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Propagation of Laser-induced Emergent Stress Waves Generated by High-energy Nanosecond Laser Pulse Irradiation in Confined Structure

閉じ込め構造中において高強度ナノ秒レーザパルス照射で発生するレーザ誘起創発的応力波の伝搬

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1. Introduction

Laser-induced emergent stress wave (LIESW) has been interested as one of promissing candidates for gene transfer into mammalian cell [1, 2]. LIESW with compressive stress can generate in a black natural rubber (NR) sheet coverd with a poly(ethylene terephthalate) (PET) sheet as transparent material, when a high-energy laser pulse with nano-order duration is irradiated to the NR surface through PET sheet.

Recently, we have reported the dynamic behavior of an impulsive acoustic wave propagating through NR sheet with several thicknesses [3], and also revealed the effect of an adhesive layer between PET and NR on the acoustic signature of LIESW [4]. It is expected that LIESW can propagate in the medium with the velocity faster than its sound speed because of shock wave formation. In this paper, we investugated the velocity of LIESW propagating from the confined structure composed of PET and NR.

2. Experimental procedure

PET/NR structure was used as laser target, in which 1-mm-thick PET sheet was stuck on a NR sheet (area : 10x10 mm^2) by using epoxy resin as adhesive. The NR sheets with the thickness of 0.53, 1.1, 2.1, and 3.2 mm were used in order to measure the propagation velocity of LIESW. A constructed structure for observing the acoustic signature is shown in Fig. 1. A 110-μm-thick poly(vinylidene difluoride) (PVDF) transducer (Tokyo Sensor) sticking to a 10-mm-thick NR as absorber was fixed on a laser target of PET/NR structure, in which the gel was also used for reducing the reflection of LIESW at interface.

Q-switched Nd:YAG (Spectra Physics, LAB-130) was used as laser source, in which the wavelength of laser light was 532 nm of second-harmonic generation. A laser pulse with about 10-ns-duration was focused on the NR surface of PET/NR structure through neutral density (ND) filter and a lens. A focused beam size was approximately 2.3 mm in diameter and the pulse energy was changed by using ND filter with different transparency. The maximum output pulse energy to the single shot operation was about 0.14 J in this experiment. The acoustic signature of LIESW was observed as temporal profile of voltage signal from PVDF transducer by using 0.5 GHz digital oscilloscope (Iwatsu-LeCroy, LT342L).

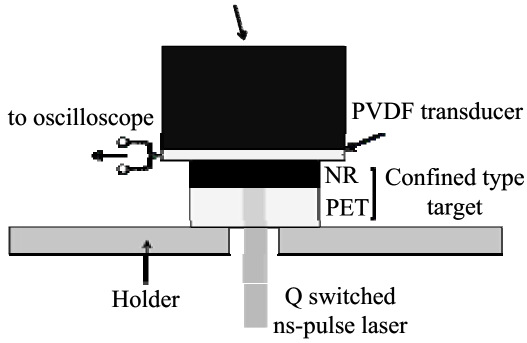

Fig. 1 Illustration of a constructed structure.

3. Results and discussion

At first, peak voltage variations of LIESW in the confined-type target using 0.53-mm-thick NR sheet were measured as function of the laser fluence in the range between 0.65 and 2.15 J/cm^2. The peak voltage as well as the ablation pressure [5] was proportional to the 0.7-th power of fluence, therefore, we can declare that the peak voltage of LIESW in the confined structure depends on the ablation pressure.

