PARTICLE MANIPULATION BY ADHERE METHOD AS TRAVELLING SURFACE ACOUSTIC WAVE

By

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

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

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November 2021

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Surface acoustic wave (SAW) is waves that propagate on the surface of the substrate. The propagating wave generated by applying the alternating voltage across electrodes on piezoelectric substates. By the propagating waves, it can be used for the separation of particles. There are two important parameters of SAW to be used in particle manipulation which are the piezoelectric substrate (PZT) and interdigitated electrode (IDE). For this project, the channel for particle manipulation will be part of the device. For SAW have two types which is Travelling surface acoustic wave (TSAW) and Standing surface acoustic wave (SSAW). TSAW device involves one IDE. In this project, the working principle of the TSAW device has been demonstrated in microfluidic systems with the alternative method. The previous method of fabrication has some disadvantages which is affect the fabrication time besides cannot vary finger dimension because of the electrode have been built in the piezoelectric substrate. In this project, adhere method has been used to replace the conventional method that involves IDE and piezoelectric substrates by using PZT substrate. In this work SAW generated on the piezoelectric substrate using interdigitated electrode fabricated using ITO coated glass in contact with each other to stimulate the wave propagation. The generation of TSAW have been observed concerning the size of interdigitated ITO glass electrode IDE needed to find the optimum time for the SAW force reached as for the best point of velocity and the best output voltage with low loss, which can generate stable TSAW. In this project, shows that 20s is the maximum point for SAW applying force to manipulate the particles. Besides that, the best distance for the best output voltage with low loss is 3 cm which is suitable for this adhere method.

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ZARAH MANIPULASI DENGAN MENGGUNAKAN TEKNIK LEKAT BAGI GELOMBANG AKUSTIK PERMUKAAN PERJALANAN

Oleh

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Gelombang akustik permukaan (SAW) ialah gelombang terhasil di atas permukaan. Gelombang terhasil daripada menggunakan arus ulangalik (AC) yang melintasi elektrod atas piezoelektrik substrat (PZT). Terdapat dua parameter penting yang digunakan bagi memanipulasi zarah iaitu PZT dan IDE. Dalam projek ini, saluran untuk memanipulasi zarah akan menjadi sebahagian daripada peranti. Bagi SAW, ia mempunyai dua jenis iaitu gelombang akustik permukaan perjalanan (TSAW) dan gelombang akustik permukaan berdiri (SSAW). Peranti TSAW melibatkan satu elektrod interdigitated (IDE). Dalam projek ini, prinsip kerja peranti TSAW telah ditunjukkan dalam sistem mikrofluidik dengan kaedah alternatif. Sebelum ini, kaedah fabrikasi mempunyai beberapa kekurangan. Dalam projek ini, kaedah melekap telah digunakan untuk menggantikan kaedah konvensional yang melibatkan IDE dan substrat piezoelektrik dengan menggunakan seramik PZT. Di bahagian permukaan, gelombang SAW dihasilkan di atas substrat piezoelektrik menggunakan elektrod IDE yang dibuat menggunakan kaca bersalut ITO yang bersentuhan antara satu sama lain untuk merangsang perambatan gelombang. Generasi TSAW telah diperhatikan dengan mengutamakan ukuran elektrod kaca ITO IDE yang diperlukan untuk mencari optimum masa bagi SAW memberikan kuasa optimum dan juga titik halalaju yang terbaik serta geometri optimum dan voltan terbaik yang mempunyai kehilangan voltan yang kurang yang dapat menghasilkan gelombang akustik permukaan perjalanan yang stabil TSAW. Bagi projek ini, 20s menunjukkan titik maksimum bagi SAW memberikan kuasa optimum untuk manipulasi zarah. Selain itu, jarak terbaik untuk voltan terbaik ialah 3 cm dimana sesuai untuk cara melekap.

