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COPLANAR ELECTRODE FLUIDIC-BASED ACOUSTIC SENSING METHOD FOR UNDERWATER APPLICATIONS

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COPLANAR ELECTRODE FLUIDIC-BASED ACOUSTIC SENSING METHOD FOR UNDERWATER APPLICATIONS

by

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TABLE OF CONTENTS

Acknowledgements…………………………………………………………… ii

Table of Contents………………………………………………………….. iii

List of Tables……………………………………………………………… ix

List of Figures……………………………………………………………... x

List of Abbreviations……………………………………………………… xv

List of Symbols……………………………………………………………. xvii

Abstrak…………………………………………………………………….. xx

Abstract……………………………………………………………………. xxi

CHAPTER 1- INTRODUCTION

1.1 Background………………………………………………………… 1

1.2 Problem Statement………………………………………………… 4

1.3 Research Objectives………………………………………………... 5

1.4 Scope of research…………………………………………………... 6

1.5 Thesis organization………………………………………………… 6

CHAPTER 2- LITERATURE REVIEW

2.1 Introduction………………………………………………………… 8

2.2 Sensing structure…………………………………………………… 10

2.3 Sensing mechanism………………………………………………… 10

2.4 Capacitive micromachined ultrasonic transducer (CMUT……………… 11

  2.4.1 Common structural design……………………………………… 12

  2.4.2 CMUT Fabrication……………………………………………… 16

2.5 Microfluidic device………………………………………………………… 21

2.5.1 Common structural design……………………………………… 22

2.5.2 Fabrication of microfluidic based device……………………...... 28

2.6 Summary…………………………………………………………………… 31

CHAPTER 3- BACKGROUND THEORY

3.1 Introduction……………………………………………………………… 33

3.2 Acoustic theory………………………………………………………….. 33

3.2.1 Velocity and density…………………………………………… 35

3.2.2 SPL,SIL AND SWL…………………………………………… 36

3.2.3 Frequency and wavelength…………………………………….. 37

3.2.4 Sensing principles……………………………………………… 39

3.3 Design structural elements…………………………………………….. 40

3.3.1 Membrane……………………………………………………… 40

3.3.1(a) Material……………………………………………… 40

3.3.1(b) Deflection theory……………………………………. 41

3.3.1(c) Impedance matching………………………………… 43

3.3.1(d) Underwater depth…………………………………… 45

3.3.2 Fluidic liquid…………………………………………………… 46

3.3.2(a) Squeeze damping theory…………………………….. 46

3.3.2(b) Liquid flow………………………………………….. 47

3.3.3 Sensing electrodes……………………………………………… 49

3.3.3(a) Parallel electrode……………………………………. 49

3.3.3(b) Coplanar electrodes…………………………………. 50

3.4 Summary………………………………………………………………….. 54

CHAPTER 4-RESEARCH METHODOLOGY AND IMPLEMENTATION

4.1 Introduction………………………………………………………………. 55

4.2 Design approaches…………………………………………………….... 55

4.3 Proposed work………………………………………………………….. 58

  4.3.1 Structure configuration…………………………………………. 58

  4.3.2 Transduction mechanisms……………………………………..... 59

4.4. Modeling……………………………………………………………….. 60

  4.4.1 Membrane……………………………………………………… 60

    4.4.1(a) Deflection response model…………………………….. 61

    4.4.1(b) Acoustic impedance……………………………………. 63

    4.4.1(c) Dimensional factor…………………………………….. 64

    4.4.1(d) Pressure response………………………………………. 66

