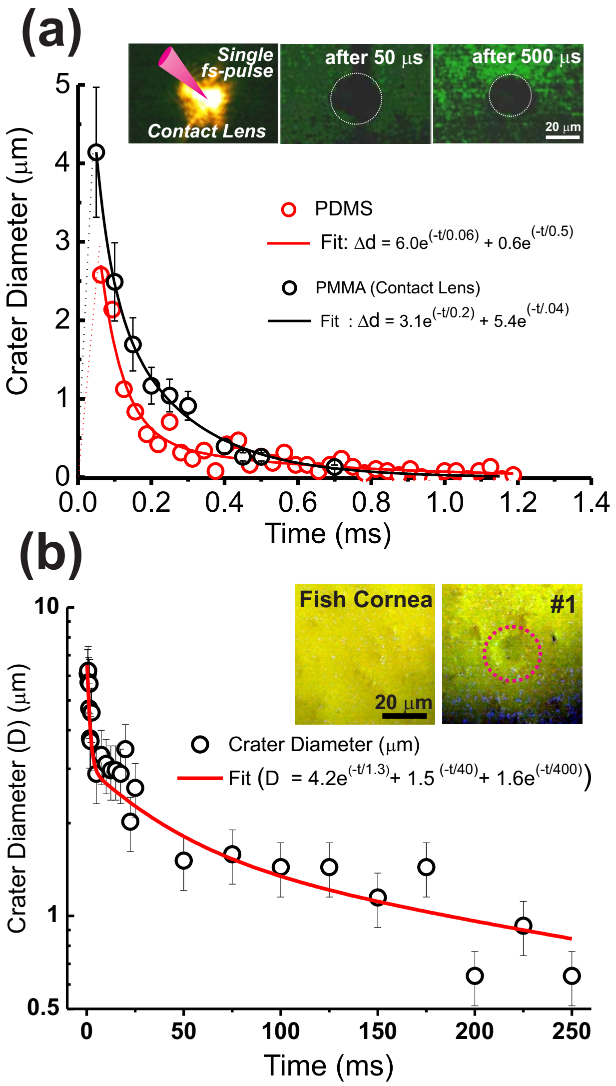

Figure 2. Transient response of soft materials towards single fs-pulse, change on crater diameter as a function of time (a) PMMA and PDMS (b) Fish Cornea.

The surface optical image trains were extracted from the fast CCD camera video captured during laser irradiation. Inset of Figure 2 (a) shows a set of crater images as a function of time delay after single-shot laser pulse with energy of 50 μJ on PMMA surface. The crater diameter has reached to its maximum value of about 26 μm within less than 0.1 ms. After 1 ms, the crater size is eventually invariant of about 22.2 μm in diameter. In case of PDMS, The crater diameter has reached to its maximum value of about 15 μJ within less than 0.1 ms. After 1 ms, the crater size is eventually invariant of about 11.3 μm in diameter. In both materials, we observe the 4 μm change in crated diameter with the time span of 1 ms. If the pulse repetition rate change from 1 kHz to 2 kHz, viz. two pulses in 1 ms time scale, perhaps make a chance of two pulses interacting with the materials without an elastic relaxation, this may increase the roughness in focal volume[6].

Fig. 2 (b) shows the time resolved relaxation of fish cornea (*invitro* conditions) where the surface was exposed to single fs- pulse with 10 μJ energy. The crater diameter has reached to its maximum value of about 20 μm within less than 0.1 ms. After 250 ms, the crater size is eventually invariant of about 5.5 μm in diameter. We observe a significant change in crater diameter as a function of time. Thus, in order to achieve better performance in fs-laser cornea cutting/dissecting operation, it is quite necessary to carefully design inter-pulse interval considering the material relaxation time with respect to the exposure of a single fs-pulse.

In summary, we have performed systematic studies on the dynamics in crater size formed on PDMS, PMMA and fish corneal surface with a single-shot fs-laser pulse extracted by double shutter gating technique[5].The observation from the current work unequivocally revealed that the relaxation time between two consecutive pulses is vital to control the surface roughness and has been affected by dynamical features of crater shape.

4 Acknowledgements

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