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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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LIST OF SYMBOLS AND ABBREVIATIONS

SAW	Surface Acoustic Wave
BAW	Bulk Acoustic Wave
TSAWs	Travelling Acoustic waves
SSAWs	Surface Acoustic waves
EOF	Electro-osmotic flow
PZT	Lead Zirconate Titanate
$BaTiO_3$	Barium Titanate
CE	Capillary Electrophoresis
$LiNbO_3$	Lithium Niobate
LiTaO3	Lithium Tantalate
ZnO	Zinc Oxide
PDMS	Polydimethylsiloxane
PMMA	Polymethyl Methacrylate
IDT	Interdigitated Transducer
IDE	Interdigitated Electrode
AC	Alternating Current
ARF	Acoustic Radiation Force
ASF	Acoustic Streaming Flow
d	Diameter of particles
f	Frequency
Fc	Centre frequency
FEM	Finite Element Method
m_e	Mass
f_e	Frequency

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Q	Quality factor
Ti	Titanium
Zr	Zirconium
Sn	Tin
Nb	Niobium
Pb	Lead
Mn	Manganese
Ba	Barium
Sr	Stronium
Ca	Calcium
Na	Sodium
Vpp	Voltage peak to peak
IPA	Isopropanol
DI	Distilled water
L	Length
W	Width
ITO	Indium Tin Oxide
F_c	Centre frequency
N	Number of IDE finger
W	Finger width/spacing aperture
π	Wavelength
C_t	Total Capacitance
V_R	Rayleigh wave velocity
Z	Impedance
RF	Radio Frequency

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S_{21}	Insertion loss
PS	Polystyrene
µl	Microlitre
Mm	Millimetre
MHz	Mega hertz

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CHAPTER 1

INTRODUCTION

1.1 Background

Separation of microparticle technique is a basic empowering in modern technology which is Lab on a Chip (LOC) technology. In LOC technology, the system is scaling down and integrated to a micro-Total Analysis Systems (μ-TAS). This technique has been used in industry, biomedical research and chemistry field [1][2]. Separation or manipulating particles technique from complex fluids also called colloid. For example, in biomedical research, they used blood cells in plasma or cancer cells [3][4]. It is means that the fluids need to be manipulated in micro size channel and need strong force that close to the fluid. In the past, there have several methods on manipulate the particles like magnetic tweezers [5], optoelectronic tweezer [6], and dielectrophoresis (DEP) [7]. However, microparticles separation system significantly increase demand and need further improved method to overcome the limitations. So, the researcher has discovered a new method to manipulate micro particles with strong forces by using SAW. By using the acoustic wave for separation particles there are advantages which label- free, non-contact and biocompatible [8][9]. It has a lot of other advantages including low fabricating cost, more sensitive and miniaturized and fast processing time compared to the conventional method.

Surface acoustic wave or Rayleigh wave means the wave that move on the surface of the substrate. It has been discovered by Lord Rayleigh in 1885 [10]. The surface of the material shows the elasticity and amplitude that decaying exponentially with depth into the material. The wave is generated by applying the alternating voltage across electrodes on piezoelectric substrates. Piezoelectric substrates are the most important part. This is because piezoelectric substrate provide transduction between electrical and mechanical response conversion of electrical signal into mechanical acoustic waves and vice versa. Piezoelectric material that generally use are Quartz (SiO_2), Lithium Niobate ($LiNbO_3$), Lithium Tantalate ($LiTaO_3$) and Zinc Oxide (ZnO). Previous studies have made comparison between quartz and Lithium Niobate [11]. It shows that different base has different properties. However, in this study, the selection for base device is piezoelectric ceramic (PZT). In previous study, SAW using PZT had higher electromechanical coupling factor with low cost and low frequency SAW actuator [12]. Besides, piezoelectric ceramic commonly uses for application that have high resonance frequency with high voltage sensitivity [13]. Due to the advantages, PZT ceramic are selected in this experiment.