  4.4.2 Fluidic liquid…………………………………………………… 67

    4.4.2(a) Flow model…………………………………………….. 67

    4.4.2(b) Effect of reservoir height on flow…………………….... 69

    4.4.2(c) Squeeze film analysis………………………………….. 70

  4.4.3 Sensing element……………………………………………….... 71

    4.4.3(a) Capacitive model………………………………………. 72

    4.4.3(b) Aspect ratio…………………………………………….. 74

    4.4.3(c) Effective depth of microchannel………………………. 74

    4.4.3(d) Electrode underneath microchannel…………………… 75

    4.4.3(e) 2D model verification………………………………….. 75

4.5 Device fabrication……………………………………………………... 76

  4.5.1 Structural parameter and specification…………………………… 76

  4.5.2 Fabrication process…………………………………………….. 82

4.5.2(a) Overview of process flow………………………………… 82
4.5.2(b) Mold………………………………………………………. 84
4.5.2(c) PDMS body……………………………………………. 86
4.5.2(d) Sensing electrodes……………………………………... 86
4.5.2(e) Final device……………………………………………. 87
4.6 Testing and experimental setup…………………………………………... 88
4.6.1 Microchannel……………………………………………………... 88
4.6.1(a) Capacitive response……………………………………. 89
4.6.1(b) 2D model verification………………………………….. 90
4.6.2 Underwater acoustic sensing……………………………………... 92
4.6.2(a) Frequency response……………………………………. 92
4.6.2(b) Burst signal generation………………………………… 93
4.6.2(c) Pulse catch testing……………………………………... 95
4.6.3 Surrounding effect………………………………………………... 96
4.6.3(a) Vibration effect………………………………………… 97
4.6.3(b) Temperature……………………………………………. 98
4.7. Summary…………………………………………………………………….. 99

CHAPTER 5- RESULTS AND DISCUSSIONS

5.1 Introduction………………………………………………………………. 100
5.2 Modeling…………………………………………………………………….. 100
5.2.1 Membrane………………………………………………………… 100
5.2.1(a) Deflection response……………………………………. 102
5.2.1(b) Acoustic impedance for underwater application………. 102
5.2.1(c) Dimensional factor…………………………………….. 103

5.2.1(d) Pressure response………………………………………. 107
5.2.2 Fluidic liquid…………………………………………………… 109
5.2.2(a) Flow analysis………………………………………... 109
5.2.2(b) Reservoir height……………………………………... 112
5.2.2(c) Squeeze film analysis……………………………….. 113
5.2.3 Sensing structure……………………………………………….. 115
5.2.3(a) Voltage distribution……………………………………. 115
5.2.3(b) Electric field…………………………………………… 115
5.2.3(c) Effective height of microchannel……………………… 116
5.2.3(d) Capacitance response for different aspect ratio………... 117
5.2.3(e) The effect of electrodes location beyond microchannel region…………………………………………………... 118
5.2.3(f) Analytical model verification………………………….. 119
5.3 Fabricated device……………………………………………………. 120
5.3.1 Mold……………………………………………………………. 120
5.3.2 PDMS body…………………………………………………….. 121
5.3.3 Sensing electrodes……………………………………………… 122
5.3.4 Final device…………………………………………………….. 123
5.4 Experimental work………………………………………………….. 124
5.4.1 Microchannel…………………………………………………... 124
5.4.1(a) Capacitive response……………………………………. 124
5.4.1(b) 2D model verification………………………………….. 127
5.4.2 Underwater acoustic sensing…………………………………... 129
5.4.2(a) Frequency response……………………………………. 129
5.4.2(b) Device sensitivity……………………………………… 131

