UNIVERSITI PUTRA MALAYSIA

DESIGN OF GALLIUM PHOSPHATE SURFACE ACOUSTIC WAVE RESONATOR USING FINITE ELEMENT METHOD

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By

SAYED ALIREZA MOUSAVI

Thesis Submitted to the School of graduate Studies, University Putra Malaysia, in Fulfillment of Requirements for the Degree of Master of Science

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DEDICATION

To my Mother, who her love and compassion endlessly pours on me

To my Father, who his words and support constantly encourages me

To my lovely sisters, Baharak and Safoora

And to all my Friends, specially Mahmood who warmly helped me in everything

Abstract of thesis presented to the senate of University Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

Design of Gallium Phosphate Surface Acoustic Wave Resonator Using Finite Element Method

By

SAYED ALIREZA MOUSAVI

March 2009

Chairman: Mohd. Nizar Hamidon, PhD

Faculty: Engineering

The research into Surface Acoustic Wave (SAW) devices began in the early 1970s and led to the development of high performance, small size, rigorous and high reproducibility devices. SAW devices have been recognized for their versatility and efficiency in controlling and processing of electrical signals. Much research has now been done on the application of such devices to consumer electronic, communication systems and process function, such as delay lines, filters, resonator, and pulse compressors.

The use of novel material, such as Gallium phosphate ($GaPO_4$), extends the operating temperature of the SAW elements. In this thesis SAW devices based on this new material, operating at resonance frequency of 433.92 MHz been studied for passive wireless application. The SAW devices consist of interdigital transducer (IDT) with 1.4 µm finger gap ratio of 1:1 of platinum and under-layer of chromium metallization. A modeling using lumped equivalent circuit (LEC) of the device and finite element modeling (FEM) was done. The frequency responses of device were simulated by S-parameter and impedance.

The impedance was used to study the mass loading effect of the Platinum electrodes of the SAW devices. The analysis of the result shows that the mass loading affects the resonant frequency of the SAW device. Furthermore, the results show that FEM approach is more precise than LEC for design and simulation of SAW resonator.

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

Rekaan Dan Analisa Simulasi Resonator Gelombang Akustik Permukaan Bagi Applikasi Tanpa Wayar

Oleh

SAYED ALIREZA MOSAVI

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Pengerusi: Mohd. Nizar Hamidon, PhD

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Kajian berkenaan peranti gelombang akustik permukaan (SAW) telah bermula seawal tahun 1970an dan membawa kepada perkembangan peralatan perlaksanaan tinggi, bersaiz kecil, tahan lasak dan pengeluaran yang tinggi. Peranti SAW memang telah dikenali dengan kecekapan dan serba-bolehnya di dalam mengawal dan memproses signal elektrik. Sehingga kini, banyak kajian yang telah dilakukan dalam perlaksanaan yang berkaitan dengan peranti elektronik pengguna, sistem komunikasi, dan sistem pemprosesan seperti talian tunda , penapis, resonator dan pemampat denyutan.

Penggunaan bahan baru seperti Gallium phosphate ($GaPO_4$) telah menambah baik tahap suhu peranti SAW. Melalui tesis ini, peranti SAW yang menggunakan bahan yang baru ini, beroperasi pada 433.92 MHz frekuensi resonan telah dikaji bagi perlaksanaan tanpa wayar tidak aktif. Peranti SAW ini mengandungi penerima gelombang antara-angka (IDT) dengan 1.4μm nisbah jarak jari 1:1 terdiri dari platinum dan lapisan bawah chromium. Model litar persamaan cantuman dan model

pembezaan terhingga (FEM) telah digunakan. Tindakbalas frekuensi peralatan ini telah di simulasikan dengan parameter S dan impedans.

