UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF COMPUTERIZED PHOTOFLASH METHOD FOR THERMAL DIFFUSIVITY MEASUREMENT

THAI MING YEOW

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By

THAI MING YEOW

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

October 2007

DEDICATION

To my dearest parents Thai Qui Yoong and Wong Ah Mooi

for their supports and concern……

To my beloved Fong Mei Mei

who loves and support me all the times...

To my supervisors

Assoc. Prof. Dr. Zaidan Abdul Wahab, Prof. Wan Mahmood Mat Yunus
and
Prof. Mohd. Maarof Moksin

for their guidance and advice…

To all my friends

for their assistance and supports…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman: Associate Professor Zaidan Abdul Wahab, PhD

Faculty: Science

Thermal diffusivity, α is a parameter that characterizes the rate of heat diffusion in the material due to heat flux in an unsteady-state process. Flash method was introduced by Parker et al (1960) as a fast and economical method for determination of thermal diffusivity. A computerized experimental system was constructed in this project to simplify and expedite the experimental process for determination of thermal diffusivity of solid samples at room temperature.

In conventional photoflash method, a high intensity photoflash was used as the energy pulse source. A thermocouple wire was used to monitor the temperature of the rear surface of the sample and captured by an oscilloscope. The calculation of thermal diffusivity value could be done either manually or with the aid of several software tools.

The present work replaces these lengthy processes by automating the firing of the photoflash and the capturing of temperature-time data of the sample rear surface. A Personal Computer equipped with a National Instrument DAQ (Data Acquisition)

card plays its role as a control center to control and monitor the experiment process from firing of flash to the completion of thermal diffusivity determination.

Various electronics circuits were studied and developed in order to facilitate the firing of flash such as relay driver circuits, photodiode amplifier and Schmitt Trigger circuit. The circuit interacts with the DAQ card to perform specific functions such as triggering acquisition or switching on the flash.

An event-driven application called ThermDiff was written using Microsoft Visual Basic 6 allowing the user to control the experimental operations interactively. The application provides a complete set of functions to the user include hardware control, data acquisition, data conditioning and computation of thermal diffusivity value. Besides, other features such as file storage, graphical presentation, printing and help system are included into the application.

The functionality and workability of the computerized experimental system were successfully tested. The reliability and accuracy was verified by testing several samples of known thermal diffusivity value: Aluminum, Silicon Carbide and Boron Carbide. As results, the computed thermal diffusivity values showed close agreements to the literature values with difference of less than ±5%.

It is recommended that future researches can be carried out to develop a computerized experimental system that is capable to determine thermal diffusivity value accurately at various temperatures.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

REKABENTUK DAN PEMBANGUNAN KAEDAH LAMPU KILAT BERKOMPUTER UNTUK PENGUKURAN DAYA RESAPAN THERMAL

Oleh

THAI MING YEOW

Oktober 2007

Pengerusi: Profesor Madya Zaidan Abdul Wahab, PhD

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Daya resapan terma, α merupakan salah satu parameter yang menyifatkan kadar penyebaran haba dalam suatu bahan disebabkan oleh aliran haba dalam proses keadaan tidak mantap. Kaedah lampu kilat diperkenalkan oleh Parker et al. (1960) sebagai suatu kaedah yang cepat dan ekonomi untuk penentuan daya resapan terma. Satu sistem eksperimen berkomputer telah dibangunkan dalam projek ini untuk memudahkan dan mempercepatkan proses eksperimen bagi penentuan nilai daya resapan terma bahan pepejal pada suhu bilik.

Dalam kaedah lampu kilat konvensyenal, suatu lampu kilat yang berkeamatan tinggi digunakan sebaga sumber tenaga denyut. Dawai termogandingan digunakan untuk memantau suhu pada permukaan belakang sampel dan direkodkan oleh sebuah osiloskop. Pengiraan nilai daya resapan terma boleh dilakukan secara manual atau dengan bantuan beberapa perisian komputer.

Dalam kajian ini, proses yang memakan masa ini digantikan dengan pengautomatik pemancaran lampu kilat dan pencatatan data suhu-masa pada permukaan belakang sampel. Sebuah komputer peribadi dilengkapi Kad DAQ dari “National Instruments”

memainkan peranan sebagai pusat kawalan untuk mengawal dan memantau proses eksperimen dari pemancaran lampu kilat hingga penyelesaian penentuan nilai daya resapan terma.

Beberapa litar elektronik telah dikaji dan dibina untuk memudahkan pemancaran lampu kilat seperti litar pemandu geganti, litar penguat diod peka cahaya dan litar picuan Schmitt. Litar ini berinteraksi dengan Kad DAQ untuk menjalankan kerja-kerja yang tertentu seperti picuan proses pemerolehan atau pengsuisan lampu kilat.

