

ACOUSTICAL LETTER

In vivo detecting of photo-thermal signal in a living leaf of a plant of a scheffelera arboricola by handmade sensor using polyvinylidene fluoride film

Yoshiaki Tokunaga[1], Masatoshi Yoshimura[1], Akiko Ujiie[3], Kaori Sakamoto[2] and Junji Hirama[1]

[1]*Department of Electrical Engineering and Electronics, Kanazawa Institute of Technology, 7–1 Ohgigaoka, Nonoichi-machi, Ishikawa, 921–8501 Japan*
[2]*Department of Applied Bioscience, Kanazawa Institute of Technology, 7–1 Ohgigaoka, Nonoichi-machi, Ishikawa, 921–8501 Japan*
[3]*General Art of Kanazawa Technical College, 2–270 Hisayasu, Kanazawa, 921–8601 Japan*

(*Received 29 June 2010, Accepted for publication 13 November 2010*)

Keywords: Plant, Kapok, PVDF film sensor, Photosynthesis, Photoacoustic signal
PACS number: 43.35.Ud [doi:10.1250/ast.32.118]

1. Introduction

Important and urgent problems such as heating crisis by CO_2 increment, food shortage have been happened around us. Unfortunately, we have no answer to solve immediately to these problems. However, we can discuss possibilities of new some ways for germination. One of keys being considered in order to solve these problems is to look at photosynthesis of plant again twice from engineering standpoint [1]. Although photosynthesis is very important things for all life on the earth, it is very difficult to investigate in order to solve the photosynthesis of a plant which belongs to a complex system.

It is well known that photosynthesis is due to photochemical reaction in a plant induced by sunlight in fields of agriculture and biology. On the other hand, from a viewpoint of microscopy, it is considered that it is mainly caused by dynamic interaction with irradiated photons and electrons in the living leaf. We have discussed the ways to introduce photoacoustic or photothermal spectroscopy for investigation of photosynthesis. In this study, we have considered that thermal phonon may also be related in this effect. Our research style is a based on analysis of excess thermal phonon concentration caused by irradiated laser beam with limited wavelength. Up to now, we have attempted to observe thermal phonon by methodology of photoacoustic spectroscopy [2]. Historically, from investigations have been already done, photoacoustic spectroscopy and microscopy are useful to study surface and inner information at various solid states such as semiconductor, polymer, metal and so on [3]. A microphone was commonly used as a detector in above investigations [4]. We want to investigate photosynthesis of plant by reformation of our system with a microphone. However, the microphone needs a closed PA cell for entering sample in order to detect vibration of gas pressure in it. Unfortunately, this methodology cannot be used for an organism since a size of sample must be measured is limited in a scale by cavity of PA cell used. A leaf's size entered in the PA cell must be determined artificially before measurement because we cannot be ignored a size of cavity of a PA cell. This process allows us to give important meaning. Therefore, leaf cut artificially is running toward death from life. From above reasons, detecting the PT signal from the leaf of plant in a nature field by microphone PA method seems to be very difficult from above reasons. So, we discuss to use the PVDF film sensor instead of microphone to avoid this difficulty. In this paper we describe to carry out an experiment in order to confirm which employment of the PVDF film sensor is reasonable or not. We first describe on the scheffelera arboricola "Kapok" and then handmade PVDF sensors for measurement. Final, we show that the amplitude or the phase of the PT signal detected from top or back side of the leaf when laser beam at 570 (green wavelength) or 633 nm (red wavelength) was irradiated to a mentioned point in top of the leaf.

2. A plant "Kapok"

Figure 1 shows a photograph of a living kapok. Because of reasons which it is not deciduous tree and also safety and strong, we can measure effectively optical and physical behaviors since it is kept in stable state of life during a year [5].

Figure 2 shows a schematic diagram based on explanation of physical phenomena, already published, in the case of irradiation of the sunlight to leaf [6]. When the sunlight is irradiated to top side of the leaf, small portion of irradiation energy may be reflected from it and also energy component without reflection may be injected into the leaf and absorption in there. In addition, portion of the energy component absorbed may be used as chemical reactions for life, and remainder may be used as luminescence or thermal radiation.

