#### Contacts

Abs	stract (Thai)
Abs	stract (English)
Ack	nowledgements
Con	itents
List	of Tables
List	of Figures
Syn	nbols
Cha	pter
1	Introductions
	Literature Reviews.
	Objectives
2	Background
	Piezoelectricity
	Pyroelectricity.
	Thermal diffusivity and measurements.
	Piezocomposite
3	Experimentals
	Materials
	Equipments
	Experimental procedures.
4	Results and Discussion
	Evaluation of the piezoelectric coefficient.
	Evaluation of the piezoelectric coefficient.
	Evaluation of the thermal diffusivity
	Applications
5	Conclusions
	Conclusions.
	Suggestions for further investigations

# Contents (continued)

	Page
Bibliography	96
Appendix	
A Peltier Element	101
B Material properties of epoxy.	102
C Heat Capacity	103
Vitae	

#### **List of Tables**

Table		Page
1.1	Value of the material parameter of the composites as reported in the	5
	literature	
2.1	Piezoelectric coefficients	15
2.2	Tensorial properties expressed in matrix notation	17
2.3	The 32 crystallographic point groups arranged by crystal systems	28
2.4	Typical data of piezoelectric material	44
2.5	Properties of P(VDF-TrFE) copolymers for different VDF fractions	46
2.6	Material parameter of the ceramic, polymer compared with	47
	composite	
2.7	Examples of the application of the piezoelectric material	52
3.1	Ceramic and epoxy parameters used in the composite fabrication	60
4.1	The value of the density, heat capacity and dielectric constant of the	76
	composite	
5.1	All of the experimental results observed in the present work	94
A.1	Heat capacity of 1-3 composite PZT/epoxy ( $\phi = 0.4$ )	105
A.2	Heat capacity of 0-3 composite PZT/P(VDF-TrFE) ( $\phi$ =0.3)	106
A.3	Heat capacity of epoxy	107

#### **List of Figures**

Figure		Page
2.1	Illustration of the piezoelectric effect	12
2.2	Definition of the piezoelectric coefficients	16
2.3	Illustration of the direction associated with the subscripts used in	18
	the matrix notation	
2.4	Schematic diagram of the setup for measuring the piezoelectric	19
	coefficient using direct piezoelectric effect	
2.5	Schematic impedance diagram in the frequency region of the	20
	piezoelectric resonance	
2.6	Equivalent circuit of a piezoelectric resonator	20
2.7	The intensity at the centre of the interference pattern of the	22
	interferometer plotted as a function of path-difference	
2.8	The sample displacement caused by an external electric field	23
2.9	Illustration of the pyroelectric effect	27
2.10	Classification of symmetry relating piezoelectric, pyroelectric and	30
	ferroelectric material	
2.11	The variation in spontaneous polarization with temperature for a	31
	ferroelectric material	
2.12	Schematic diagram for the measurement of the thermal diffusivity	36
2.13	Temperature wave inside the sample	36
2.14	Demonstration showing of the temperature fluctuations at the time	38
	at which the surface temperature is a maximum	
2.15	Classification of two-phase composites with respect to	41
	connectivity	
2.16	Structure of the PZT	42
2.17	Schematic representation of a 1-3 composite PZT/polymer	43
2.18	Low ceramic volume fraction 0-3 connectivity composite	45
2.19	Schematic diagram of a classical single-element transducer	50
2.20	Setup of pulse-echo response	51

Figure		Page
2.21	Principle of ultrasonic imaging systems	51
2.22	Excellence in medical diagnostic achieved with modern ultrasonic	52
	imaging	
2.23	Typical configuration of IR detector	54
2.24	Design of a compensated pyroelectric detector	54
2.25	Operating of detector	55
3.1	Heating rate used in the sintering process	58
3.2	Heating rate used in annealing process	58
3.3	Dicing machine	59
3.4	Low-pressure chamber	59
3.5	Dicing direction	60
3.6	Heating rate used in the sintering process	61
3.7	Heating rate used in annealing process	61
3.8	The compression process	63
3.9	The composites that were sandwich between polyamide sheet	63
	were put on mold	
3.10	The mold was heated by hot compressor	64
3.11	Photograph of the composites	64
3.12	Polarizing a piezoelectric material	65
3.13	Poling setup	66
3.14	Schematic of the interferometer adapted to measure piezoelectric	68
	coefficient	
3.15	The sample whose surface was made reflective using a small piece	69
	of mirror attached onto the sample	
3.16	The experimental arrangement used to measure the pyroelectric	71
	coefficient	
3.17	Temperature sensor	71
3.18	The temperature sensor circuit	71

