# 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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# 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 |
| $\rho$ | Medium/material density |
| $f$ | Frequency |
| $\lambda$ | 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 |
| $\Delta l$ | Displacement |
| $\Delta C_T$ | 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.

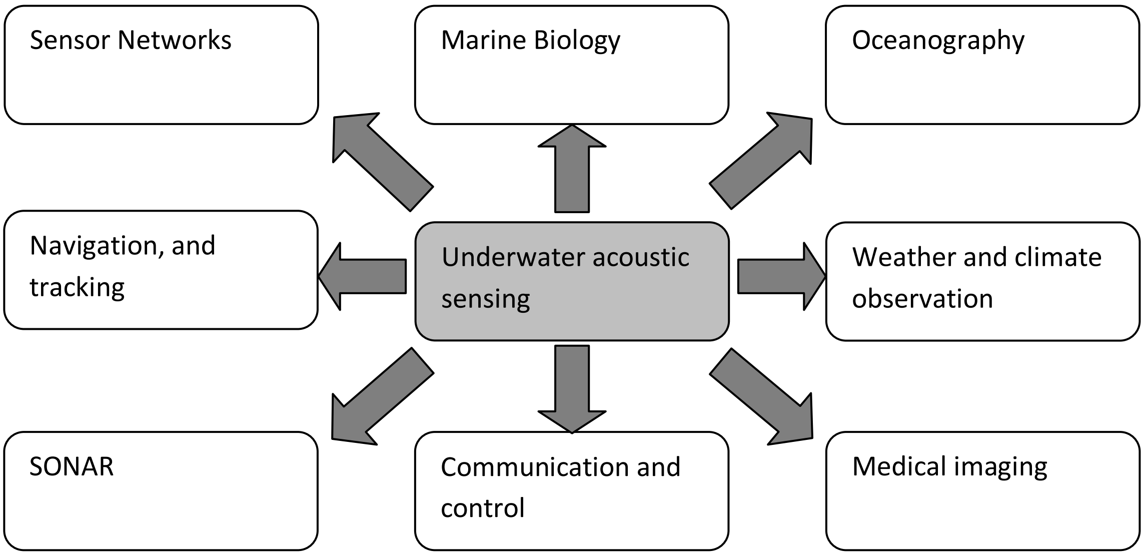

Figure 1.1: Summary of various applications of underwater acoustic sensing.

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