FABRICATION OF FREQUENCY SELECTIVE STRUCTURE AND EVALUATION OF MICROWAVE TRANSMISSION ON ENERGY SAVING GLASS

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The use of energy saving glass has become very popular in the modern day building design. This energy saving property is achieved by applying a very thin tin oxide (SnO$_2$) coating on one side of the glass. This coating can provide good thermal insulation to the buildings by blocking infrared rays while being transparent to visible part of the spectrum. Drawbacks of these energy saving windows is that it also attenuates the transmission of useful microwave signals through them. These signals fall within the frequency band of 0.8GHz to 2.2GHz. In order to pass these signals through the coated glass, the use of aperture type frequency selective surface (FSS) has been proposed. In the present work, SnO$_2$ thin film with FSS structure was fabricated using RF magnetron sputtering technique and printed circuit board technology. Deposition time, dissipation power and oxygen flow rate were varied during the sputtering deposition process. Atomic force microscopy (AFM) and field emission-scanning electron microscopy (FE-SEM) were used to analyze the surface morphology and roughness of the SnO$_2$ thin film. Two point electrical probe analysis was used to determine the sheet resistance and resistivity of the SnO$_2$ thin film. Thickness of SnO$_2$ thin film was measured using surface profiler. Good correlation between the surface properties and electrical properties of SnO$_2$ thin film was obtained. Microwave transmission through SnO$_2$ coated glass with FSS structure was also analyzed using network analyzer. The result of computer simulation was confirmed and consistent with the network analyzer results that showed the improvement of SnO$_2$ coated glass with the FSS structure. Thermal analysis demonstrated that FSS structure had allowed the transmission of GSM mobile signal penetrate in the buildings while blocking the infrared light with the SnO$_2$ film properties.
ABSTRAK

# CONTENTS

<table>
<thead>
<tr>
<th>TITLE</th>
<th>i</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>vi</td>
</tr>
<tr>
<td>CONTENTS</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF SYMBOLS AND ABBREVIATIONS</td>
<td>xix</td>
</tr>
</tbody>
</table>

## CHAPTER 1 INTRODUCTION

1. Background of Research  
   1.1  
2. Problem Statement and Objective  
   1.2  
3. Scope of Research  
   1.3  
4. Outline of Thesis  
   1.4

## CHAPTER 2 LITERATURE REVIEW

1. Energy Saving Glass  
   2.1  
2. Thin Film Deposition  
   2.2

## CHAPTER 3 RESEARCH METHODOLOGY

1. Radio Frequency (RF) Magnetron  
   3.1  
   Sputtering Deposition  
   3.2  
2. Computer Simulation Technology (CST)  
   3.2.1  
3. Printed Circuit Board Technology and  
   3.3  
   Fabrication of FSS Structure  
   3.3.1  
4. Thin Film Characterization  
   3.4  
   Surface Profiler and Two Point Probe  
   3.4.1
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4.2</td>
<td>Field Emission Scanning Electron Microscope (FESEM) and Atomic Force Microscope (AFM)</td>
</tr>
<tr>
<td>3.4.3</td>
<td>X-Ray Diffraction (XRD) and UV-Vis</td>
</tr>
<tr>
<td>3.5</td>
<td>Spectrum Analyzer, Network Analyzer, Glass and Thermal Properties</td>
</tr>
<tr>
<td>3.6</td>
<td>Glass Dielectric Constant Measurement</td>
</tr>
</tbody>
</table>

**CHAPTER 4 ELECTROMAGNETIC SIMULATION USING CST: FSS STRUCTURE**

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>CST Simulation Using Various SnO$_2$ Sheet Resistance Values</td>
</tr>
<tr>
<td>4.1.1</td>
<td>CST Simulation Using Conventional Sheet Resistance</td>
</tr>
<tr>
<td>4.1.2</td>
<td>CST Simulation Using Sheet Resistance of SnO$_2$ Thin Film Deposited Using RF Magnetron Sputtering System</td>
</tr>
<tr>
<td>4.2</td>
<td>CST Simulation Using Various Shape of FSS Structure</td>
</tr>
</tbody>
</table>

