The Dominant Role of Cavitation in Stone Damage During Dusting Produced by Holmium:YAG Laser Lithotripsy

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Background

During Holmium (Ho):YAG laser lithotripsy (LL), rapid vaporization of fluid at the tip of the laser fiber results in the formation of a vapor bubble that improves laser energy transmission to the stone. The contribution of cavitation to stone damage in LL, particularly by the bubble collapse, has not been well understood. Here, we investigate the contribution of the LL-generated bubble collapse to stone damage during dusting treatment.

Material and Methods

1. Dusting mode (0.2 J, 20 Hz) of a clinical laser lithotripter (H Solvo 35-watt laser, Dornier MedTech) was investigated.
2. BegoStone samples were treated with the fiber perpendicular to the stone, and crater volume and geometry were quantified using optical coherence tomography (OCT) (Fig. 1).

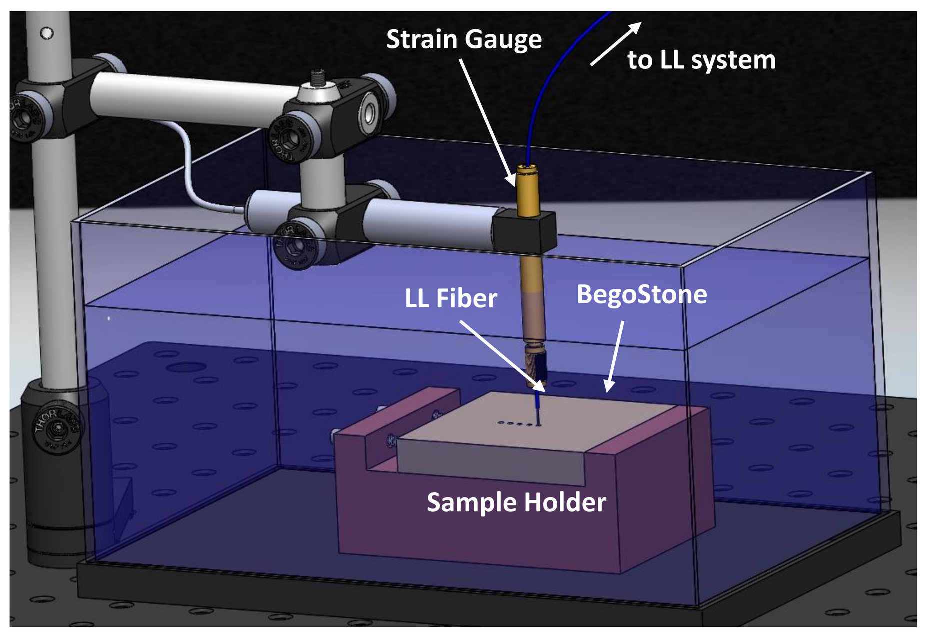

Figure 1. Schematic of the benchtop setup for BegoStone crater damage experiments.

3. A novel counter-plate setup was developed to alter the LL-generated bubble dynamics and minimize the damage produced by bubble collapse.

Counter-Plate Experimental Setup

- Counter-plate designed with a 1 mm through-hole for inserting the optical fiber and 0.75 mm height spacers at the 4 corners (Fig 2 a-c).
- Fiber tip is positioned 0.5 mm from stone/glass surface and 0.25 mm from counter-plate surface (Fig 2 d).