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Acoustic wave has propagating along the substrate of an elastic material effected by the wavelength (*λ*) that directly proportional to velocity and inversely proportional to frequency. There is equation is stated in Equation 1.1 [14] :

$$fc = \frac{V_R}{\lambda} \qquad \text{(Equation 1.1)}$$

Where:

VR = Rayleigh wave velocity determined by material properties
λ = wavelength defined as the periodicity of the IDE

For the past over 20 years, surface acoustic wave has been used in military applications for radar then consumers area such as television and mobile phone [15]. Back then, they needed high performance with low cost for the mass production. SAW and Bulk Acoustic Wave (BAW) resonators two competing technology for the best performance. The difference between BAW and SAW filters which BAW is having acoustic wave that propagating in bulk effected by the thickness of substrates. For SAW, acoustic wave has propagating on the surface of substrate effected by the wavelength (λ) that directly proportional to velocity and inversely proportional to frequency. As shown in Equation 1.1. The performance increased by time that make SAW device demand, especially in the electronic world. Radio frequency (RF) and Intermediate frequency (IF) filters were involved in the SAW device. SAW IF filters usually used to reduce the physical size of the device to narrow the bandwidths and for specific signal in the receiver. Alternatively, after discovered they have found that SAW RF filters is way better than IF filters. This is because can use for higher frequency from MHz and above to GHz [16].

The current issues that world facing which is global COVID-19 pandemic that caused by the extreme acute respiratory coronavirus syndrome 2 [SARS-CoV-2] or known as coronavirus which is an infectious disease. It was identified in December 2019 reported in Wuhan, China. To date, the scientists all over the world worked on the cure but still not found yet. The size of coronavirus is less than 5 *μm* [17]. It is very small and easily spreads through droplets of saliva or spread discharge from the nose when an infected person sneeze or cough. Even so, there are many ongoing clinical trials evaluating potential treatments. Separation and manipulation technique are very important technique in the diagnostics and therapeutics research. Therefore, the particles of coronavirus can be use by manipulation technique in further study. For future researcher, they can manipulate sputum that affected to find the cure in easier way by using acoustic wave technique. Manipulating and controlling fluids commonly in range micron size like ion and molecule [18]. However, there are the briefly idea to be use as in a future analysis or manipulate the virus not specific for only coronavirus. For the development especially in practical applications achieving a more comprehensive extensive and profound understanding of standing actuated manipulated is vital.

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Recent years SAW technologies have widely used by researcher in particles alignment and mixing liquids droplets [19], pumping concentrating [20] and patterning microparticle [21]. In latter work, the researcher have use SAW to manipulate particles by use single SAW known as TSAW or multiple SAW known as SSAW [22]. Various application of microparticle manipulation by using SSAW and TSAW. SSAW generated by a pair of IDE while TSAW produced by a single IDE [8]. Usually alternating current electrical signal in radiofrequency (*RF*) range applied across the IDE. Then IDE help to generate the acoustic wave on piezoelectric substrate from the signal. In micro scale channel, the fluid will face some difficulties because the pressure node that form inside the channel. However, IDE dimension is giving effect to their acoustic wave output which is influence to the frequency (*f*) and voltage (*V*). The structural diagram of the IDE with the important dimensions shown in Figure 1.1 [23].

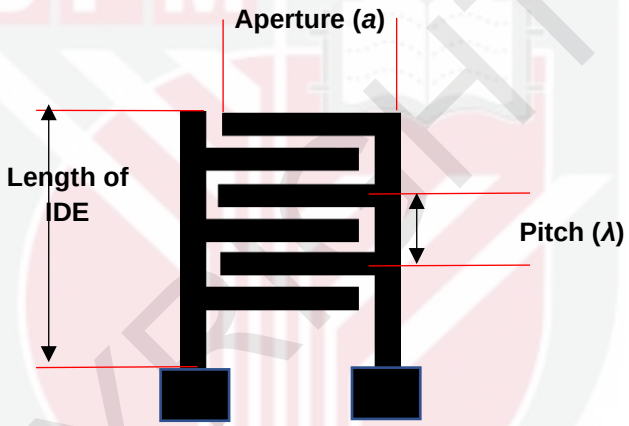

Figure 1.1: The Structural Diagram of the Interdigitated Electrode (IDE) (Source: A. Nisar et al., 2007)