**CHAPTER 5 SnO$_2$ THIN FILM ANALYSIS**

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Electrical Properties of SnO$_2$ Thin Film Deposited at Various Parameters</td>
</tr>
<tr>
<td>5.1.1</td>
<td>Thickness and Sheet Resistance of SnO$_2$ Deposited at Different Deposition Time</td>
</tr>
<tr>
<td>5.1.2</td>
<td>Correlation between Thickness and Sheet Resistance of SnO$_2$ Thin Film</td>
</tr>
<tr>
<td>5.2</td>
<td>Physical properties of SnO$_2$ Thin Film</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Roughness analysis using AFM</td>
</tr>
<tr>
<td>5.2.2</td>
<td>FESEM Result of SnO$_2$ Thin Film</td>
</tr>
<tr>
<td>5.3</td>
<td>Structural Composition and Optical Properties of SnO$_2$ Thin Film</td>
</tr>
<tr>
<td>5.3.1</td>
<td>XRD Result of SnO$_2$ Thin Film</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Optical Transmission through SnO$_2$ Thin</td>
</tr>
</tbody>
</table>
Film

5.4 Thickness and Sheet Resistance of SnO₂ Deposited at Different Oxygen Flow Rate

5.5 Physical properties of AFM Result for SnO₂ thin film

5.5.1 FESEM Result of SnO₂ Thin Film

5.5.2 XRD Result of SnO₂ Thin Film Deposited at Different Oxygen Flow Rate

5.6 Thickness and Sheet Resistance of SnO₂ Deposited at Different Dissipation Power

5.6.1 AFM Result of SnO₂ Thin Film Deposited at Different Dissipation Power

5.6.2 FESEM Result of SnO₂ Thin Film Deposited at Different Dissipation Power

5.7 XRD Result of SnO₂ Thin Film Deposited at Different Dissipation Power

CHAPTER 6 MOBILE RADIO SIGNAL TRANSMISSION AND THERMAL PROPERTIES THROUGH SnO₂ THIN FILM DEPOSITED AT VARIOUS PARAMETERS

6.1 Signal Magnitude Analysis

6.1.1 Signal Magnitude Analysis Result of SnO₂ Film Deposited at Different Deposition Time

6.1.2 Signal Magnitude Analysis Result of SnO₂ Film Deposited at Different Oxygen Flow Rate

6.1.3 Signal Magnitude Analysis Result of SnO₂ Film Deposited at Different Dissipation Power

6.2 Signal Transmission Analysis

6.2.1 Signal Transmission Result of SnO₂ Film Deposited At Different Deposition Time
6.2.2 Signal Transmission Result of SnO$_2$ Film Deposited At Different Oxygen Flow Rate

6.2.3 Signal Transmission Result of SnO$_2$ Film Deposited At Different Dissipation Power

6.3 Thermal Insulation Properties

CHAPTER 7 CONCLUSION

7.1 Strength of this Project

7.2 Future Work

REFERENCES

APPENDICES
LIST OF FIGURES

2.1 Illustration of energy saving glass with the FSS structure. 8
3.1 Flow chart to fabricate energy saving glass 11
3.2 Tin oxide (SnO$_2$) target material. 12
3.3 Fluorine Tin Oxide (FTO) target material. 12
3.4 Schematic diagram of magnetron source. 13
3.5 Magnetron sputtering operation system. 14
3.6 Overview of RF magnetron sputtering setup. 15
3.7 CST studio suite 2013 used for simulation. 15
3.8 Basics procedure in CST simulation. 16
3.9 Process flow of FSS formation. 17
3.10 Procedure on frequency selective structure (FSS) printed on the glass. 18
3.11 Front illustration for the glass before and after coating. 19
3.12 Surface profiler Alpha Step IQ. 20
3.13 Electrical properties measured using 2 point probing. 21
3.14 Image of the FESEM (JEOL JSM-7600F) operation system. 21
3.15 Configuration of the FESEM (JEOL JSM-7600F) operation system. 22
3.16 Image of the Park System AFM (model XE-100) operation system. 22
3.17 Configuration of the Park System AFM (model 23
XE-100) and its operation.

