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Early dynamics of laser-induced cavitation bubble induced in laser ablation of solid in water

Động học sớm của bóng khí sinh ra trong quá trình phá hủy chất rắn trong môi trường nước

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Abstract

In this study, we observed the evolution of a cavitation bubble induced by focusing a nanosecond-pulsed laser on an epoxy-resin surface using a photoelasticity imaging technique. The radius-time curve of the bubble within the first 1000 ns was reported for different pulse energies from 20 to 60 mJ. The result showed that the bubble expanded faster at higher laser energy but followed a simple rule $R{\sim}at^{0.3}$

Keywords: Photoelastic images; laser-induced cavitation bubble; expansion rate.

Tóm tắt

Trong nghiên cứu này, chúng tôi quan sát sự phát triển của một bóng khi sinh ra khi hội tụ một xung laser nano giây lên trên một bề mặt epoxyresin bằng phương pháp chụp ảnh quang đàn hồi. Đường cong bán kính-thời gian của bóng khí trong khoảng 1000 nano giây đầu tiên đươc ghi lại ứng với năng lượng xung laser từ 20 đến 60 mJ. Kết quả cho thấy bóng khí giãn nở nhanh hơn khi năng lượng xung cao hơn, tuy nhiên tuân theo một quy luật đơn giản $R{\sim}at^{0.3}$.

Từ khóa: Hình ảnh quang đàn hồi; bóng khí sinh ra bởi tia laser; tốc độ giãn nở.

1. Introduction

When focusing a pulsed laser onto a solid target immersed in a liquid, first, the laser ablates the material and forms a high-pressure plasma. This high pressure, high-temperature plasma imitates a cavitation bubble that expands and collapses many times on the solid target [1]. Even though the evolution of laser-induced cavitation bubbles in liquids has been widely reported in the literature, some critical mechanisms are still poorly understood. Thus, the laser-induced cavitation bubble is still a subject of continuous interest.

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Conventionally, the dynamics of laser-induced cavitation bubble is studied at late stages, when the bubble reaches its maximum radius and collapses [2]–[4]. The observation of the early dynamics is rarely reported. In this work, we aim to advance the understanding of the early dynamics of laser-induced cavitation bubble by providing observation of the evolution of the bubble within the first 1000 ns after irradiation. The radius-time curve was also studied with the pulse energy regulated from 20 to 60 mJ. With the high-resolution photoelasticity imaging technique, we provide a sufficient description of the early dynamics of the laser-induced cavitation bubble in the liquid-ablation phase.

2. Material and methods

A hemispherical cavitation bubble was induced by mg. focusing a laser beam (1064 nm, 13 ns in FWHM) on to an epoxy-resin block in pure water. The laser pulse energy was regulated from 20 to 60 mJ. The epoxy-resin blocks have a dimension of 5.8x22x28 mm3. The evolution of the cavitation bubble was observed by using a custom-designed photoelasticity imaging technique. The imaging system is similar to our previous report [5] and only a brief description is provided here. We used a pump-and-probe system with a polariscope added to provide a photoelasticity image. An ICCD camera was used together with a set of Neutral-Density filters as a recording device. The camera gate width was 40 ns. The delay time was defined as the interval between the pump and probe pulses and was adjusted by a delay generator. The evolution of the bubble was observed in 1000 ns after irradiation with the time-resolution of 100 ns.

3. Results and discussions

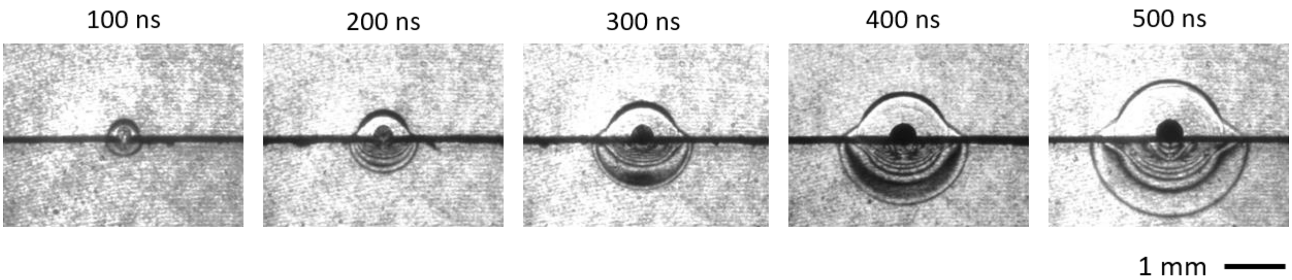

Figure 1: Evolution of laser-induced cavitation bubble at early stage. Pulse energy: 20 mJ. Laser came from above.

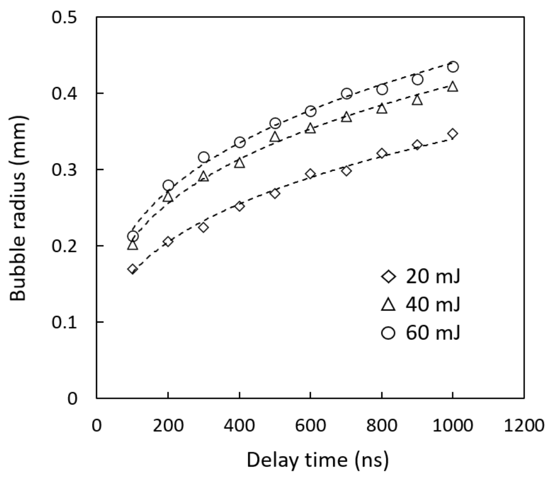

Figure 2: Change of bubble radius with time, observed at different pulse energies. The dashed lines are fitting curves by the power rule..

Figure 1 presents the evolution of a cavitation bubble within the first 1000 ns after irradiation. The pulse energy was 20 mJ. The black horizontal line in the middle of the image is the target surface. The upper half is the water and the lower half is solid. At 100 ns delay time, the shock-wave front and the cavitation bubble can be distinguished. The shockwave front appears in the liquid as the sharp black curve. The cavitation bubble appears in the image as the tiny black hemispherical, located inside the shock wavefront. The shock wave traveled into the water at supersonic velocity, rapidly outdistancing the cavitation bubble. The bubble expanded with time, at a much slower rate in comparison to the shock wave. In the solid phase, a stress wave can be observed as semi-circles rapidly expanding into the target. The image of the stress wave in the solid phase includes a pressure wavefront followed by photoelastic fringes. The dynamics of stress waves have been described in detail in our previous work [6].

The bubble radius was measured and plotted as a function of time. Figure 2 summarizes the radii variation of the cavitation in water from 100 to 1000 ns after irradiation for different pulse energy from 20 to 60 mJ. From the figure, we found that the bubble expanded faster with increasing pulse energy. We also found that the early changes of bubble radius R with time t can be well fitted by a simple relationship:

$$R = at^{0.3} \quad (1)$$

Where is a constant chiefly dependent on the pulse energy. This simple expression allows to estimate the bubble expansion velocity as:

$$v = \frac{d_R}{d_t} = 0.3at^{-0.7} \quad (2)$$

These simple expressions will be useful for further analysis of the bubble pressure distribution during the early stages using Rayleigh-Plesset equation, which is the topic of our research in the future.

4. Conclusions

By using a custom-designed photoelasticity imaging technique, we have provided a direct observation of the early dynamics of a laser-induced cavitation bubble in liquid ablation phase. The result shows that the bubble expand faster with higher pulse energy. The early change of bubble radius with time can be well fitted by a simple relationship, which is useful for further investigation of the pressure distribution within the bubble.

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