Suatu aplikasi berpandukan peristiwa dipanggil ThermDiff dibangunkan dengan menggunakan Microsoft Visual Basic 6 membolehkan pengguna mengawal operasi eksperimen secara interaktif. Aplikasi ini dilengkapkan dengan set fungsi yang sempurna kepada pengguna termasuk pengawalan perkakas, pemerolehan data, pelaziman data dan mengira nilai daya resapan terma. Di samping itu, fungsi-fungsi lain seperti penyimpanan fail, pemaparan grafik, pencetakan dan sistem bantuan turut dirangkumi aplikasi ini.

Fungsi dan kebolehan sistem eksperimen berpandukan komputer ini telah berjaya diuji. Kebolehpercayaan dan kejituan sistem telah disahkan dengan pengujian beberapa sampel yang nilai daya resapan termanya diketahui: Aluminium, Silikon Karbida dan Boron Karbida. Sebagai keputusan, nilai daya resapan terma yang dikira menunjukkan persetujuan yang hampir sama dengan nilai rujukan dengan perbezaan kurang daripada ±5%. Adalah dicadangkan kajian ini dapat diteruskan dengan pembangunan sistem berpandukan komputer yang dapat menentukan nilai daya resapan terma pada sebarang suhu.

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First of all, I would like to express my deepest gratitude to my parents for giving me supports in material and spiritual form all the time and the immeasurable love given to me keeping me living in comfortable and peaceful conditions.

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Special thanks to my course mates and friend are also great supporters for me, I appreciated all the helps and supports given to me.

Finally, may all of them who have helped and supported me living in peace, happiness and prosperous.

I certify that an Examination Committee has met on 4th October 2007 to conduct the final examination of Thai Ming Yeow on his Master of Science thesis entitled “Design and Development of Computerized Photoflash Method for Thermal Diffusivity Measurement” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the degree of Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date: 22 January 2008

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

THAI MING YEOW

Date: 3 December 2007

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LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
ANSI	American National Standard Institution
API	Application Programming Interface
BJT	Bipolar Junction Transistor
CAD	Computer Aided Design
CAM	Computer Aided Modeling
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DAC	Digital to Analog Converter
DAQ	Data Acquisition
DC	Direct Current
DLL	Dynamic Link Library
DSP	Digital Signal Processing
DUT	Device under Test
FFT	Fast Fourier Transform
GB	Gigabyte
GPIB	General Purposes Interface Bus
GUI	Graphical User Interface
HTML	Hypertext Markup Language
IC	Integrated Circuit
I/O	Input/Output
ISA	Industrial Standard Architecture
LSI	Large Scale Integration

MAX	Measurement & Automation Explorer
MB	Megabyte
MS-DOS	Microsoft Disk Operating System
NI	National Instruments
PC	Personal Computer
PCI	Peripheral Component Interconnect
PFI	Programmable Function Input
RAD	Rapid Application Development
SDI	Single Document Interface
SPDT	Single Pole Double Throw
STC	System Timing Control
T.D.	Thermal Diffusivity
TTL	Transistor-transistor Logic
USB	Universal Serial Bus
VLSI	Very Large Scale Integration
Win32	32-bit Windows

LIST OF SYMBOLS

α	thermal diffusivity
$\alpha_{corrected}$	corrected value of thermal diffusivity
α_x	thermal diffusivity calculated at x percent rise
β	adjustable parameter of the energy pulse
Δ	sampling rate
λ	thermal conductivity
ρ	density
ω	dimensionless parameter
τ	pulse time
a_k	raw data point with index k
b_i	new data point derived from averaging of neighboring points
c	specific heat / number of adjacent points involved in averaging
C_p	heat capacity
d	sum of specified element values
f	frequency
f_n	frequency estimated at the discrete value
F_k	parameter
F_n	parameter
g	small depth at the front surface
i	index of element in an array
I_p	current generated by photodiode
K_C	correction factor for Cowan cooling curve data
K_R	correction factor for Taylor rising curve data
K_x	constant corresponding to x% of maximum temperature rise

L	thickness of the sample
N	total number of data points / points of input
Q	energy of the light pulse
R_f	resistance
S	seeback coeffcient
T	temperature
T_M, T_{Max}	maximum temperature rise at the sample rear surface
t	time
$t_{1/2}$	time required for the back surface of the sample to reach half the maximum temperature rise
t_c	characteristic rise time
t_k	time when k-th points is sampled
t_x	time required to reach x% of T_{Max}
$t_{0.5}$	time required to reach half maximum temperature rise
$t_{0.25}$	time required to reach 25% maximum temperature rise
$t_{0.75}$	time required to reach 75% maximum temperature rise
V	voltage / dimensionless parameter
V_b	base voltage
V_{in}	input voltage
V_{out}	output voltage

CHAPTER 1

INTRODUCTION

Thermal diffusivity α is a parameter that characterizes the rate of heat diffusion in the material due to a heat flux in an unsteady-state heat transfer process. It measures how quickly a material can absorb heat from its surroundings and change temperature. Higher value of thermal diffusivity implies higher rate of heat propagation. Photoflash method is a simple and inexpensive method for determination of thermal diffusivity, α.