3.18 Glazing incidence diffraction experimental setup.

3.19 Picture of the Panalytical X’Pert Pro-MRD used for the measurement.

3.20 Illustration of UV-Vis spectrometry.

3.21 Measurement setup for spectrum analyzer.

3.22 Spectrum analyzer of Advantest R3132 used in measurement.

3.23 Experimental setup for spectrum analysis.

3.24 Measurement setup for network analyzer testing.

3.25 Picture of Rohde&Schwarz network analyzer (ZVB 4) used in the measurement.

3.26 Experimental setup for the network analyzer testing.

3.27 Measurement setup for temperature measurement.

3.28 Experimental setup for temperature measurement.

3.29 IR thermometer used in temperature measurement.

3.30 Agilent 4291B used for dielectric constant measurement.

3.31 Glass attached to the rod for measurement.

4.1 Dielectric constant measured by Agilent 4291B.

4.2 Illustration of sheet resistance measured by the 2 point probe.

4.3 Microwave transmission at various ohmic sheet resistances and without FSS structure.

4.4 Microwave transmission at various ohmic sheet resistances and with FSS structure.

4.5 Microwave transmission at 4 ohmic sheet resistances and with and without FSS structure.

4.6 Microwave transmission at 6 ohmic sheet resistances and with and without FSS structure.
4.7 Microwave transmission at various deposition times with the FSS structure.
4.8 Microwave transmission at various oxygen flow rate with the FSS structure.
4.9 Microwave transmission at various dissipation powers with the FSS structure.
4.10 Design of cross-dipole frequency selective surface unit cell on energy saving glass.
4.11 Design of circle frequency surface unit cell on energy saving glass.
4.12 Design of pentagon frequency selective surface unit cell on energy saving glass.
4.13 Design of triangle frequency selective surface unit cell on energy saving glass.
4.14 Design of combine structure frequency selective surface unit cell on energy saving glass.
4.15 A plot demonstrating technique to measure full width half maximum, minimum transmission loss and peak frequency from the simulation result.
4.16 Transmission loss through different shapes of frequency selective surface.
4.17 Effect on different shapes through FWHM and peak frequency analysis.
4.18 Minimum transmission loss through different shapes of frequency selective structure.
4.19 Surface area etched with the minimum transmission loss with different shapes.
5.1 Thickness of SnO\textsubscript{2} film under different deposition time.
5.2 Correlation between sheet resistance and resistivity of the SnO\textsubscript{2} thin film under different deposition time.
5.3 AFM image of SnO$_2$ thin film deposited at (a) 10 minutes, (b) 20 minutes and (c) 30 minutes deposition time.

5.4 FESEM image of SnO$_2$ thin film deposited at (a) 10 minutes, (b) 20 minutes and (c) 30 minutes.

5.5 XRD image of SnO$_2$ thin film that deposited at different deposition time.

5.6 Transmittance of SnO$_2$ thin film that deposited at different deposition time.

5.7 Thickness and deposition rate of SnO$_2$ film under different oxygen flow rate.

5.8 Correlation between sheet resistance and resistivity under different oxygen flow rate.

5.9 AFM image of SnO$_2$ thin film deposited at (a) 0 sccm, (b) 4sccm, (c) 8sccm and 16sccm.

5.10 FESEM images of SnO$_2$ thin film deposited at (a) 0 sccm, (b) 4sccm, (c) 8sccm and (d) 16sccm of O$_2$ flow rate. The RF power and total pressure were 225W and 8.25mTorr, respectively.