Figure		Page
3.19	The photograph of the sample holder in the thermal diffusivity	73
	measurement	
4.1	Scanning electron micrograph of the 0-3 composite PZT/P(VDF-	75
	TrFE)	
4.2	Scanning electron micrograph of the 1-3 composite PZT/epoxy	76
4.3	Surface displacement versus driving voltage of the poled PZT	77
	$(\phi = 1)$ at 1 $kHz$	
4-4	Surface displacement of the poled PZT ( $\phi = 1$ ) plotted as a	78
	function of driving voltage averaged over the frequency rang of 1	
	kHz to 5 kHz	
4.5	Surface displacement versus driving voltage of the 1-3 composite	78
	PZT/epoxy ( $\phi = 0.6$ ) at 1 kHz	
4.6	Surface displacement of the 1-3 composite PZT/epoxy ( $\phi = 0.6$ )	79
	plotted as a function of driving voltage averaged over the	
	frequency rang of 1 kHz to 5 kHz	
4.7	Surface displacement versus driving voltage of the 1-3 composite	79
	PZT/epoxy ( $\phi = 0.4$ ) at 1 kHz	
4.8	Surface displacement of the 1-3 composite PZT/epoxy ( $\phi = 0.4$ )	80
	plotted as a function of driving voltage averaged over the	
	frequency rang of 1 kHz to 5 kHz	
4.9	Plot of the frequency dependence of measured $d_{33}$ of PZT and	81
	composite	
4.10	Theoretical predicted value of elastic compliance and	81
	piezoelectric coefficient of 1-3 composites PZT/epoxy	
4.11	A typical temperature pattern used for measuring the pyroelectric	83
	coefficient	
4.12	Variation of polarization with temperature for the poled PZT	83

Figure		Page
4.13	Variation of polarization with temperature for 1-3 composite	84
	$PZT/epoxy (\phi = 0.6)$	
4.14	Variation of polarization with temperature for 1-3 composite	84
	$PZT/epoxy(\phi = 0.4)$	
4.15	The phase retardation of a temperature waves passing through the	85
	1-3 composite PZT/epoxy ( $\phi = 0.4$ ) plotted as a function of the	
	modulated frequency	
4.16	An illustration of the calculation attenuation an phase retardation	86
	of the temperature waves for the 1-3 composite PZT/epoxy ( $\phi$ =	
	0.4)	
4.17	The phase retardation of a temperature waves passing through the	87
	1-3 composite PZT/epoxy ( $\phi = 0.4$ ) plotted as a function of the	
	modulated frequency	
4.18	Measured current as a function of the modulated frequency for 1-3	87
	composite PZT/epoxy ( $\phi = 0.4$ )	
4.19	The phase retardation of a temperature waves passing through the	88
	1-3 composite PZT/epoxy ( $\phi = 0.6$ ) plotted as a function of the	
	modulated frequency	
4.20	Measured current as a function of the modulated frequency for 1-3	88
	composite PZT/epoxy ( $\phi = 0.6$ )	
4.21	The phase retardation of a temperature waves passing through the	89
	epoxy plotted as a function of the modulated frequency	
4.22	Measured current as a function of the modulated frequency for	89
	epoxy	
4.23	The phase retardation of a temperature waves passing through the	90
	0-3 composite PZT/P(VDF-TrFE) ( $\phi$ = 0.3) plotted as a function	
	of the modulated frequency	

Figure		Page
4.24	The phase retardation of a temperature waves passing through the	90
	0-3 composite PZT/P(VDF-TrFE) ( $\phi = 0.3$ ) plotted as a function	
	of the modulated frequency	
4.25	Measured current as a function of the modulated frequency for 0-3	91
	composite PZT/P(VDF-TrFE) ( $\phi = 0.3$ )	
4.26	The phase retardation of a temperature waves passing through the	92
	LiTaO <sub>3</sub> plotted as a function of the modulated frequency	
4.27	Measured current as a function of the modulated frequency for	92
	LiTaO <sub>3</sub>	
A.1	Heat flow plotted as a function of the temperature of the 1-3	103
	composite PZT/epoxy ( $\phi = 0.4$ )	
A.2	Heat flow plotted as a function of the temperature of the 0-3	104
	composite PZT/P(VDF-TrFE) ( $\phi = 0.3$ )	
A.3	Heat flow plotted as a function of the temperature of epoxy	105

#### **Symbols**

A =Electrode area

C = Capacitance

 $C_V$  = Volume heat capacity

c = Stiffness

 $c_p$  = Specific heat capacity D = Dielectric displacement

d = Thickness

 $d_{ii}$  = Piezoelectric stress coefficient

 $d_{ac}$  = Surface displacement

E = Electric field

e = Piezoelectric stress coefficient

F = Force

f = Frequency

g = Piezoelectric strain coefficient
h = Piezoelectric strain coefficient

I = Light intensity

i = Electric current

k = Electrical coupling factor

k = Thermal conductivity

 $k_r$  = Temperature wave vector

L = Inductance

m = Mass

P = Polarization

*p* = Pyroelectric coefficient

Q = Charge

R = Resistance

 $S_{ij}$  = Strain tensor

s = Electric compliance

T = Temperature

 $T_C$  = Curie temperature

t = Time

V = Voltage

#### **Symbols (continued)**

Penetration depth  $x_r$ 

UThermal energy =

ZAcoustic impedance =

= Position

 $\varepsilon$ Permittivity of a medium =

Permittivity of free space  $oldsymbol{arepsilon}_0$ 

 $\mathcal{E}_r$ Relative permittivity

Stress tensor  $\sigma_{ij}$ 

γ Thermal expansion =

λ Wave length =

β Heating rate =

Angular frequency ω =

Electric susceptibility χ

 $an \delta$ Loss tangent

Absorbility  $\eta$ 

Thermal diffusivity α =

 $ho \ \xi$ Density =

Poling ratio =

Volume fraction of ceramic