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Estimation of Thermal Diffusivities of High Polymer Transparent Films by Laser-Induced Thermal Wave

レーザ誘起熱波による高分子透明膜の熱拡散率の推定

Akiyuki Minamide [1†], Hiroyuki Kobayashi [2], Masatoshi Yoshimura [2], Koji Aizawa [2], and Yoshiaki Tokunaga [2] ([1] Kanazawa Tech. College, [2] Graduate School, Kanazawa Inst. of Tech.)
南出章幸 [1]，小林弘幸 [2]，吉村政俊 [2]，會澤康治 [2]，得永嘉昭 [2] ([1] 金沢高専，[2] 金沢工大院)

1. Introduction

Recently, transparent polymer films are being widely used in the industrial world. To understand the utility of the films, it is necessary to clarify not only their mechanical but also their thermal properties. At this point, however, even thermal diffusivity, a fundamental physical property, has not been thoroughly examined.

We have developed a scanning photoacoustic microscope (SPAM) and since 1989 have employed it in the study of material characteristics [1-2]. Unfortunately, while the bulk material can be evaluated using the SPAM, transparent high polymer films cannot [3-5].

The primary goal of our present research is to develop a type of multi-purpose laser-induced thermal wave microscope (LITWM) that can be used for these films and for biomaterials comprehensively. As a first step in development, we intend to devise a thermal diffusivity measurement technique for high polymer transparent films.

In this paper, using our proposed method, we describe the experimental results on values of thermal diffusivity for high polymer transparent films.

2. Sample preparation and experimental setup

Figure 1 shows a configuration of an experimental sample and a photograph. The laser is irradiated to two parts with and without a transparent film: (P_1) and (P_2), respectively. At the P_1, the modulated laser is not absorbed in the transparent film, yet is absorbed at the surface of the opaque substrate. A thermal wave (TW) is generated from the substrate surface, and a part of the TW propagates in the transparent film and thereby causes a temperature change on the film's surface. The phase of the TW signals in P_1 and P_2 were measured to estimate the thermal diffusivity of the transparent film, and those phase differences θ were calculated [6].

minamide@kanazawa-tc.ac.jp

We used a carbon material as a black substrate (Toyo-tanso Co., Ltd., ISEM-3). The dimensions of the substrate were 10 × 10 ×5 mm^3. The tiny air gap exists between the substrate and the transparent film when the film is put on the substrate. **Table I** shows TW impedances of each material. Because the TW impedance of the carbon is about 2500 times as large as that of air, the TW cannot efficiently propagate to the film. Therefore, the transparent film was affixed to the substrate using an epoxy adhesive. Refer to Ref. [7] for the measurement system.

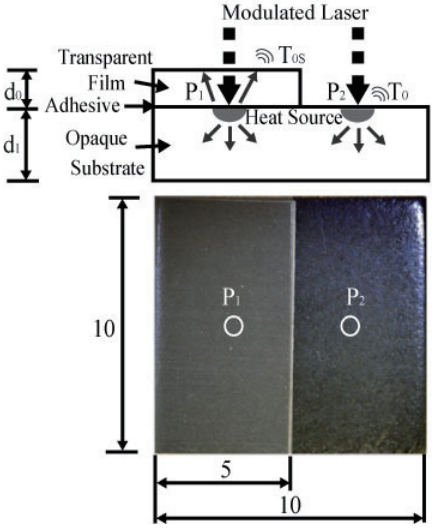

Fig. 1 Configuration of sample and an experimental sample

Table I Comparison of TW impedances of each material (Modulation frequency:10 Hz)

Material	TW impedance
Carbon	1.1×10^5
Air	4.4×10
Epoxy resin	4.6×10^3

3. Results and discussion

First of all, we examined whether the measurement of the TW signal depended on the interfacestute of the opaque substrate. The surface of the carbon substrate was artificially altered with an abrasive, and the modulation frequency (f)

dependence of the TW signal was measured under each condition. **Table II** shows these experiment results. The TW signal amplitude obtained was $f^{-0.9}$ dependence, and it was almost the same as the $f^{-1.0}$ dependence according to the R-G theory. Therefore, the TW signal amplitude did not depend on the interfacestute of the carbon substrate.

Table II The TW signal depended on the interfacestute of the opaque substrate

Abradant	f dependence of TW signal
Alumina powder 1, 0.3, and 0.06 μm	$f^{-0.9}$
Alumina powder 1 and 0.3 μm	$f^{-0.9}$
Alumina powder 1 μm	$f^{-0.9}$
without Alumina powder (emery paper only)	$f^{-0.9}$

Figure 3 shows the experimental results on the relation of θ and $\sqrt{f}$ when a 58-μm-thick PVDF film is used. In the condition that a ratio of the film thickness (d_0) and the thermal diffusion length (μ_0) is from 1.2 to 2.0, we obtain the approximation straight line [6]. From a slope of this line, we can calculate the thermal diffusivity (α_0) and obtain a value of 4.5×10^{-8} m^2/s. The value is smaller than expected from parameters published by the PVDF polymer maker [8]. Next, we experimented by using polyethyleneterephtalate (PET) and poly imide resin (PI) to examine this cause.

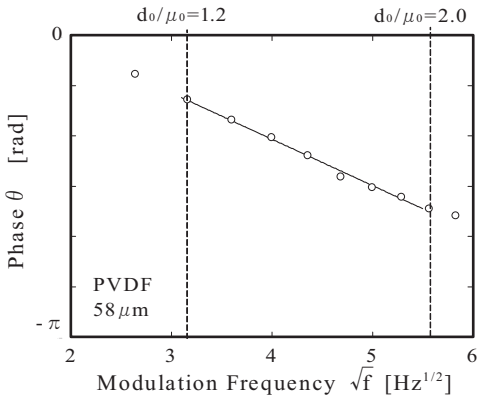

Fig. 3 Relation between θ and $\sqrt{f}$ in the 58μm-thick PVDF film

Figure 4 shows the experimental results in the PET film. **Table III** shows representative data on measured films. In this table the symbol "α" represents thermal diffusivity calculated from the parameters published by the maker. In the cases of PET and PI, the obtained thermal diffusivities agreed with those values α.

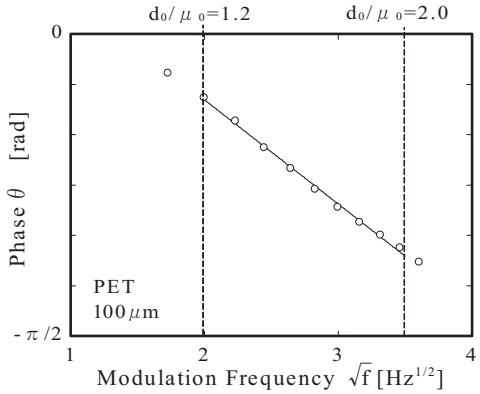

Fig. 4 Relation between θ and $\sqrt{f}$ in the PET film

Table III Measured results of α_0 on various films

Film	d_0 [μm]	α_0 [m^2/s]	α [m^2/s]	Company
PVDF	58	4.5×10^{-8}	7.9×10^{-8}	Tokyo Sensor
PET	100	11×10^{-8}	9.4×10^{-8}	Teijin Chemicals
PI	25	13×10^{-8}	10×10^{-8}	DuPont Toray

4. Conclusion

We described the experimental results on the thermal diffusivities of high polymer transparent films such as PVDF, PET, and PI as measured by our proposed method.

Acknowledgements

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