Development of Microgap and Nanogap Automated Permittivity Measurement System

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LIST OF ABBREVIATIONS

PMS	Permittivity Measurement System
MNAPMS	Micro and Nanogap Automated Permittivity Measurement System
V	Voltage
I	Current
A	Cross section of plate
x	Gap distance of nanogap
ε_r	Relative permittivity
ε_o	Electric constant
f	Frequency
X_c	Capacitance reactance
Z	Impedance
θ	Phase difference
R	Resistance
C	Capacitance
Q	Coulomb
k	Boltzmann constant
e	Charge of electron
T	Period of full cycle
n_o	Concentration of the species
S_n	unit less parameter
RF	Radio Frequency
L	Inductance
DC	Direct Current

I-V	Current vs Voltage
DUT	Device Under Test
SBC	Single Board Computer
I/O	Input Output Port
OSC	Voltage vs Time measurement
DA	Amplitude vs Frequency measurement
LOGIC	Measurement using logic analyzer
DNA	Deoxyribonucleic Acid
ANN	Artificial Neural Network
GUI	Graphic User Interface
GPIO	General Purpose Input Output

Membangunkan Sistem Automatik Pengukur Ketelusan Peranti Sela Mikro dan Nano

ABSTRAK

Objektif kajian ini adalah untuk membangunkan sistem elektronik yang terintegrasi dengan kapasitor biopenderia bersela nano. Sistem ini disebut Permittivity Measurement System (PMS). Ia mengukur nilai galangan kapasitor bersela nano dan mengira nilai ketelusan berdasarkan spesifikasi parameter kapasitor bersela nano yang diperolehi melalui proses pencirian. Parameter itu adalah kelebaran jurang, rintangan dalaman, nilai kapasitor dengan tanpa sampel, dan kawasan keratan rentas plat. Satu sampel kapasitor nanogap dan sepuluh sampel kapasitor microgap juga dicirikan. Terdapat lima komponen yang digabungkan untuk menghasilkan PMS. Komponen pertama adalah penjana gelombang bentuk sinus. Teknik yang digunakan untuk menjana gelombang sinus adalah penjana gelombang sinus kaedah digital. Julat frekuensi keluaran ialah dari 10Hz sehingga 1kHz dan voltan puncak ke puncak keluaran ialah 6V ke -6V. Komponen kedua adalah penapis lulus rendah. Komponen ini digunakan untuk menapis hingar dari gelombang sinus. MAX262 penapis aktif sejagat boleh aturcara dipilih sebagai penapis lulus rendah. Komponen ketiga yang mewujudkan PMS dan bersambung dengan kapasitor bersela nano adalah pengukur galangan. Kaedah automatik keseimbangan jambatan digunakan untuk mengukur nilai galangan dari kapasitor nano sela. Sebuah litar pemilih yang mempunyai lapan peringkat ditambah bagi meluaskan julat pengukuran galangan. Amplitud gelombang sinus yang dikenakan pada kapasitor nano sela ialah 200mV. Komponen keempat adalah pengukur pembezaan fasa. Ia bertanggungjawab untuk mengukur beza fasa antara gelombang arus dan voltan. Komponen kelima dan bahagian terpenting PMS adalah XScale-Mini SBC. Ianya bertanggung jawab untuk mengawal, menangkap, dan menganalisis isyarat daripada bahagian-bahagian lain dari PMS. Visual C++ digunakan untuk membangunkan bahagian perisian XScale-Mini SBC. Gelombang arus, gelombang voltan, dan juga keluaran pembezaan fasa ditangkap dan dianalisa. Semua litar diuji dan isyarat yang dihasilkan dipaparkan dan dibincangkan. Ujian menunjukkan bahawa PMS mampu untuk mengukur dengan ketepatan sehingga 85%. Simulasi untuk model elektrik DNA semasa imobilisasi dan hibridisasi dilakukan. Litar yang dibina diuji melalui pengukuran kapasitor mikro dan nano sela tanpa sampel.

