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TIME-RESOLVED STUDY OF LASER-INDUCED BUBBLES AND SHOCKWAVES IN AGAR GEL TISSUE PHANTOMS

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INTRODUCTION

Laser-tissue interactions have been extensively used in a number of biomedical treatments. However, the high optical absorption in tissue and the use of relatively long laser pulses or, in many cases, cw laser exposure, frequently results in excessive laser-heating producing undesirable collateral damage. Short pulsed lasers are one of the most precise tools for delivering energy and can allow for the greatest finesse [1]. Laser pulses with duration of only a few nanoseconds, and as short as a few hundreds of femtoseconds, seem to be a good alternative to minimize or even suppress laser-heating undesirable effects [2].

This work presents a time-resolved study of the interaction of short laser pulses with agar gel tissue phantoms. By using a pump-probe laser system, the phenomenon of laser-induced bubble formation in the agar gel is optically imaged onto a CCD; the design of the experimental set up allows us to record both the launching and the propagation of the shockwave that is the precursor to the bubble expansion. Laser-induced bubble formation and acoustic/shock wave propagation have been extensively investigated in water, whereas very few studies incorporate biological tissues or even tissue models such as agar gels [3,4].

EXPERIMENTAL SET UP

Our laser source is composed of a pair of Nd:YAG lasers that produce pulses of 9ns duration, at 532 and 1064nm wavelength. These lasers are conveniently set as a pump-probe system, and are synchronized through a pulse delay generator that allows setting probe to pump delays as short as 100ps; although we set our minimum delay to 10ns. In our experiments, the green (532nm) pulse is used as the pump pulse to excite the bubble formation, while the near infrared (1064nm) pulse is used to illuminate the interaction region. An optical imaging system consisting of a set of lenses and a CCD is used to image the target plane for every single pump pulse that is delivered on target. The agar gel phantom is placed on a computer controlled x-y-z translation stage (1μm step).

RESULTS AND DISCUSSION

We carried out time-resolved measurements, of both the bubble formation and shockwaves, with a resolution of a few nanoseconds starting at very early stages and lasting until the bubble size becomes quasi-stable. We can identify four distinct regions of interest, the shockwave propagation, the bubble formation, the bubble (partial) collapse and the quasi-stable bubble (see figure 1), which occur at distinct time scales of ns, μs and ms. In order to properly study these phenomena it is required to have the ability to set convenient probe to pump time delays. Our experimental set up possesses that feature, such that we can set delays of 10ns from 0 (pump pulse delivery) to 100ns for monitoring shockwave propagation speed, 200ns delays from 100ns to 1μs for monitoring maximum bubble size, 3μs delays from 1μs to 100μs for monitoring bubble partial collapse, and 30μs delays from 100μs to 1ms for monitoring quasi-stable bubble size.

Our results show that the launch of the shockwave occurs well within the pump pulse duration. A very interesting finding is that the higher the pump irradiance the earliest the shockwave is triggered; this is an indication that the mechanism that gives rise to the shockwave has a strong dependence on the pump pulse irradiance, which is in agreement with the claim by other authors that the bubble expansion has its origin in optical breakdown. Once the shockwave is launched, the bubble starts to form very rapidly, the bubble expands reaching its maximum in 1-10μs, only to partially collapse and to expand again, completing a few cycles, until it becomes to a quasi-stable size (figure 2).

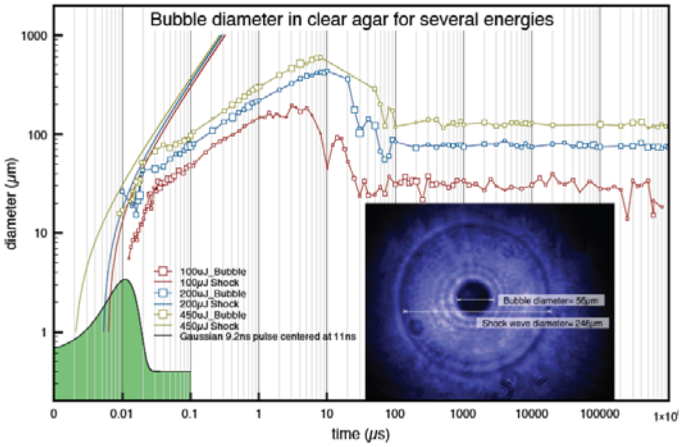

Figure 1. Bubble diameter and shockwave front as a function of time for several energies. The insert shows an image of both the shockwave front and the bubble expansion. The laser pulse is drawn to illustrate where within the pulse the shockwave and the bubble occur.

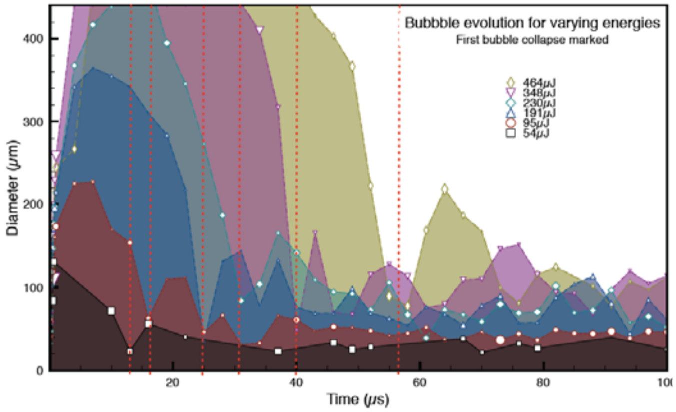

Figure 2. Bubble size evolution for several energies. Notice the cyclic expansion-collapse of the bubble.

There exists a well defined linear relationship between the maximum and quasi-stable size of the bubble for bubbles excited at different energies. The size of the bubble and the collapse period depends on both, delivered laser pulse energy and mechanical properties of the irradiated material. Also, our measurements show that the amount of energy coupled into the bubble is very small (less than 1%) as compared to the delivered energy (figure 3). The last is quite relevant in the context of medical applications since it implies very low, almost negligible, laser-heating of the tissue.

We will discuss the feasibility of the use of short laser pulses for microprocessing of tissue, with fine control of energy delivery and monitoring of time-resolved effects at very early stages with nanosecond time resolution. These time-resolved measurements would allow gaining insight on the understanding of the optical and biophysical mechanisms involved in the type of laser-matter interactions depicted in this work.

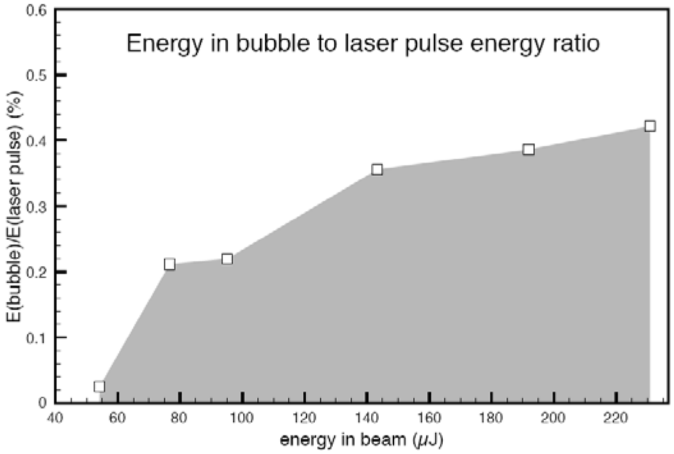

Figure 3. The ratio between energy in the bubble and the laser pulse energy delivered on target.

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