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Research for engineering applications of laser-induced thermal waves and emergence stress waves

レーザによって誘起された熱波と創発的応力波の工学応用に関する研究

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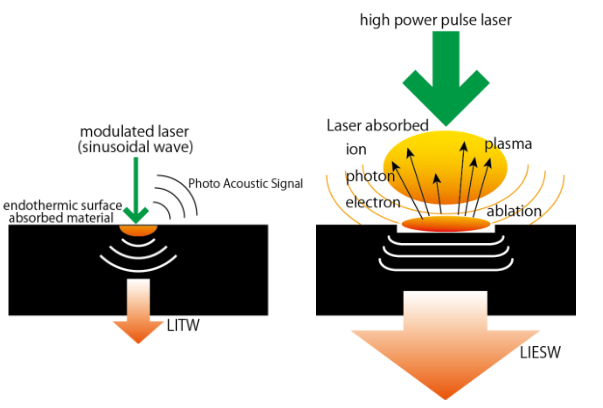
1. Introduction

Through the invention of various lasers and advanced materials, investigators in many engineering fields have given considerable attention to the photothermal (photoacoustic) effects caused by the interaction between lasers and target materials. Engineering applications of laser-induced thermal waves (LITW) and laser-induced emergence stress waves (LIESW) have also been developed. [1-3] These waves can be generated easily by selective combination of a laser and a target material. In this paper, we represent the characteristic difference between LITW and LIESW and then better combinations of target materials and lasers.

2. Generation Method of LITW and LIESW

Figure 1 shows principles of the generation method of LITW and LIESW. [4] The lasers and the target materials we used in the experiments were summarized in **Table I**. We used He-Ne laser, Ar laser, and Nd:YAG pulse laser as energy sources for transforming light to heat.

The conditions of the target material are described as follows. Surface absorption of the laser light is strong, and the conversion efficiency to heat is high. For LIESW generation, it is also necessary that the thermoelasticity modulus of the target material is large. In addition, it is important in the engineering application that the target material is inexpensive and easily obtained.



(a) LITW (b) LIESW
Fig. 1 Principles of generation method of LITW and LIESW.

The photoabsorption thicknesses of graphite (GP) and natural rubber (NR) are 12.6 μm and 35.7 μm, respectively, making them endothermic surface absorbing materials. Obtaining these materials is easy, and their price is several hundred yen each.

Table I List of lasers and target materials used in our experiment.

Generated Wave	Laser / Power (Company, Type)	Target Material (Company, Type)
Thermal Wave (LITW)	He-Ne / 10 mW (Spectra Physics, Model1127)	Graphite (Toyo Tanso, ISEM-3)
	Ar-ion / 10 mW (Spectra Physics, Stabilite2017)	
Emergence Stress Wave (LIESW)	Nd:YAG / 2.5 J/cm^2 (Spectra Physics, Lab-130)	Natural Rubber (Best Sound Lab, NR-4)

3. Engineering Applications of LITW and LIESW

3.1 Application of LITW

Figure 2 shows an example of an engineering application of thermal waves (TW). A graphite and a He-Ne laser were used as a target material and a laser source. However, an acousto-optic modulator must be used to transform sinusoidal waves ranging from 2 Hz to 1000 Hz to a continuous wave of laser light because thermal waves generally use a sinusoidal wave. The thermal diffusivity α can be estimated by measuring the

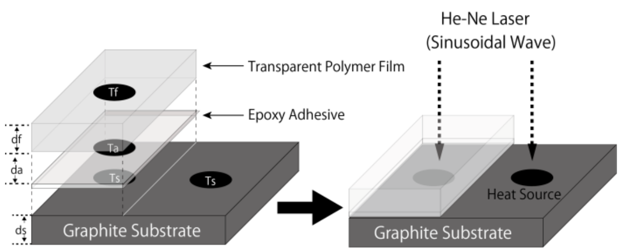


Fig. 2 Configuration for measurement of thermal diffusivity in transparent polymer films.

phase difference of the thermal wave propagated in polymer and the heat source of the graphite surface formed by laser irradiation.

Table II shows estimated values of thermal diffusivities of five polymers: polyethylene terephthalate (PET), polycarbonate (PC), polyethylene (PE), polypropylene (PP), and polyviniliden fluoride (PVDF). Each value came within a one percent error margin in the thermal diffusivity of all the polymer films. The effectiveness of this method in determining the thermal diffusivity measurement of the transparent polymer film became clear. [5]

Table II Results of estimated value of thermal diffusivity in our experiments.

Material (Company)	Film Thickness d_0 [μm]	Thermal Diffusivity $\alpha \times 10^{-8}$ [m^2/s]	
		Estimated Value	Literature Value
PET (DuPont Teijin Films)	100	10.1	9.4
PC (DuPont Teijin Films)	100	12.2	12.1
PE (Asahi Kasei)	54	15.8	16.0
PP (Kokuyo)	58	5.0	5.3
PVDF (AMP)	52	5.8	5.4

3.2 Application of LIESW

Figure 3 shows an example of an engineering application of LIESW. This device was adhered under a glass-base dish that immobilized HeLa cells. Natural rubber was used as a target material and Nd: YAG pulse laser was used as an energy source. Using this system, an experiment for transfection of plasmid DNA into HeLa cells was carried out. [6] **Figure 4** shows a typical temporal profile of the PVDF transducer signal when PVDF is placed on the back of the target device. The experiment results of gene transfection into HeLa cells are summarized in **Table III**.

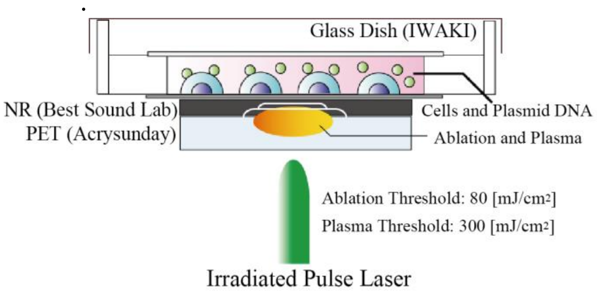


Fig. 3 Configuration for transfection of plasmid DNA into HeLa cells.

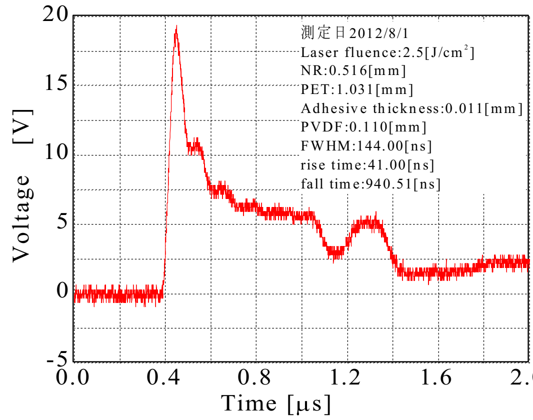


Fig. 4 Temporal profile of the acoustic signature of LIESW.

Table III Experiment results of gene transfection into HeLa cells

Contents	Results
Gene transfection efficiency	3 %
Cell survival rate with LIESW (without LIESW)	70 % (95 %)

4. Summary

We described engineering applications of LITW and LIESW. We found that these waves can be generated easily by selective combination of a laser and a target material.

Acknowledgment

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