Impedans digunakan untuk mengetahui kesan jisim muatan oleh elektrod platinum peranti SAW. Analisa telah menunjukkan bahawa kesan jisim muatan boleh mempengaruhi resonan peranti tersebut. Bawasa nya Keputusan telah menunjukkan bahawa pendekatan FEM ada lah lebih tepat dari LEC bagi rekabentuk dan simulasi resonator SAW.

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I certify that a Thesis Examination Committee has met on 3 March 2009 to conduct the final examination of Sayed Alireza Mousavi on his thesis entitled "Design of Gallium Phosphate Surface Acoustic Wave Resonator Using Finite Element Method " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis submitted to the Senate of University Putra Malaysia and has been accepted as fulfillment of the requirements for the degree of Master of Science. Members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that this 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 institutes.

Sayed Alireza Mousavi

Date:

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LIST OF ABBREVIATIONS

AFM	Atomic Force Microscopic
Au	Gold
AVL	AVL GmbH
BAW	Bulk Acoustic Wave
COM	Coupling Of Mode
Cr	Chromium
CVD	Chemical Vapor Deposition
DOF	Degree Of Freedom
EBL	Electron-beam Lithography
EMI	Electromagnetic Interference
EUV	Extreme Ultraviolet
FEM	Finite Element Model
$GaPO_4$	Gallium Phosphate
IDT	Interdigital Transducer
IF	Intermediate Frequency
ISM	Industrial, Scientific, and Medical
ITO	Indium Tin Oxide
LEC	Lump Equivalent Circuit
LGS	$La_3Ga_5SiO_{14}$ langasite
$LiNbO_3$	Lithium niobate
$LiTaO_3$	Lithium Tantalite
MEMS	Micro-Electro-Mechanical-Systems
MR	Metallization Ratio
Ni	Nickel

PCB	Printed Circuit Board
pC/N	Pico Coulomb over Newton
PDE	Partial Differential Equation
PEC	Parameters of Equivalent Circuitry
ppm	part per million
PMMA	Polymethyl Methacrylate
Pt	Platinum
RF	Radio Frequency
SEM	Scanning Electron Microscope
SAW	Surface Acoustic Wave
SAWR	Surface Acoustic Wave Resonator
Zr	Zirconium
g	beam steering angle
m	Cut angle
K	Coupling factor
t	Delay time
r	Density
C	Stiffness Coefficient
D	Electric displacement
e	Dielectric permittivity
E	Electric field
u_0	Free-surface velocity of SAW
u_m	Metallized velocity of SAW
R	Mass loading in term of ratio

U	Displacement
S	Strain
T	Stress
s	Mass per unit area
Q	Mechanical quality factor
p	Period
J	Phase shift
d	Piezoelectric coefficient
P	Polarization
f_s	Potential
y	Propagation angle
j	Amplitude of acoustic wave
f	SAW frequency
l	SAW wavelength
q	Temperature
TC	Temperature Coefficient
$G_a(f)$	Radiation conductance
$B_a(f)$	Susceptance conductance
$Y(f)$	Admittance
$Z(f)$	Impedance
w	Acoustic aperture
w	Angular frequency
N_p	Number of finger-pairs in IDT

N_g	Number of strip in Reflector
L	Length
Γ	Magnitude of reflection coefficient
d	Detuning parameter
C_0	Capacitance/finger pair/ cm
C_r	Series capacitance
C_t	IDT static capacitance
L_r	Series inductance
R_r	Series resistance
d_p	Penetration depth
d_e	Effective cavity length
d_t	IDT distance
d_g	Distance cavity between IDT and reflector
t_g	Delay
c_{12}	Reflectivity
r_s	Strip reflection coefficient
Q	Quality Factor
q	Complex Charge

CHAPTER 1

INTRODUCTION

1.1 Introduction

There has been a tremendous growth in the telecommunications industry over the past few decades with a subsequent increase in demand for high quality and reliable components. Surface Acoustic Wave (SAW) is being used as the main principle component in devices that are successfully applied to electrical signal processing for more than three decades. They are prevalently applied in the telecommunication industry, particularly as band-pass filters both in IF and RF sections, or in resonators due to their perfect performance, high accuracy, and smallness of size.