3. PVDF film sensors

Figures 3(a) and (b) show a schematic diagram on two kinds of the PVDF film sensors made for detecting the PT signal in the leaf. One is used for measurement of the PT signal radiated from the top side and another for measurement of the PT signal radiated from back side of the leaf. The former sensor is formed a transparent window with, removal of Ni-Cu metal electrode, $3\,mm^2$ diameter in center portion of whole area of the PVDF film. Laser beam was irradiated to the living leaf after passing through this portion. Dimension of sensor was about $10 \times 10\,mm^2$. Representative thickness of PVDF film was around $110\,\mu m$. An electrical signal from the PVDF film sensor was detected

Fig. 1 Photograph of kapok.

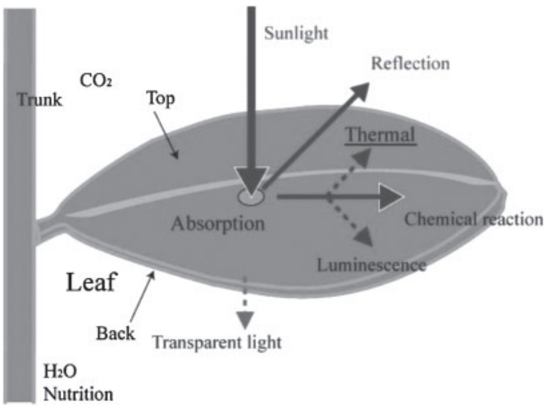

Fig. 2 Schematic diagram for explanation of physical phenomena in irradiation to leaf surface.

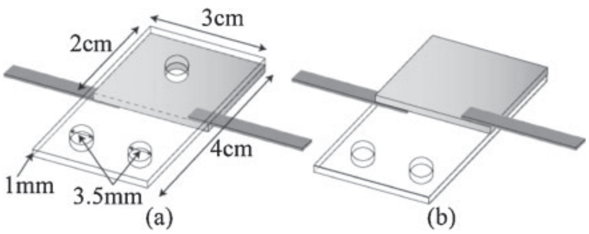

Fig. 3 Schematic diagram on two kinds of PVDF film sensors. (a) for top detection. (b) for back detection.

by two Ni-Cu electrodes contacted opposite side to suppress electric noises.

Figure 4 shows a measurement method of the PT signal from the leaf and a configuration of the PVDF film sensor in a practical use. Dimensions of the leaf were $4.8 \times 7.0\,cm^2$. The leaf measured was set in a position between two PVDF film sensors. In this case, the contact method between the leaf and the two PVDF films was direct one without any adhesive since use of the adhesive may set in limit to CO_2 intake or O_2 excretion of stomata in top and back sides of the leaf.

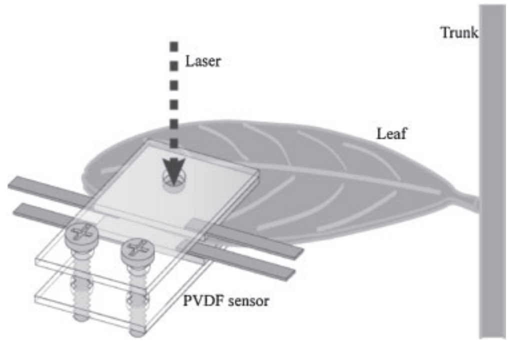

Fig. 4 Leaf and a configuration of the PVDF film sensor in a practical use.