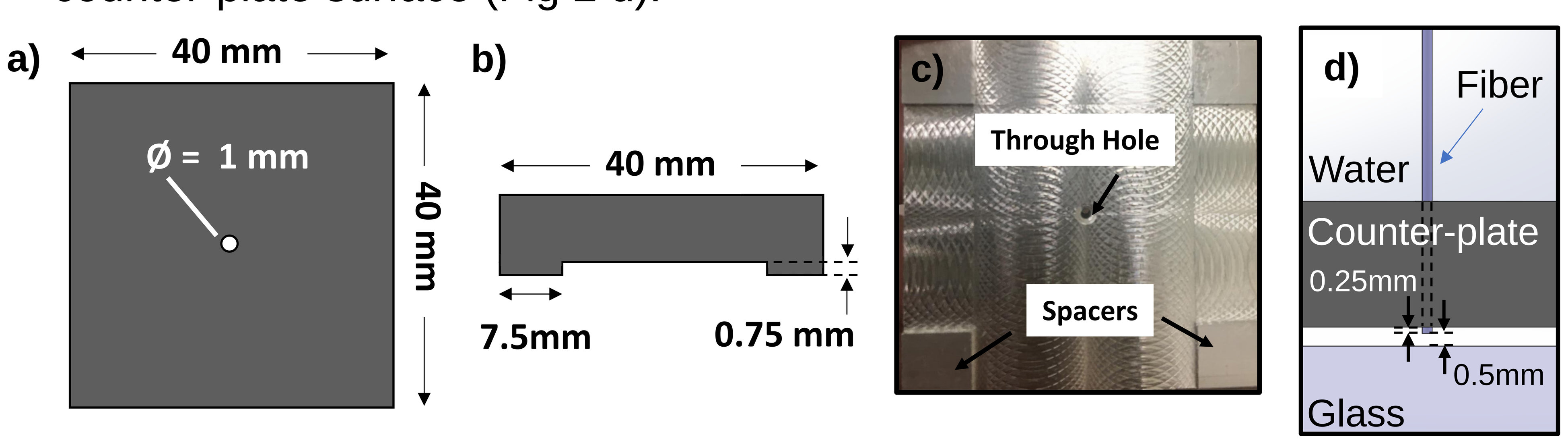

Figure 2. a) Top view and b) side view of the counter-plate setup. c) Photograph of the machined counter-plate. d) Schematic of the benchtop setup for the counter-plate experiments

➢ High-speed imaging demonstrates the counter-plate alters the direction of the bubble collapse towards the counter-plate (Fig. 3).

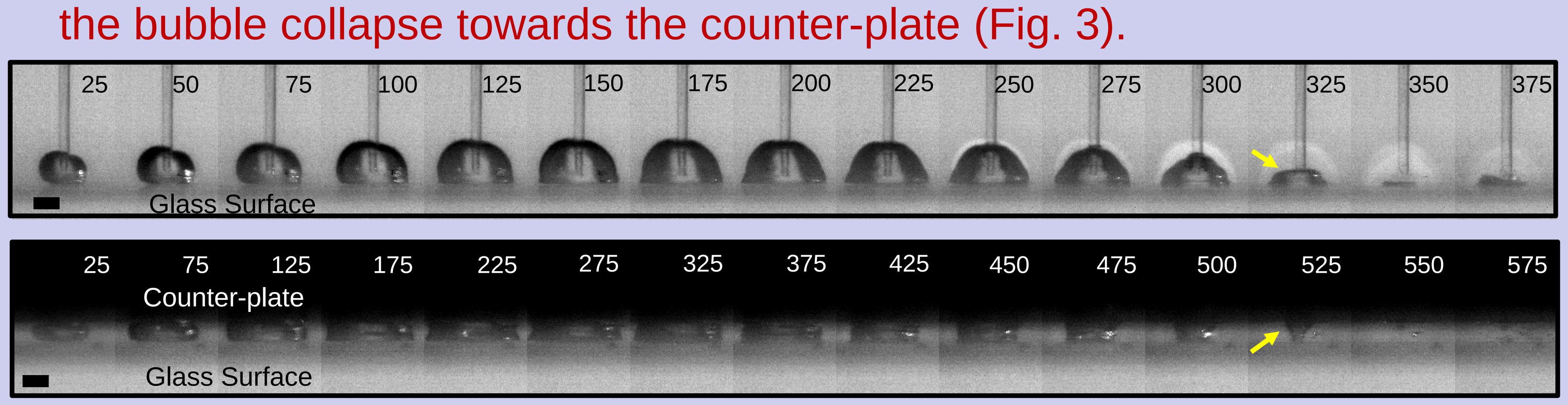

Figure 3. LL-generated bubble expansion and collapse a) without and b) with the counter-plate. The counter-plate alters the collapse point of the bubble from downward towards the glass surface to upward towards the counter-plate surface (yellow arrow). Time in µs, scale bar = 1 mm.