It is also employed in wireless communication systems due to demanding of higher operating frequencies, wider bandwidth and lower insertion loss. Besides, the high accuracy and crystal stability over time make SAW a suitable device in sensors application (e.g. pressure, temperature, and strain). Consequently, there is an increasing urgent need to improve this device in design, modeling, simulating, techniques of fabrication, and response prediction. The recent advances in sensor technology have become mainly possible by means of microtechnology, particularly with microfabrication technique to produce this device in real-life [1].

With the large number of components that are indispensable to achieve of the required functionality, the electric wiring of spatially distributed systems becomes complex and causes difficulties in system handling and installation. Through the use of wireless systems these problems can be overcome. Wireless systems have been successfully applied to the processing of electrical signals for more than 30 years, particularly in the telecommunication industry. This was first demonstrated in 1965, by the use of voltage-excited metal-film interdigital transducers on the surface of piezoelectric substrate as described by White and Voltmer [2]. Since then, however, SAW devices have become popular in consumer and communications systems [3, 4]. These wireless systems also can be used as a sensor, where they can communicate by ultrasonic or infrared signals [1].

The advantage of being wireless is that these SAW devices can be placed in unrestricted locations, and therefore making measurement close to its occurrence possible, independent of potentially harsh circumstances, such as in the power plant. At present, this knowledge is gained from costly periodic shutdowns and manual inspection. Because of the characteristics of SAW devices such as small in size, rugged and light weight which makes them a good choice for highly integrated wireless transceivers.

In addition, with the introduction of passive SAW devices in wireless application, no local power source for the device is required. SAW devices offer new and exciting perspectives for remote monitoring and control of moving parts, even in harsh environments where no other devices can operate. Another advantage is that no semiconductors are used in conjunction with the sensors, which are able to withstand a high dose of radiation and a powerful electromagnetic interference (EMI) up to the power endurance of the devices.

Surface acoustic waves are essentially mechanical waves (i.e. conventionally called acoustic waves) which propagate on the surface of an elastic medium with most of its energy concentrated near the substrate surface. In general, piezoelectric substrates such as quartz are used as elastic medium. The physical phenomenon on which the SAW devices are based is piezoelectricity, (i.e. the virtue by which certain materials produce electrical charge when mechanically strained or vice versa), which follows as structure depicted in Figure 1.1.

Figure 1.1 illustrates the relationship between stimulus and strain. It is valid for stationary/slowly changing events (i.e. piezoelectric actuator or sensor) or dynamic events (i.e. SAW device excited by an RF signal).