5.4.2(c) Pulse catch technique…………………………………….. 131

5.4.3 Surrounding effect……………………………………………... 134

5.4.3(a) Vibration effect………………………………………… 135

5.4.3(b) Temperature effect……………………………………... 136

5.5. Summary………………………………………………………………….. 137

CHAPTER 6-CONCLUSION AND FUTURE WORK

6.1 Conclusion…………………………………………………………... 140

6.2. Future Work………………………………………………………………. 141

References……………………………………………………………………. 143

List of Publications

LIST OF TABLES

Page

Table 2.1 Basic structural layer of CMUT 12

Table 2.2 Basic fabrication process of CMUT 17

Table 2.3 Common micro fluidic based device 22

Table 2.4 Summary of development of membrane based device 32

Table 4.1 The membrane’s dimension 62

Table 4.2 Material properties of membrane materials 62

Table 4.3 Acoustic properties of air, water and PDMS 63

Table 4.4 Membrane geometry specification 65

Table 4.5 Structure design specification 68

Table 4.6 Properties of liquid candidates 68

Table 4.7 Material specifications 69

Table 4.8 Structure specification for flow model 69

Table 4.9 The thin film geometry 70

Table 4.10 Material properties of liquid materials 70

Table 4.11 Material properties of the structure 73

Table 4.12 Model dimension 73

Table 4.13 Specification of the fabricated device 82

Table 4.14 Testing specification 96

Table 5.1 Reflection coefficient 103

LIST OF FIGURES

		Page
Figure 1.1	Summary of various applications of underwater acoustic sensing	2
Figure 2.1	The map of topics of interest for literature review process	9
Figure 2.2	Structural difference for acoustic sensing	10
Figure 2.3	Cross sectional view of CMUT	12
Figure 2.4	CMUT with non uniform membrane	14
Figure 2.5	CMUT with multiple electrodes	14
Figure 2.6	CMUT with isolation posts	15
Figure 2.7	CMUT with liquid cavity	15
Figure 2.8	Sacrificial release process to realise the membrane structure	19
Figure 2.9	Microchannel used for detection, control and sorting of the droplets	23
Figure 2.10	Microchannel used for pumping,transportation and mixing of microfluidic materials	24
Figure 2.11	Top view of single sided electrode configuration	25
Figure 2.12	Membrane structure controlling microfluidic flow	25
Figure 2.13	Membrane structure acting as microvalve for microdispensar.	26
Figure 2.14	Basic process of softlitography	29
Figure 3.1	Propagation of a longitiudinal wave.	34
Figure 3.2	The original and deflected of the membrane	42
Figure 3.3	Some of the energy is reflected due to the acoustic impedance mismatch	44
Figure 3.4	Squeeze effect of thin film	46

Figure 3.5 Parallel electrode configuration 49
Figure 3.6 Cross sectional view of coplanar electrodes configuration 51
Figure 3.7 Cross sectional area that shows the effective electric field only bounded inside the microchannel and related to penetration depth theory 52
Figure 3.8 Equivalent circuit of coplanar electrodes 53
Figure 4.1 Flow chart of methodology. 56
Figure 4.2 Fluidic based acoustic sensor 58
Figure 4.3 FEM model of circular shape membrane 61
Figure 4.4 2D asymmetric model concept 64
Figure 4.5 Critical region under investigation 68
Figure 4.6 Cross sectional area of microchannel 72
Figure 4.7 FEM model approach 73
Figure 4.8 Location of electrode underneath beyond microchannel 75
Figure 4.9 Simplified equivalent circuit of microchannel for modeling 76
Figure 4.10 The structural parameter of the device 77
Figure 4.11: Flow chart of dimension selection of membrane and electrodes 79
Figure 4.12 Fabrication process (a) –(g) 83
Figure 4.13 The concept used to control the thickness of the membrane 85
Figure 4.14 SOLIDWORK drawing of the device mold 86
Figure 4.15 Example of coplanar PCB drawing 87
Figure 4.16 Microfluidic filling up process 88
Figure 4.17 Experimental setup to validate the FEM model 90
Figure 4.18 Conceptual diagram for estimating the volumetric capacitive 91

change based on capacitors in parallel configuration

Figure 4.19 Experimental setup for the frequency response 93

Figure 4.20 Burst signal 94

Figure 4.21 Burst signal set up to provide different burst cycle 95

Figure 4.22 Final setup of pulse catch technique with different pulse cycle 96

Figure 4.23 Experimental setup to investigate the effect of vibration 97

Figure 4.24 Experimental setup to study the temperature variation effect 98

Figure 5.1 Contour plot of five different type of deflection mode. 101

Figure 5.2 Acoustic response of three different materials 102

Figure 5.3 Axisymmetric radial deflection profile for three different pressures 104

Figure 5.4 The relationship between the membrane thickness and the maximum deflection 104

Figure 5.5 The relationship between the membrane radius and the maximum deflection 105

Figure 5.6 The relationship between the structural ratio and the deflection ratio 106

Figure 5.7 The relationship between the pressure signal and the deflection ratio 107