Results: OCT Crater Volume Analysis

- BegoStone samples were treated in both air and water with up to 1000 laser pulses with the fiber-stone standoff distance (SD) of 0 and 0.5 mm.

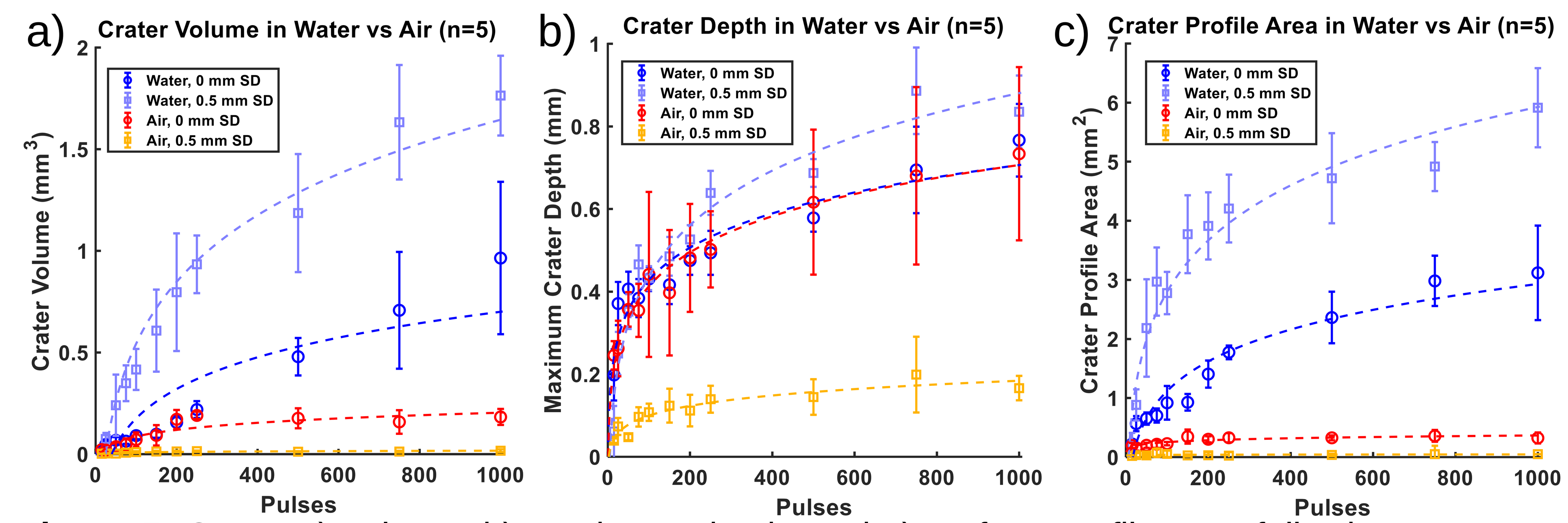

Figure 5. Crater a) volume, b) maximum depth, and c) surface profile area following treatment with a perpendicular fiber at 0- and 0.5-mm SD in water (cool colors) and in air (warm colors).

➢ An increase in stone damage observed for a SD = 0.5 mm compared to SD = 0 mm (Fig. 6) → secondary processes contribute significantly to stone damage besides photothermal damage.

➢ Increased fragmentation observed for treatment in water compared to in air → cavitation contributes to improved damage in water.

