Utilizing Transient Effects for Ablating Glass Using Combined Picosecond and Nanosecond Laser Pulses

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In industrial fields including consumer electronics, micro-manufacturing and medical engineering, short and ultrashort pulsed lasers are commonly used for various glass processing applications. While lasers with pulse durations in the nanosecond (ns) regime typically can offer higher ablation rates, picosecond (ps) and femtosecond lasers generally ensure higher process quality [1]. The temporal shaping of laser pulses is of high interest since a positive effect on ablation rate or quality has been reported [2]. In this work, we explore a hybrid approach by utilizing a unique dual-seeder laser system capable of simultaneously generating two pulses with pulse durations of 1 ps and 10 ns, respectively, with a tunable temporal delay d between the pulses and approximately equal pulse energy at an infrared (IR) wavelength of 1030 nm. The delay is considered positive for trailing ns pulses, while $d = 0$ when the rising flanks of the pulses coincide. Our goal is to enhance the ablation efficiency by utilizing a leading ps-pulse to induce transient effects, which increase the absorption of IR ns-pulses.

Transient effects in the laser-glass interaction are investigated by focusing the beam on a soda-lime glass sample and measuring the transmitted intensity using a photodiode (PD), for different d. For ps-pulse energies below the ablation threshold and for positive delays $d \geq 0$, the transmission of the ns-pulses is significantly reduced. For leading ns-pulses, no reduction is observed, suggesting the presence of an effect triggered by the ps-pulse-glass interaction. The PD signal depicted in Fig. 1a) shows the reduced amplitude of the ns pulse after passing through the glass. In a single-shot ablation experiment, the pulse packets of varying envelope energy E_p are focused on a soda-lime glass sample and the resulting ablation craters are characterized. Increased ablation depth is observed for $d \geq 0$, compared to leading ns-pulses. This effect is magnified by increasing E_p, as is depicted in Fig. 1b). Utilizing the two-pulse approach at optimized settings, the ablation depth can exceed the depth caused by a single ps-pulse with equal envelope energy (Fig. 1c)). The significantly increased ablation depth is evident for $d =$ 40 ns. These observations stimulate further research on this effect and its applications.

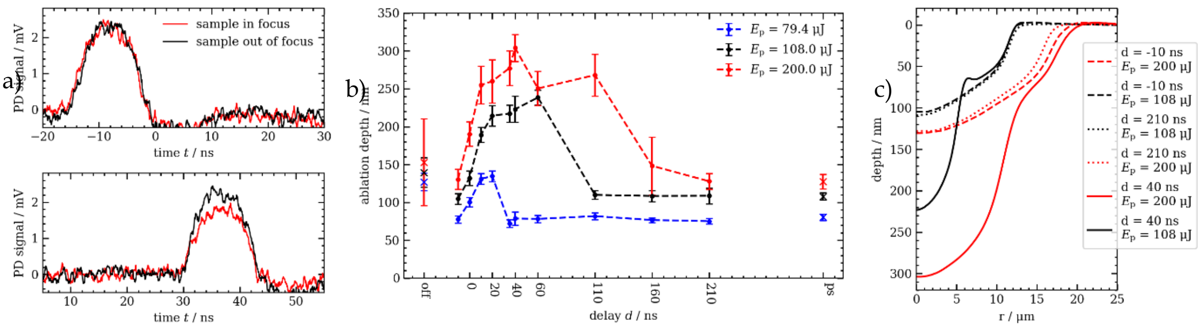

Figure 1: a) Transmission photodiode signal with subtracted ps-pulse signal. The ps-pulse starts at $t = 0$. The measured signal of the ns pulse is reduced for $d \geq 0$. b) Mean ablation depth as a function of d and different envelope pulse energies E_p. For the setting "off", the ns seeder was disabled, and the full envelope energy is contained in the ps-pulse alone. At a delay of 310 ns (labeled as "cut"), the internal modulator of the laser fully suppresses the ns pulse. c) Radial profiles of ablated spots for different delay settings and pulse energies.

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