Acoustic Wave and Bond Rupture Based Biosensor – Principle and Development

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

at Massey University, Palmerston North
New Zealand

by

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2009

Abstract

Bond rupture is an experimental methodology that is used to augment a conventional mass balance biosensor. A good point-of-care biosensor is fast, reliable, simple, cost-effective, and detects low concentrations of the target analyte. Biosensor development is a multidisciplinary field and bond rupture testing is of technical interest to many groups. The Bond rupture methodology endows a mass probe with the ability to discern bond strength. The recognition of specific bonds by mass loading is separated from erroneous non-specific binding by a probe of the force between the analyte and the transducer. Bond rupture is achieved by acoustic excitation of the point of attachment. The force is incremented gradually until rupture occurs.

The advancement of bond rupture biosensors beyond the lab requires improved understanding of the mechanisms of bond rupture by base excitation, the transducers, and the supporting hardware. Bond rupture has traditionally been used in conjunction with the Quartz Crystal Microbalance (QCM). There exists, however, a variety of sensors and transducers to which the bond rupture methodology could be applied. The time, cost and experience required for comprehensive investigation of all avenues is prohibitive.

To further the development of bond rupture characteristic experiments are designed and carried out on the QCM platform. Numerical simulations are constructed which model the current bond rupture approach. This work is limited to the simulation of bond rupture by base excitation. From the results of the experimental investigation a number of improvements to the bond rupture technique are proposed. Improvements are tested by simulation and the Surface Acoustic Wave (SAW) device is selected to advance the bond rupture craft. A prototype SAW bond rupture device is designed. The prototype device is manufactured and tested, confirming the principle of SAW bond rupture.

Future work is required to progress the SAW bond rupture methodology before possible integration with other sensor systems. Because of this work, and the evaluation of the SAW bond rupture prototype, much is learned about the advancement of SAW device bond rupture.

ACKNOWLEDGEMENTS

This work would not have been possible without the support and encouragement of my three supervisors. Although we have been frequently scattered around the country and, at times, the world, we have maintained close contact and your guidance has been invaluable. I would like to thank Yong Yuan for many helpful discussions on all manner of topics, for initiating this project and for hosting me at Industrial Research Limited (IRL). I would like to thank Peter Xu for guiding me into this PhD and all throughout, for your enthusiasm, leadership, and always prompt feedback. I would like to thank John Bronlund for his unique perspective and close guidance while I was on campus. I would like to thank Matthew van der Werff, another PhD candidate from this diverse group, without whom there would be no bond rupture hardware.

I would like to thank Massey University for the award of the Massey University Doctoral Scholarship which supported me during the first three years of this work. And thanks to IRL for keeping me gainfully employed while I finished this thesis part time. I enjoyed my time at IRL immensely and I would like to thank them for hosting me, and this project. This work was performed under the auspices of the Foundation for Research, Science and Technology of New Zealand by Industrial Research Ltd. under New Economy Research Fund C08X0408. I appreciate the invaluable help and assistance from Harry Chen without whom I would have been lost in the lab. I am grateful for the help of all the Engineering and Applied Physics Group at Industrial Research Limited, Gracefield, Lower Hutt for your technical guidance and vibrant discussions.

It is a pleasure to thank my parents, Stephen and Sandra, and sisters, Carrissa and Shaelyn, for all their support during my long university career and for their endless supply of encouraging remarks. Thank you to all my friends who keep me sane throughout this experience. I must apologise to my family and all who are close to me for all the times I have bored them with the gory details of my work. I am grateful to all who have been so patient with me over this journey. I have learned a lot and, I think, come very far since we started.

RELATED PUBLICATIONS

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Nomenclature

A	Area
A	Acoustic Amplitude
B_a	Acoustic Susceptance
c_{ij}	Shear stiffness coeficients
C	Capacitance
C_0	Parallel capacitance of BVD equivalent circuit
C_m	Motional capacitance of BVD equivalent circuit
C_Q	Sensitivity of QCM to mass change
C_S	Sensitivity of SAW device to changes in mass
D	Dissipation, the reciprocal of Quality
d_{ij}	Piezoelectric coefficients
e	Piezoelectric Constant
E	Energy
E	Young's Modulus
$\boldsymbol{f}$	Body forces on a fluid
f	Frequency
f_0	Centre frequency if SAW device
g	Piezoelectric voltage coefficient
G	Shear Modulus (Modulus of Rigidity)
G_a	Radiation Conductance
h	Layer thickness
h_l	Guide layer thickness
h_q	Quartz thickness
h_s	Substrate thickness
$h(t)$	Time transfer function
$H(\omega)$	Frequency transfer function
I	Current
IL	Insertion Loss
k	Electromechanical coupling factor
l	Length of IDT
L	Inductance
L_m	Motional inductance of BVD equivalent circuit
m	Mass

N	Number of finger pairs in IDT transducer
N_f	Frequency Noise
p	Pressure
$p(t)$	Probability as a function of time
Q	Quality Factor
QCM	Quartz Crystal Microbalance
r	Radius or radial distance
R	Resistance
R_m	Motional resistance of BVD equivalent circuit
S	Sensitivity
SAW	Surface Acoustic Wave
t	Time
TCD	Temperature Coefficient of Delay
TCF	Temperature Coefficient of Frequency
u	Displacement
v	Poissons Ratio
v	Velocity
$\boldsymbol{v}$	Flow velocity
v_s	Shear Velocity
v_s	Phase velocity of substrate
v_{SAW}	Surface Acoustic Wave velocity
V	Voltage
V_d	Driving voltage
w	IDT finger Width
W_A	Work of Adhesion (J)
Z	Impedance
α	Thermal expansion coefficient
α	Angular Acceleration
ε	Dielectric Constant
θ	Angular displacement
λ	SAW wavelength
μ	Dynamic Viscosity
ρ	Density
τ	Time constant for exponential decay

τ	SAW delay time
υ	Kinematic Viscosity (μ/ρ)
ω	Angular frequency
ω_0	Centre frequency if SAW device, angular frequency