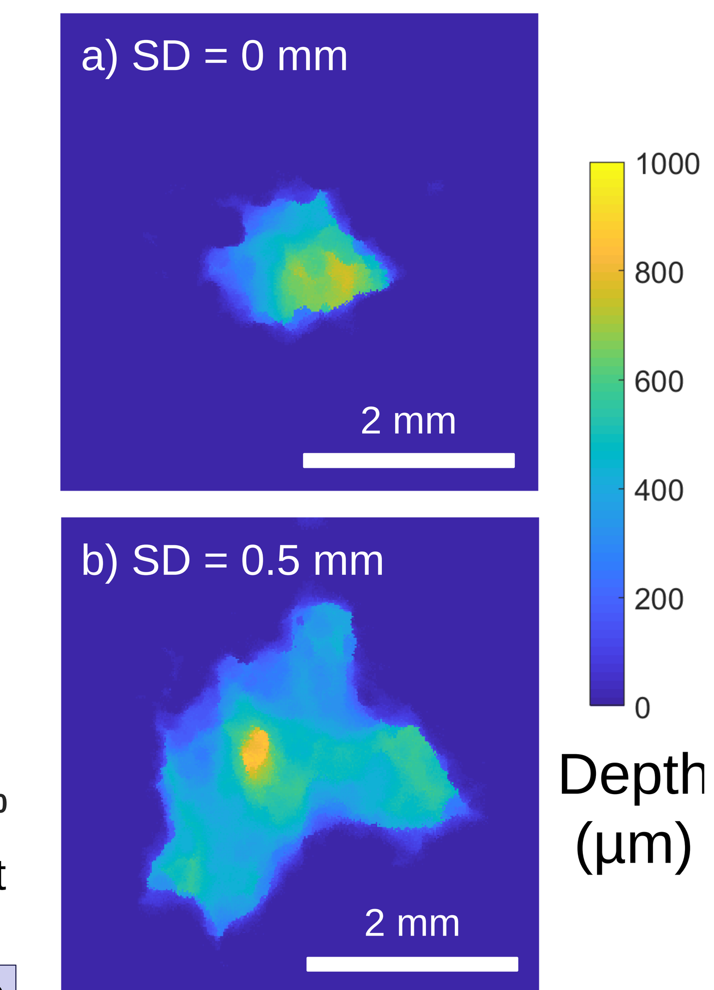

Figure 6. Representative craters following treatment of 1000 pulses in water with the fiber at a) SD = 0 mm and b) SD = 0.5 mm.

Results: Counter-Plate Experiments

- BegoStone samples were treated with and without the counter-plate up to 1000 laser pulses with the fiber-stone standoff distance (SD) of 0.5 mm.