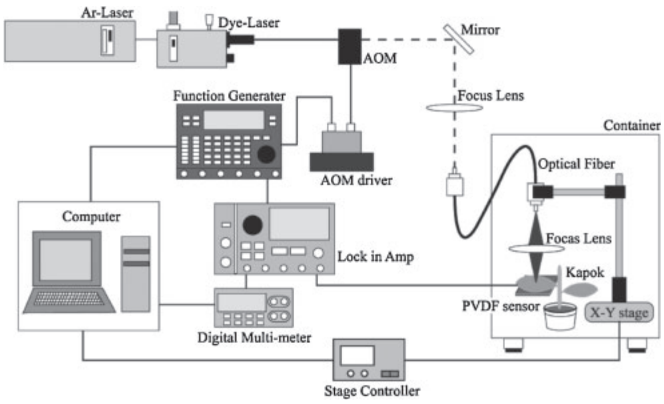

Fig. 5 Block diagram of measurement system.

4. Experimental setup

Figure 5 shows a schematic diagram of measurement system used in our experiment. Our main apparatus were as followings: Dye laser (Spectra physics, 375B) excited by Ar ion laser (Spectra physics, Stabilite 2070) was used as a light source. Dye laser beam modulated sinusoid ally by acousto-optic modulator (HOYA, A160) controlling by a function generator (NF, WF1946B) was irradiated on the top of the living leaf using optical fiber (Edmund optics, OPTFIBER UV/VIS). The laser beam diameter irradiated on the surface of the living leaf was about 3 mm. A shift of the laser beam was done in a *X*-*Y* stage controlled by a personal computer. After the PT signal from the top or the back of the leaf was detected by the PVDF film sensor, it was treated signal processing by lock-in amplifier (NF, LI-574A).

The Kapok was set at always 25 degree of temperature in an air closed and light shunt container.

5. Experimental results

Figures 6(a) and (b) show dependence of laser modulation frequency (f-dependence) of amplitude of the PT signal measured in top and back sides of the leaf when laser with 570 or 633 nm is irradiated on top of the leaf. It was found that f-dependence on the amplitude of the PT signal at top side of the leaf were both -0.97 in ranging from 10 to 100 Hz. In addition it was found that amplitudes of the PT in the irradiation of 633 nm were lower than those of 570 nm

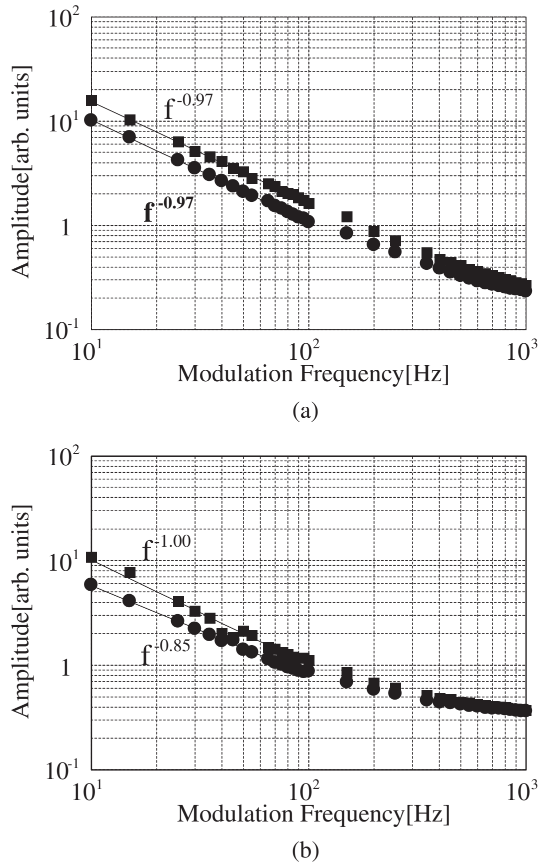

Fig. 6 Measured result on f-dependence of amplitude of PT signal (●: 633 nm, ■: 570 nm). (a) top detection. (b) back detection.