1.1 Research Problems

Experiments that required routine data collection can be done more easily with the help of computers. In photoflash experiment, data points were collected repeatedly in very short intervals, and would be more effectively done in a computer-controlled environment. Development of computerized system would help to enhance and expedite the experiment.

1.2 Importance of the Study

Researches about thermal diffusivity are not something new. For instance, in Universiti Putra Malaysia, many researches pertaining to thermal diffusivity were carried out. (Teh, 2001), (Josephine, 2003). Regardless what methods are used, what types of samples are tested or how the apparatuses are set up, computer is one of the essential instruments in an experimental setup. Computers play important roles many experimental processes such as data capturing, data manipulation and analysis, equipments control, signal generation, simulation etc.

Computer interfacing and automation are common terms to many people yet projects that computerize thermal diffusivity measurement are still rarely conducted. Although computers have been used for the above-mentioned purposes, complete and specialized solutions for the entire experimental procedure are still needed.

Considering the problems above, an all-in-one solution for determination of thermal diffusivity is needed. Photoflash method was chosen because it is one of the fastest and most economical methods for determination of thermal diffusivity while providing reasonable accuracy. Thus, specialized software to computerize photoflash method was developed.

1.3 Objectives of the Study

As mentioned in previous section, all-in-one solutions for determination of thermal diffusivity are hardly available in the market. The objectives of this project are:

(i) To develop a user friendly computerized experimental system for determination of thermal diffusivity of solids at room temperature based on photoflash method that runs under the most popular Win32 (Windows 95, Windows NT or later) platform.

(ii) To perform thermal diffusivity measurement in a fraction of time compare to the manual calculation method.

(iii) To attempt the usability of general-purpose programming language as an alternative to the commonly used LabVIEW graphical language as a development tool for computer interfacing.

1.4 Scope of Study

The project involves the following aspects:-

(i) Selection of a suitable programming language and tools and familiarized with it. Microsoft Visual Basic 6 was used as the programming language, development environment and compiler while NI-DAQ API (Application Programming Interface) was used to interface with the acquisition hardware.

(ii) Study or design related algorithms for manipulation and processing of captured data such as smoothing, normalization, interpolation, determination of parameters etc.

(iii) Design and handle GUI (Graphical User Interface).

(iv) Design electronic circuits for switching, amplification and triggering.

(v) Design routines for data capturing, flash switching and data storage.

(vi) Software integration – integration of GUI, processing routines and acquisition routines to create a complete software system.

(vii) Test various samples and compare with reference values to verify the reliability and accuracy of the system.

(viii) Creation of documentation or help system.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Various Techniques for Determination of Thermal Diffusivity

Methods used for measuring thermal diffusivity can be categorised into two main classes: transient heat-flow methods and periodic heat-flow methods. The basic principle for the former is that if one end of a sample is heated periodically, then the temperature of the sample also varies with the same period with diminishing amplitude. As temperature wave travels along the sample with finite velocity there is a varying phase relationship. Measurement of the amplitude decrement and either phase difference or velocity enables the diffusivity to be determined. For the latter, a sample is initially in equilibrium with uniform surrounding temperature, and then the part of it is subjected to a change in thermal flux. The thermal diffusivity is evaluated from changes in temperature which occur in measured time intervals at one or more points within the sample. The naming of these methods are given based on the originator or to the nature of the technique used (Toloukian, 1970):

i. transient heat-flow methods
   - a) Forbes' bar method
   - b) Moving heat-source method
   - c) Thermoelectric effect method
   - d) High intensity arc method
   - e) Flash method

ii. periodic heat-flow methods

a) Modified Angstrom's method

b) Temperature wave velocity

c) Temperature wave amplitude-decrement method

d) Phase-Lag method

e) Radial-wave method

Amongst these methods, more attention is given to the flash method and the modified Angstrom's method. The have the advantages of being high speed and considerable freedom from the effect of heat losses. These methods are valuable for usage under extreme conditions, for instance at very high temperature.

2.2 Reviews on Flash Methods

Flash technique is not a new method for determination of thermal physical properties of materials. The method was firstly used for homogenous, isotropic and opaque materials. However, it was proven to work well when applied on disperse non-homogenous materials, materials with two-dimensional anisotropy, multi-directional anisotropic, layered materials as well as translucent materials. (Maglic et al., 1992)

The prototype of flash method was developed and studied by Parker et al in 1961. In their research, the model was used to measure thermal diffusivity, heat capacity and thermal conductivity of solid materials. A high intensity short duration heat pulse is absorbed in the front surface of a thermally insulated specimen with a few millimeter thickness and coated with camphor black to enhance heat absorption. An oscilloscope was used to record the resulting temperature rise at the rear surface of the specimen. The output of the oscilloscope was captured by oscilloscope camera.