Development of Micro and Nanogap Automated Permittivity Measurement System

ABSTRACT

The goal of this research is to develop an electronic system that integrated with nanogap capacitor biosensor. This system is called Permittivity Measurement System (PMS). It measures the impedance value of the nanogap capacitor and calculates the permittivity value based on the parameter specification of nanogap capacitor obtained through characterization process. The parameters are gap width, internal resistance, capacitance value with no sample, and cross section area of the plate. One sample of nanogap and ten samples of microgap capacitor are characterized. Five components combined to create PMS. The first component is the sinusoidal wave generator and the technique that employed for sinusoidal wave generation is the digital approximation sinusoidal wave generation technique. The output frequency range is from 10Hz until 1kHz and the output peak to peak voltage is 6V to -6V. The second component is the low pass filter. This component is used for filtering the noise from sinusoidal wave. MAX262 programmable universal active filter is selected as the low pass filter. The third component that creates PMS and has contact with the nanogap capacitor is the impedance measurement unit. The auto balancing bridge method is employed to measure the impedance value of the nanogap capacitor. A range circuit with eight level of selection is added to wider the impedance measurement range. The amplitude of the sinusoidal wave that applied to the nanogap capacitor is 200mV. The fourth component is the phase differential measurement unit. It is responsible to measure the phase difference between current and voltage wave. The fifth and the main component of PMS is the XScale-Mini SBC. It is responsible to control, capture, and analyze signal from the other component of PMS. Visual C++ is used to develop the software part of XScale-Mini SBC. The current wave, voltage wave, and also the output phase differential is captured and analyzed. All the circuits are tested and the produced signals is shown and discussed. The test shows that PMS is capable to measure up to 85% of accuracy. The simulation for the electrical model of DNA during immobilization and hybridization is performed. The fabricated circuit is tested through the measuring of micro and nanogap capacitance.

CHAPTER 1

BACKGROUND

1.1 Introduction

This chapter explains the development background of Micro and Nanogap Automated Permittivity Measurement System (MNAPMS). Next, the objective and the scope of the research are highlighted. After that, the problem concerning other method of DNA immobilization and hybridization detection is discussed. Lastly, the organization of this thesis is explained.

1.2 Overview of MNAPMS

The development idea of the Micro and Nanogap Automated Permittivity Measurement System came during the characterization process of the fabricated nanogap capacitor using Novocontrol Alpha-A Dielectric Analyzer. The analyzer is bulky, non-portable, expansive, and non-specific. Thus, another compact, portable, low cost, and specific system should be developed with fully integrated with the micro and nanogap capacitor in order to obtain the higher accuracy result.

The developments of MNAPMS are divided into three difference parts. The first part is the fabrication and characterization of micro and nanogap capacitor. It is developed using standard CMOS fabrication procedure. The second part is the development of Permittivity Measurement System (PMS). This electronic system integrates with the nanogap capacitor and measure the permittivity value of the sample introduce to the capacitor. The reasons for measuring the permittivity value instead of

capacitance value is because the permittivity value represented the value of the introduced sample in the capacitor but capacitance value represent the value of the capacitor with it sample. Although both values can produce the significant result, but the permittivity values are not tied to the type of capacitor that used in the measurement process. This means that whatever the type of micro and nanogap capacitor used in the measurement process the results are still the same. In order for the PMS to calculate the permittivity, value from the measured impedance, the gap length and the section area of the plate for the fabricated nanogap capacitor are required. The combination of nanogap capacitor with PMS is called the Micro and Nanogap Permittivity Measurement System (MNPMS). The third part of MNAPMS is the addition on Artificial Neural Network (ANN) to the MNPMS. The ANN is responsible to analyze the calculated permittivity value in order to determine the result of the DNA sample whether it hybridize or mismatch. The ANN requires training before it can make a proper decision. Figure 1.1 shows the three parts of MNAPMS.

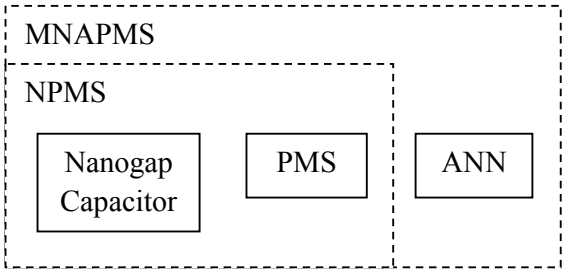

Figure 1.1**:** Three parts of MNAPMS

1.3 Problem Statement

The standard commercial approach to deoxyribonucleic acid (DNA) hybridization detection are based on the use of fluorescent, radioscope and other labels that can be schematically summarized in the following procedure:

i) A probe of single-stranded known sequence of DNA is immobilized on a substrate;

ii) The unknown sequence (target) is labeled with a specific tag;

iii) When hybridization occurs, the target sequence binds to its complementary strand immobilized on the surface; and

iv) Its presence can be optically detected.