Figure 5.8 Deflection ratio against underwater depth 108

Figure 5.9 Pressure distribution inside the device at selected device dimension 109

Figure 5.10 Contour plot of the velocity across the devices 110

Figure 5.11 Flow direction of both materials 110

Figure 5.12 Flow response comparison of both materials 111

Figure 5.13 Flow velocity at the region of interest for different height of reservoir. 113

Figure 5.14 The damping ratio across different modes for two different backing materials 114

Figure 5.15 Voltage distribution of simulated FEM 115

Figure 5.16 Electric field distribution of simulated FEM 116

Figure 5.17 Effective height of microchannel 117

Figure 5.18 The C^*_{FEM} for different aspect ratio 118

Figure 5.19 Effect of extending sensing electrode beyond microchannel region 119

Figure 5.20 Comparison of C^* between FEM and analytical model 120

Figure 5.21 Top part creation mold with different wall height to manipulate produce different thickness of the membrane 121

Figure 5.22 Peeling off process to separate the PDMS stamp from the mold. 121

Figure 5.23 Examples of broken membrane or rupture due to very thin membrane 122

Figure 5.24 SEM Image 122

Figure 5.25 PCB fabrication of sensing electrodes 123

Figure 5.26 Final process 124

Figure 5.27 Sample of liquid inside microchannel viewed through handheld microscope at Δl 125

Figure 5.28 Schematic diagram of the resulted capacitance response inside microchannel 126

Figure 5.29 Estimating the capacitance change along the microchannel 128 using FEM, analytical and experimental approaches (3D verification)

Figure 5.30 The plot of capacitance changes against signal's frequency 130

Figure 5.31 Capacitive response for different burst cycle. 132

Figure 5.32 Capacitive response vs no of burst cycle (1 to 10) 133

Figure 5.33 Capacitive response of dual burst cycle(n=3 and n=5) 134

Figure 5.34 Capacitive response at f = 90Hz 135

Figure 5.35 The effect of rapid transition of frequency's vibration on the capacitive response 136

Figure 5.36 The effect of temperature variation on the device's capacitive response 137

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
BAW	Bulk Acoustic Wave
CMOS	Complimentary Metal Oxide Semiconductor
CMUT	Capacitive Micromachined Ultrasonic Transducer
DC	Direct Current
DUT	Device Under Test
EM	Electromagnetic
FEA	Finite Element Analysis
FEM	Finite Element Model
IC	Integrated Circuit
LCR	Inductance Capacitance Resistance
LOC	Lab On Chip
LPCVD	Low Pressure Chemical Vapor Deposition
MEMS	Microelectromechanical Systems
PC	Propelyne Carbonate
PDMS	Polydimethyldiloxane
PECVD	Plasma-Enhanced Chemical Vapor Deposition
RF	Radio Frequency
RMS	Root Mean Square
SAW	Surface Acoustic Wave
SEM	Scanning Electrode Microscope
SONAR	Sound Navigation and Ranging

SPL	Sound Pressure Level
μTAS	Micro Total Analysis System
LOCOS	Local Oxidation of Silicone

LIST OF SYMBOLS

Si_3N_4	Silicon Nitride
P	Pressure of sound
x	Displacement of particle
c	Speed of sound
t	Time
I	Intensity
P_o	Amplitude of pressure
P_{rms}	rms value of pressure
P_{ref}	Reference sound pressure
ρ	Medium/material density
f	Frequency
λ	Wavelength
S_R	Receiving sensitivity
V_C	Output voltage
P_F	Sound pressure in fluid
w_m	Membrane deflection
P_t	Total pressure
r_m	Radius of the membrane
D	Flexural rigidity
E	Young Modulus
v_p	Poisson ratio
t_m	Thickness of the membrane
Z	Acoustic impedance