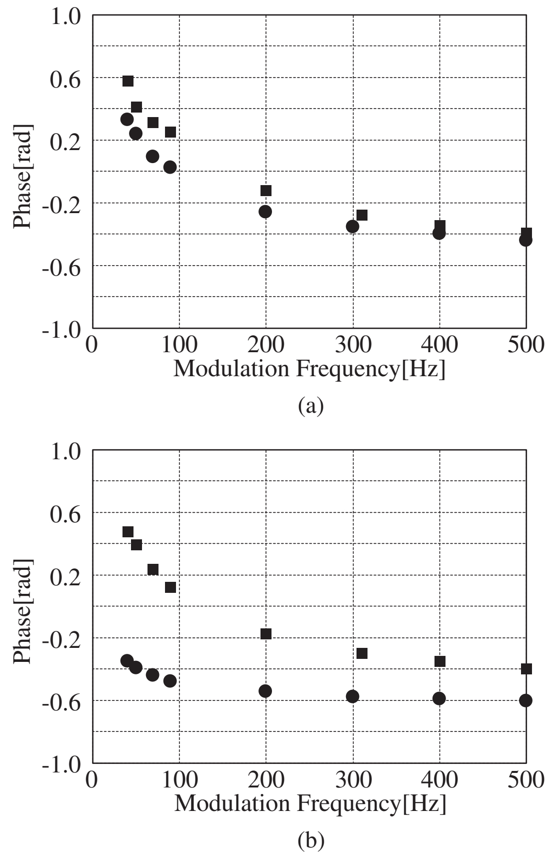

Fig. 7 Measured results on phase of PT signal (●: 633 nm, ■: 570 nm). (a) surface detection. (b) back detection.

irradiation. On the other hand, f-dependence on amplitudes of the PT signal measured in back of the leaf were different with -1.00 at 570 nm and -0.83 at 633 nm in ranging from 10 to 100 Hz. As fact must be emphasis we found that amplitude of the PT caused by irradiation of 633 nm was lower than that of 570 nm. This deviation seems to be relation with energy absorption due to photosynthesis. Figures 7(a) and (b) show measured results on phase of PT signal from top and back. As shown in Fig. 7(a), phase differences between with 570 and 633 nm in ranges from 10 to 100 Hz were small amounts. On the other hand, in back of the leaf phase delays of the PT signal caused by 633 nm irradiation were larger than those of 577 nm in ranging from 10 to 100 Hz as shown in Fig. 7(b). From above experimental results proposed method allows us to contain higher possibility for investigating some information on photosynthesis of the leaf. We are now studying these phenomena in details.

6. Summary

We described experimental results of amplitude and phase of the PT signal, measured by the PVDF film sensors, from top or back in the leaf of "Kapok." Obtained results were as following: f-dependence on amplitude of the PT signal were both -0.97 at 570 or 633 nm irradiation in top of the leaf and f-dependence on the amplitude of PT signal in back of the leaf were -1.06 at 570 nm and -0.83 at 633 nm irradiations in ranging from 10 to 100 Hz. Phase delays of the PT signal at 633 nm irradiation was larger than those of 570 nm irradiation in ranging from 10 to 100 Hz.

References

[1] Photosynthesis Education Team, *The Science of Photosynthesis* (The University of Tokyo Press, Tokyo, 2007) (in Japanese).

[2] Y. Tokunaga, M. Yoshimura, Y. Ishimaru and J. Hirama, "Research on photo-thermal signal of a scheffelera arboricola caused by Dye laser radiation," *Proc. Symp. Ultrason. Electron.*, **29**, 153 (2008).

[3] A. Mandelis, *Progress in Photothermal and Photoacoustic Science and Technology*, Vol. I, *Principles & Perspectives of Photothermal & Photoacoustic Phenomena* (Elsevier, Tronto, 1992).

[4] A. Rosencwaig, *General Theory of the Photoacoustic Effect in Condensed Media: The Gas Microphone Signal, Photoacoustics and Photoacoustic Spectroscopy* (Wiley, New York, 1980), p. 93.

[5] J. Hirama, M. Onodera, T. Hamamoto, N. Takahashi, H. Miura, T. Miyamoto and N. Hirota, "Behavior of the bio-electric potential on the leaf for the $1/f$ fluctuated light stimuli," *J. Shita*, **9**, 103–106 (1997) (in Japanese).

[6] K. Shibata, *Hikari to Syokubutsu* (Baifukan, Tokyo, 1982), p. 27 (in Japanese).