The required instrumentation is bulky, costly, and not portable. For this reason, a number of new approaches for direct label-free detection of DNA hybridization have been proposed in the last decade such as detection based on quartz crystal microbalance (QCM) (Okahata, 1998), the cantilever-based techniques (Cai L., 2000), and several examples of electronic detection method (De Pablo P.J., 2000). Direct electronic detection has several advantages with respect to other approaches. The detector is incorporated in the substrate, the output signal can be directly acquired and processed on a chip, and automatic recognition is achievable in real time and at low cost. This research will help to enhance the detection of hybridized DNA and at the same time developed a DNA hybridization detection kit in a low cost approach.

The detection method for the immobilization and hybridization of DNA is almost the same as the standard commercial approch except for the immobilization process is done on the nanogap capacitor. The permitivity value of the DNA sample during immobilization and hybridization is measured and compared. If there are significant change in the measured permittivity value during immobilization and hybridization, the sample is consider hybridize. Otherwise, it is consider mismatch.

1.4 Objective

The objective of this research is to develop a measurement system that measures the permittivity value of micro and nanogap capacitor. This system is designed to detect the immobilization and hybridization of deoxyribonucleic acid (DNA).

1.5 Research Scope

This research is embarked based on these following scopes:

i) To execute masking design and fabrication process of micro and nanogap capacitor together with morphological and electrical characterization. One sample of nanogap capacitor and ten samples of microgap capacitor are morphologically and electrically characterize. The characterization result is crucial for the design of PMS.

ii) To design and simulate the Permittivity Measurement System (PMS) circuits. It consists of power supply circuit, sinusoidal wave generation circuit, low pass filter circuit, and impedance measurement circuit and phase differential measurement circuit. The National Instrument MultiSim simulation software is used to validate the circuits design.

iii) To write the programming code for XScale-Mini single board computer using Visual C++. An analysis is done in order to obtain the permittivity value from the captured signals. A Graphic User Interface (GUI) is used as the system interface and displays the output result.

iv) To fabricate the Permittivity Measurement System (PMS) circuits. The fabricated circuits are interfaced with the XScale-Mini single board

computer. The samples of micro and nanogap capacitors are used to test the measurement accuracy of PMS.

1.6 Thesis Organization

This research thesis is divided into seven chapters. Chapter 1 explains the background development of MNAPMS. Next, the research objective and the research scope are defined and the problem statement is discussed.

Chapter 2 highlights the theoretical approach for the development of PMS. The chapter starts with explanation of biosensor application and continues with the discussion about the principle of the capacitor and the theory for the use of nanogap capacitor as a biosensor. The method of impedance measurement and its principle are discussed before a brief explanation of DNA.

Chapter 3 discusses about nanogap capacitor and its fabrication process. This chapter starts with the clarification of the starting material used for the fabrication of nanogap capacitor. Then, the chapter continues with the discussion of the masking design and the fabrication process step. After that, the morphological and electrical characterization for ten fabricated microgap sample and one sample of nanogap capacitor is explained. Lastly, the calculation of an electrical modal for nanogap capacitor during immobilization and hybridization state is done.

Chapter 4 explains about the hardware design of PMS. The design procedures starts with the design of power supply circuit and continues with the design of sinusoidal wave generation circuit, programmable low pass filter circuit, impedance measurement circuit, and the phase measurement circuit. The design of each circuit is thoroughly explained and the simulation result using NI Multisim 10 are showed and

discussed. The simulations of the electrical model for DNA immobilization and hybridization are also done and the capacitance value for those models is calculated.

Chapter 5 discusses about the software development part of PMS. The chapter starts with the discussion of GUI design for PMS. Next, the whole PMS programming is summarized on the general flow chart and the specific programming for the low pass filter, clock generation, signal capture, signal analysis, and display programming flow chart are also explained.

Chapter 6 is about the testing and interfacing of the fabricated circuit with XScale Mini Single Board Computer. This chapter starts by explaining the type of test that is performed to the fabricated circuits. The programming function that associated with the sinusoidal wave generation circuit, programmable low pass filter circuit, impedance measurement circuit, and phase differential measurement circuit is also discussed. The measurement for accuracy of the fabricated PMS is done.

Chapter 7 summarizes the main contribution of the thesis and possible direction for future research is presented.