K	Elasticity modulus
V_z	Acoustic velocity (material dependant)
R_e	Reynolds number
K_n	Knudsen number
C	Capacitance
$\mathcal{E}_o$	Electric constant
$\mathcal{E}_r$	Dielectric constant (Dieletric permittivity)
A	Area of plates
d	Plate separation
w_e	Width of electrode
w_c	Microchannel width
g_e	Half gap separation
l	Length of electrodes
w_{eff}	Effective width
h	Height of microchannel
C_{eq}	Equivalent capacitance
R	Reflection coefficient
Z_1	Acoustic impedance of medium 1
Z_2	Acoustic impedance of medium 2
g	Gravitational force
h_{uw}	Underwater depth
P_{atm}	Atmospheric pressure
P_{hyd}	Hydrostatic pressure
h_w	Height of mold’s wall

h_r	Height of reservoir
C^*	Capacitance per unit length
Δl	Displacement
ΔC_T	Change of total capacitance
C^*_{FEM}	Capacitance per unit length of FE model
C^*_{ana}	Capacitance per unit length of analytical model

KAEDAH PENDERIAAN AKUSTIK BERASASKAN BENDALIR ELEKTROD KOPLANAR UNTUK APLIKASI BAWAH AIR

ABSTRAK

Tesis ini mencadangkan kaedah penderiaan akustik berasaskan cecair untuk aplikasi bawah air. Mekanisme penderiaan yang dipilih adalah berdasarkan konsep kemuatan yang terhasil daripada elektrod koplanar. Struktur tersebut dicadangkan untuk mengatasi beberapa permasalahan yang timbul daripada peranti sediada iaitu Pemuat Mikromesin Transduser Ultrasonik. Isu kebolehbergantungan, disebabkan lengkungan membran yang berlebihan diatasi dengan menyuntik cecair di bawah lapisan membran bagi menambah nilai redaman ketika beroperasi di bawah tekanan luaran dan voltan yang tinggi. Penggunaan teknik litografi lembut untuk fabrikasi memberi kelebihan disebabkan proses yang lebih ringkas. Kaedah penderiaan ini dibuktikan melalui kitaran lengkap yang terdiri daripada proses pemodelan, fabrikasi dan pengujian. Dimensi struktur mematuhi kriteria yang ditetapkan seperti teori lengkungan membran dan teori penembusan kedalaman. Ujian akhir menunjukkan kebolehan peranti untuk mengesan isyarat akustik 200kHz yang dipancarkan melalui peranti bawah air dengan bacaan sensitiviti sebanyak 0.67pF/Pa. Kesan persekitaran seperti getaran pada frekuensi rendah (10Hz to 100Hz) dan perubahan suhu (-20℃ to 30℃) juga didapati tidak memberi kesan terhadap operasi peranti. Ini menujukkan kestabilan peranti untuk berfungsi pada keadaan tertentu.

COPLANAR ELECTRODE FLUIDIC-BASED ACOUSTIC SENSING METHOD FOR UNDERWATER APPLICATIONS

ABSTRACT

The thesis proposed a novel fluidic-based acoustic sensing method for underwater applications. The capacitive principles based on coplanar electrodes configuration is selected as the sensing mechanism. The new structure device was proposed to overcome several issues faced by the conventional device based on Capacitive Micromachined Ultrasonic Transducer (CMUT) by adapting the microfluidic technology. Reliability issues caused by the over deflected membrane was overcame by introducing the liquid backing material underneath the membrane which increases the damping at high operating voltage and high external pressure. The use of softlitography technique for fabrication also gave an advantage due to its process simplicity. The sensing concept was proven through a development cycle which consists of modelling, fabricating and testing. The structural design had satisfied several design rules such as membrane deflection theory as well as penetration depth theory. The final testing showed the ability of the device to detect 200kHz acoustic signal transmitted from the underwater acoustic projector with capacitive pressure sensitivity of 0.4 fF/Pa. It was also found that the constant frequency vibration (10Hz to 100Hz) and change of temperature (-20℃ to 30℃) has minimal effect on the sensing performance, thus showcased the stability of the sensor.