Figure 2 shows the time dependence of the rising edge of LIESW as function of NR thickness, in which the laser fluence is kept at 3.34 J/cm^2. The estimated propagation velocity of LIESW through NR sheet was 1.8-1.9 km/s, whereas that of the impulsive acoustic wave in the direct-type target

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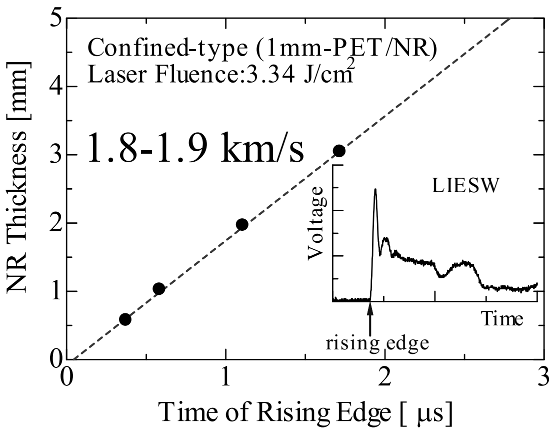

Fig. 2 Time dependence of the rising edge as function of NR thickness at a fluence of 3.34 J/cm^2.

(NR sheet without PET) was 1.59 km/s [3] when the least square fitting was applied to the obtained results. This value was much larger than a sound speed of bulk NR (1.546 km/s).

In our experiment of LIESW treatment to the mammalian cells, a glass-base dish is used in order to imprison the cells in a culture. A laser target is fixed on the outside surface of a glass-base dish, therefore, LIESW propagates in the mammalian cells and a culture through a glass plate as shown in Fig. 3.

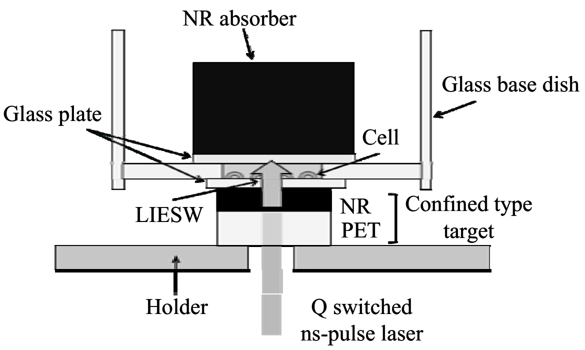

Fig. 3 Illustration of LIESW treatment to the mammalian cells using a laser target and a glass-base dish.

Figure 4 shows the temporal profiles of LIESW at the respective parts in the structure composed of the target and glass-base dish, in which the acoustic signatures at the backside NR of the target, at 0.16-mm-thick glass plate placing on the target, and at 0.16-mm-thick glass plate through water in the dish were displayed. The propagation time of LIESW through a 0.11-mm-thick glass plate of dish and water layer (1.32 mm in depth) was about 0.77 μs when the time difference of the rising edges was use. This propagation time is almost

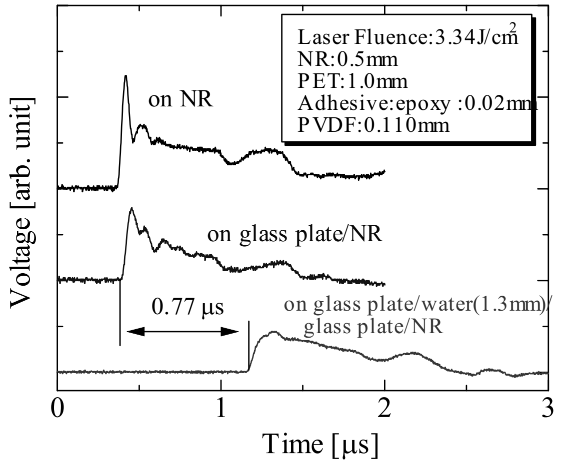

Fig. 4 Typical temporal profiles of LIESW at the respective parts in the structure composed of the confined-type target and glass-base dish. The NR thickness and the laser fluence are 0.53 mm and 3.34 J/cm^2, respectively.

equal to that in water region because the glass plate is much thinner than the water layer, therefore, the estimated propagation velocity of LIESW in water was approximately 1.9 km/s. The sound speed of water at the temperature of 25 ^{o}C is 1.497 km/s [6], therefore, we declare that LIESW with shock speed propagates in water of a glass-base dish through the target.

4. Conclusion

We conclude that LIESW generating in the confined region by high-energy nanosecond single pulse irradiation propagates with shock speed in the target and in a water of a glass-base dish.

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