In addition, the fabrication steps also play an important role. Commonly researcher used photolithography method to develop IDEs on the surface. This conventional method have disadvantages such as time consuming and relatively costly [24]. Alternatively, method use in this project can reduce the fabrication time compared to conventional method. The other method which is used in previous work is screen printing method [25]. Even though screen printing method is smooth, uniform, and best reproducibility there also have their weakness. The difficulty that researcher facing is when must to reduce the scale of electrode for the miniature application that not compatible to the screen- printing method. Furthermore, this method having low lithographic resolution of the emulsion layer and mesh dimensions limit the improvement in the resolution of printing [26]. At present, SAW transducer use indifference of analysis systems for chemical and biomedical applications. Microfluidics system is the famous technology that using SAW transducer for acoustic mode analysis [27].

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Recently, polymer channel is used because it is easy to fabricate, low cost and easy to move the molding. Besides, it is transparent that makes it easy to see the particles pass through the channel with UV light not easy absorb [23]. The good properties about polymer is there are good chemical resistance [28]. PDMS is widely used to actively developed polymer for the microfluidics as it has prominent capabilities compared to other polymers, together with very low electromagnetic energy dissipation, high dielectric electricity, the wide temperature range of use, elastomeric residences, biocompatibility, non-toxicity, excessive optical transparency, fuel permeability, reversible and irreversible bonding, clean molding and low chemical reactivity [24].

1.2 Problem Statement

By all the improvement technology to manipulate the particles there still a challenge. Compared to the other method, TSAW are non-invasive, harmless to microparticles, applicable to all types of microparticles by their properties, low power consumes and easy to integrate with microfluidic device. SAW devices has been design and fabricated in previous research. However, this design has many limitations such as can only use one parameter which is fix IDE size and distance between transmitter and receiver.

SAW device has been used for particle manipulation in previous work. The new design is needed for flexibility and costs save. Further, to cultivate of SAW device, transmitter generation of wave need to be optimized. It can be optimized by improve the generating by IDE. Thus, the effected of IDE generating needs to be study in better which is to fabricate with optimum IDE design for wave generation.

1.3 Objective

The objectives to overcome the challenge and studies are:

1. To design the alternative method for SAW between IDE and piezoelectric substrate and study its effect
2. To validate the new SAW device
3. To observe the effect of frequency and voltage on various size of IDE fabricated in house as particle manipulation

1.4 Scope of Study

The substrate use in this project is PZT ceramic substrates which is piezoelectric in nature. It was selected because it has higher electromechanical coupling factor with affordable price. Furthermore, the PZT has low frequency

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SAW actuator that suitable for the polymer particles. Even though PZT ceramic substrates has low frequency SAW actuator does not mean that the travelling wave cannot manipulate the particles that applied on it.

1.5 Thesis Content

Chapter 1 presents an overview of the current technology that has used specifically in particles manipulation by using the SAW. This chapter state the problem statement of this work, objectives of the research and scope of study.

Chapter 2 establishes the review of literature related to this study. It includes the detail on the current method of manipulation of particles. Besides, the important parameter for the particle manipulation microfluidic channel have been explained. The parameter such as dimensions finger of IDE give effect to the frequency and input voltage.

Chapter 3 describes the methodology of the experiment. It discusses about fabrication step electrode with different finger size on the PZT substrates. Besides, the flow of this work to achieves the objectives and solve the problem statement have been discussed. In addition, characterized technique and measurement discussed detail.

Chapter 4 discuses about the experimental results from the characterization techniques and analyze the data. The data that have been analyze and discuses which it is related to the objective and help solving the problem statement.

Chapter 5 for the conclusions part which must relate to the objectives. Besides, the recommendation is provided for further work.

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