CHAPTER 1

INTRODUCTION

1.1 Background

Acoustic sensing is a field that deals with the reception process of acoustic signal. It is a technology that has been inspired from biological nature such as communication process of bat and dolphin. The use of acoustic for terrestrial application includes for military (Becker & Gu, 2000), structural monitoring (Hamdi et al. 2013; Mostafapour & Davoudi, 2013), level sensor (Osborne et al., 2004) and ecological monitoring(Blumstein et al., 2011). For underwater application, early history of acoustic sensing is recorded way back in 1490 when Leonardo Da Vinci had detected the vessel through an inserted tube underwater as well as when underwater bell was designed for hazards warning during 19th century. Modern application of underwater acoustic sensing is primarily influenced by the sonar technology and frequently related to the oceanography application (Zielinski et al., 1995;Zhao, 2010). Apart from that, the use of acoustic in immersion application also benefits humankind in some ways. As an example, the technology has contributed to the important application in medical imaging (B. Bayram et al., 2005; Chen et al., 2008; Vaithilingam et al., 2006) and near surface application such as underwater sensor network, sound and vibration instrument, navigation and fault detecting industries and underwater communication (Culver & Hodgkiss, 1988). Figure 1.1 shows various applications of underwater acoustic sensing and indicates the significance of such field to be studied and explored.

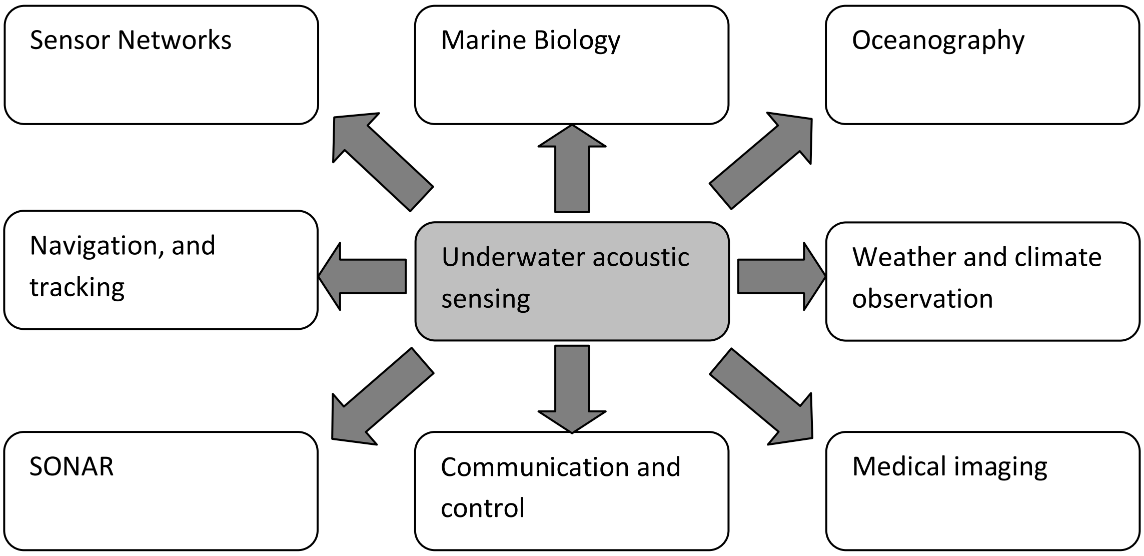

Figure 1.1: Summary of various applications of underwater acoustic sensing.

In recent years, underwater acoustic sensor experienced a revolution in terms of its device fabrication, which shares the same technology as in Integrated Circuit (IC) technology, (Esashi, 2010; Gentili et al., 2005; Jin et al., 1998; Oralkan & Ergun, 2002). Fabrication process based on surface micromachining and bulk machining has brought the device technology into micro and nanoscale size which is proven to have substantial advantages in terms of its power consumption, reliability, handling and portability (Arshad, 2009). The progress, hence benefits the ocean and underwater research field due to the fact that the use of acoustic signal is preferred compared to other type of signal wave such as radio frequency (RF) due to its acoustic nature that is more prone to underwater noise (Akyildiz et al., 2005;Singer et al., 2009).

In terms of performance, acoustic sensing can be classified into several categories. Different applications sometimes require different device performance to suit its operation. Structural design and fabrication process are two key factors that