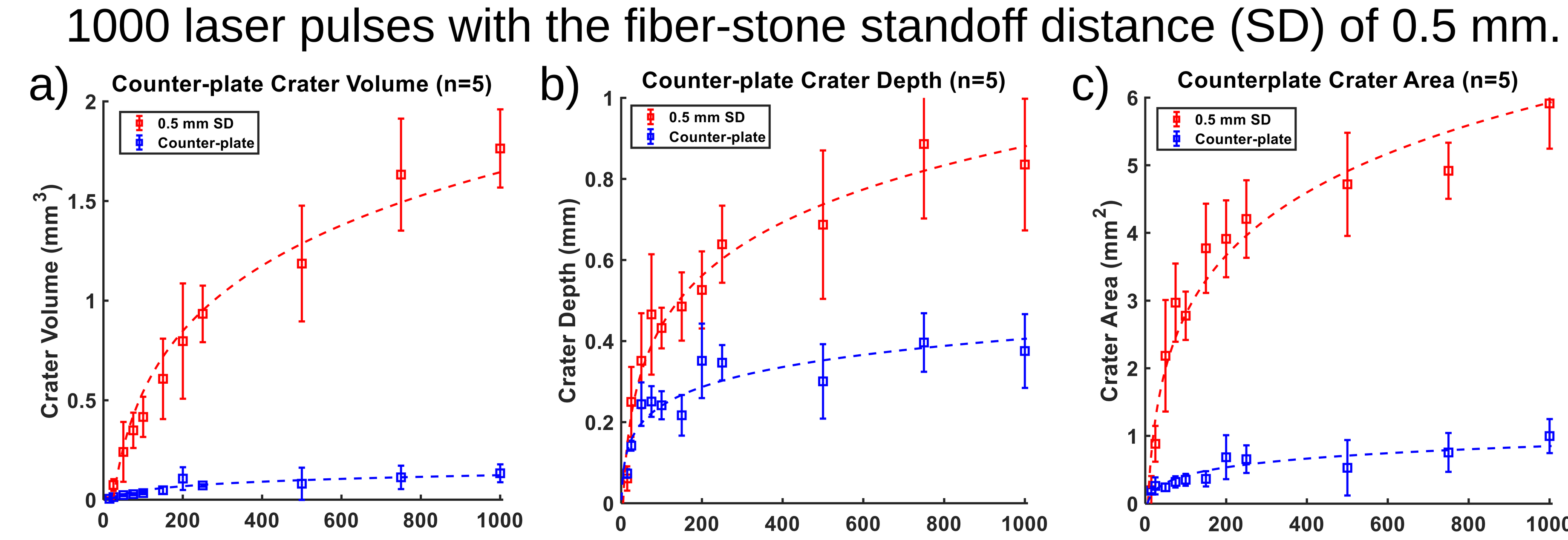

Figure 7. Crater a) volume, b) maximum depth, and c) surface profile area following treatment with a perpendicular fiber at 0.5 mm SD with (blue line) and without (red line) the counter-plate.

➢ The counter-plate significantly reduced the stone damage, particularly the crater volume and surface area (Fig. 7, 8) → cavitation is a major contributor to stone damage during dusting for Ho:YAG laser lithotripsy.

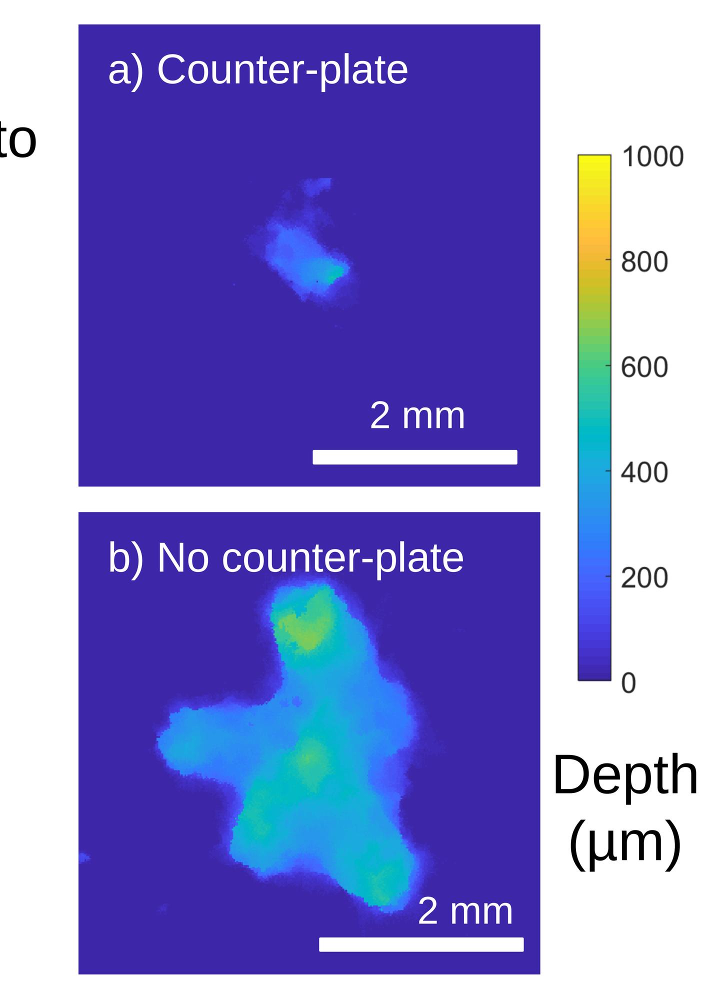

Figure 8. Representative craters following treatment of 1000 pulses a) with and b) without the counter-plate.

Conclusions

This study presents new findings regarding the dominant role of cavitation in stone dusting.

➢ Photothermal ablation is negligible in stone dusting at low pulse energy levels (e.g., 0.2 J) while stone damage is mainly produced by the violent bubble collapse. Stone dusting efficiency may be futher improved by:

(1) Adjusting fiber-stone distance to maximize jet impact and water hammer pressure on the stone surface.

(2) Optimizing the combination of pulse energy, width, and frequency to improve cavitation induced damage.

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