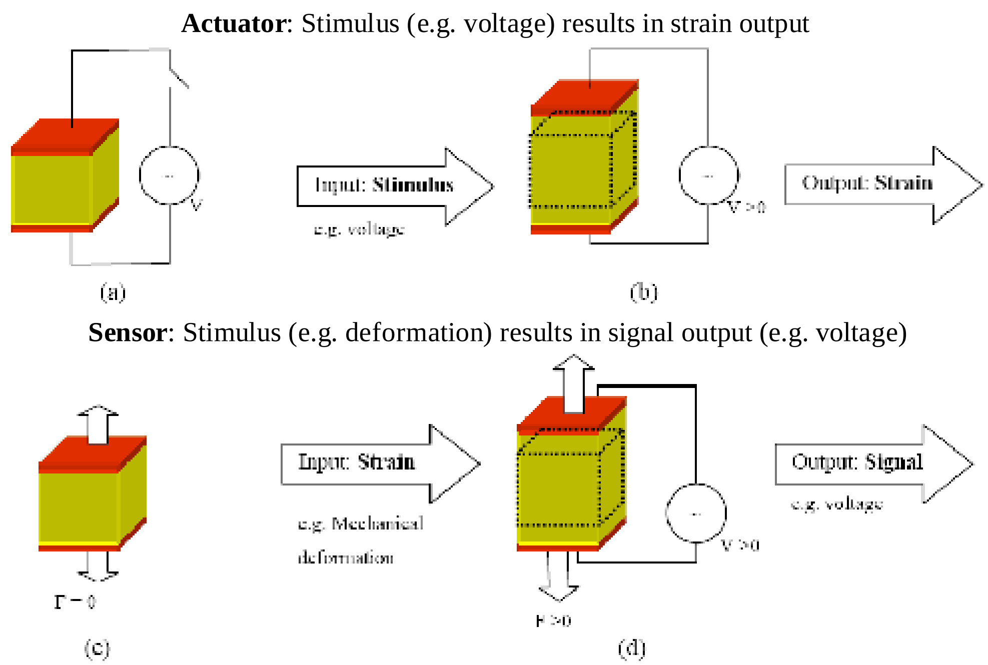

Figure 1.1: Stimulus-strain Relationship for Piezoelectric Substrate

The most important part of a SAW device is the Interdigital Transducer (IDT) or electrodes as shown in Figure 1.2. IDT is patterned on the surface of the piezoelectric substrate by using lithographic techniques. When an alternating electric input signal is applied to the electrodes, the electric field penetrates the piezoelectric substrate and surface acoustic waves are induced due to piezoelectric coupling. Similarly, charge accumulates on the electrodes in response to the acoustic waves, which in turn induces secondary acoustic waves. In this manner, IDTs can act as transmitters, receivers and reflectors collectively [5].

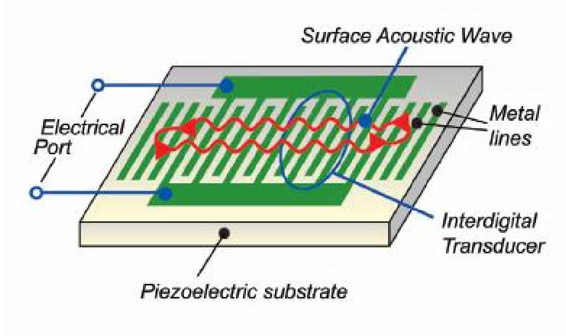

Figure 1.2: IDT in a SAW Device

Acoustic wavelength l is given by u/f where u is the velocity of SAW and f the frequency. The periodicity of the required interdigital electrodes is related to the acoustic wavelength l, and is equal to $l/2$ as shown in Figure 1.3. The surface wave velocity is typically five orders of magnitude smaller than that of electromagnetic waves in free space and therefore the wavelength is also much smaller at the same frequencies, which translate into smaller device sizes.

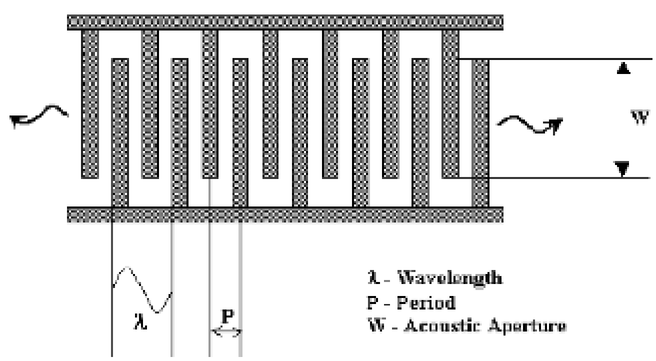

Figure 1.3: IDT Periodicity and Wavelength

Basically, there are two types of structure for SAW devices: delay line and resonator. A delay line is shown in Figures 1.4 (a) and (b), consists of two interdigital transducers (IDTs) (or an IDT and reflector), and a propagation path between them, while a resonator has one or two IDTs between the reflectors as shown in Figures 1.4