Microscale shockwave characterization following dual threshold laser-induced breakdown

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Laser induced cavitation through a breakdown in liquid is extensively investigated for its important role in different technological and medical processes. The latter example is laser induced breakdown (LIB) assisted laser nano-surgery of cells and tissues for which an investigation was made on the formation of cavitation bubbles caused by the interplay of multiphoton and cascade ionization of water by the femtosecond laser [1]. It was shown that femtosecond laser pulses can produce a highly localized LIB, but according to [2], similar effect with an even lower energy conversion to mechanical effects can be achieved by using few tens of picosecond long excitation laser pulses.

In this work we have performed microscale shockwave characterization following LIB caused by the MOPA based fiber laser (pulse duration 60 ps at 515 nm wavelength) and monitored the cavitation bubble size and plasma. The detection of shockwaves and cavitation bubbles was realized by a laser diode short pulsed illumination system [3], while the pressure gradients and shockwave duration were measure by both a high performance custom-made optical hydrophone and a piezo-resistive sensor (results partially presented in Figure 1).

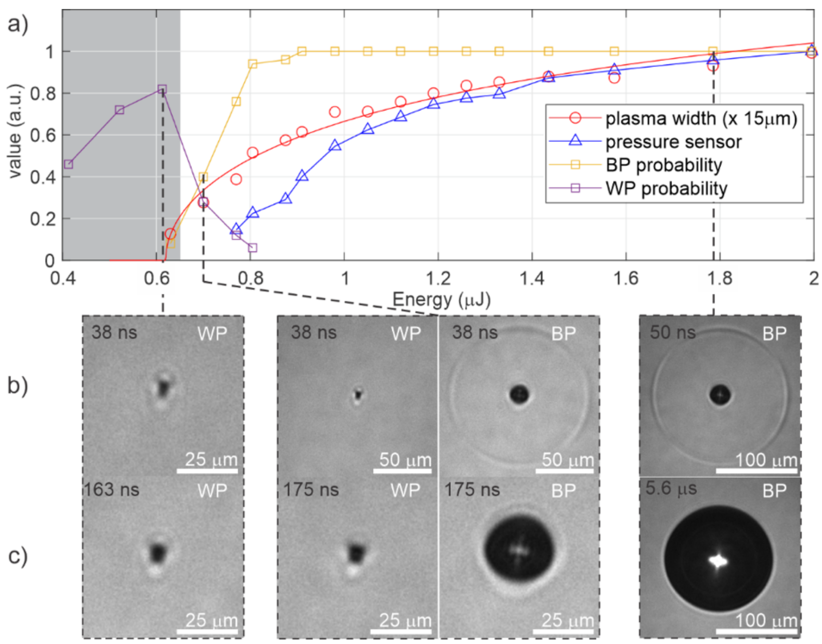

Fig. 1. Cavitation bubble generation in dependence to excitation laser energy. Plot a) shows measured plasma width, pressure sensor measurements and event probabilities for the bright plasma (BP) and weak plasma (WP) events. The row of images noted with b) show bubble with and without optically resolved shockwave formation right after the LIB while the c) row show images of the bubble nearing its maximum radius. At 0.7 μJ both event types can be detected. The black time values are the time stamps of the illumination pulse after LIB.

At excitation pulse duration of 60 ps, a weak overlap in time between the free electron population and the laser pulse can be expected [4], limiting the cascade ionization and heating up of the focal volume. Two types of events were observed when varying the excitation energy, either a few microns diameter cavitation bubble formation was observed above a certain minimal energy density threshold (WP event), or an approximately ten times larger bubble above a second energy density threshold (BP event). Fifty events at the same energy were captured at the 1s interval between laser shots, with the experiments repeated for each type of event at varied energies. The two event groups had a difference in the transferred laser energy to mechanical effects on the order of a few hundred times at minimal change in laser energy, placing the energy either above or below the second threshold. A sharp drop in the shockwave pressure was measured between the high energy and low energy bubbles. This can have a beneficial result in the reduced mechanical stress on the water-based media, such as tissues.

To confirm the cavitation events leading to low energy bubble formation, fifty shots were imaged at varied delay of the illumination system capturing the bubble growth dynamics and extracting both the maximum bubble radius and bubble lifetimes. From this a probability graph for the corresponding event type is shown in Figure 2.

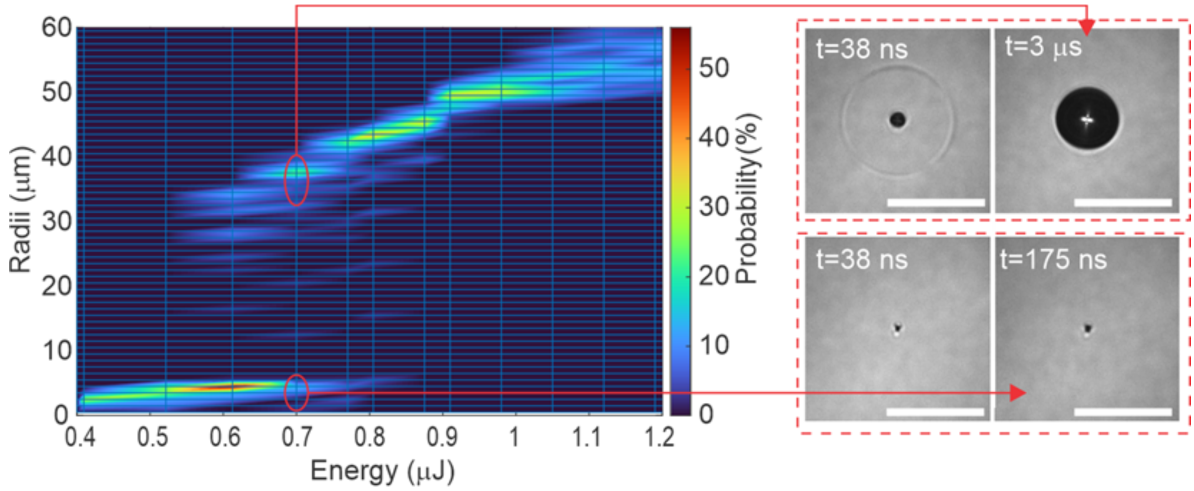

Fig. 2. Probability graph of produced cavitation bubble maximum radius vs excitation laser energy. Two groups of events were identified with notable difference in deposited excitation laser energy seen in cavitation bubble size difference and lifetime. The white scale bar equals 100 μm.

References

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