5.11 XRD image of SnO$_2$ thin film that deposited at different oxygen flow rate.

5.12 Transmittance of the SnO$_2$ thin film that deposited at different oxygen flow rate.

5.13 Correlation of thickness and deposition rate of SnO$_2$ thin film with different dissipation power.

5.14 Correlation between sheet resistance and resistivity under different dissipation power.

5.15 AFM image of SnO$_2$ thin film that deposited (a) 150W, (b) 200W, (c) 225W, (d) 250W and (e) 300W.

5.16 FESEM images of SnO$_2$ thin film deposited at (a) 150W, (b) 200W, (c) 225W and (d) 250W and (e)
300W of dissipation power. The deposition time and total pressure were 20 minutes and 8.25 mTorr, respectively.

5.17 XRD image of SnO$_2$ thin film that deposited at different dissipation power.

5.18 Transmittance of SnO$_2$ thin film that deposited at different dissipation power.

6.1 Mobile signal strength tested with spectrum analyzer at (a) 0°, (b) 15° (c) 30°.

6.2 Signal magnitude analysis on a SnO$_2$ thin film with FSS structure that deposited at different deposition time.

6.3 Signal magnitude analysis on a SnO$_2$ thin film with FSS structure that deposited at different deposition time.

6.4 Signal magnitude analysis at 15 degree on a SnO$_2$ thin film that deposited at different deposition time.

6.5 Signal magnitude analysis at 15 degree on a SnO$_2$ thin film with FSS structure that deposited at different deposition time.

6.6 Signal magnitude analysis at 30 degree on a SnO$_2$ thin film that deposited at different deposition time.

6.7 Signal magnitude analysis at 30 degree on a SnO$_2$ thin film with FSS structure that deposited at different deposition time.

6.8 Signal magnitude analysis on a SnO$_2$ thin film that deposited at different oxygen flow rate.

6.9 Signal magnitude analysis on a SnO$_2$ thin film with FSS structure that deposited at different oxygen flow rate.
6.10 Signal magnitude analysis at 15 degree on a SnO$_2$ thin film that deposited at different oxygen flow rate.

6.11 Signal magnitude analysis at 15 degree on a SnO$_2$ thin film with FSS structure that deposited at different oxygen flow rate.

6.12 Signal magnitude analysis at 30 degree on a SnO$_2$ thin film that deposited at different oxygen flow rate.

6.13 Signal magnitude analysis at 30 degree on a SnO$_2$ thin film with FSS structure that deposited at different oxygen flow rate.

6.14 Signal magnitude analysis on a SnO$_2$ thin film that deposited at different dissipation power.

6.15 Signal magnitude analysis on a SnO$_2$ thin film with the FSS structure that deposited at different dissipation power.

6.16 Signal magnitude analysis at 15 degree on a SnO$_2$ thin film that deposited at different dissipation power.

6.17 Signal magnitude analysis at 15 degree on a SnO$_2$ thin film with the FSS structure that deposited at different dissipation power.

6.18 Signal magnitude analysis at 30 degree on a SnO$_2$ thin film that deposited at different dissipation power.

6.19 Signal magnitude analysis at 30 degree on a SnO$_2$ thin film with the FSS structure that deposited at different dissipation power.

6.20 Signal transmission testing on a SnO$_2$ thin film that deposited at different deposition time.

6.21 Signal transmission testing on a SnO$_2$ thin film.
with the FSS structure that deposited at different deposition time.

6.22  Signal transmission testing on a SnO₂ thin film that deposited at different oxygen flow rate.

6.23  Signal transmission testing on a SnO₂ thin film with the FSS structure that deposited at different oxygen flow rate.

6.24  Signal transmission testing on a SnO₂ thin film that deposited at different dissipation power.

6.25  Signal transmission testing on a SnO₂ thin film with the FSS structure that deposited at different dissipation power.

6.26  Measured temperature for different samples of glass.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>Distance</td>
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<tr>
<td>Θ</td>
<td>Bragg angle</td>
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<tr>
<td>λ</td>
<td>Wavelength</td>
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<tr>
<td>l</td>
<td>Length</td>
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<td>A</td>
<td>Area</td>
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<td>w</td>
<td>Width</td>
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<tr>
<td>R</td>
<td>Resistance</td>
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<tr>
<td>Rho</td>
<td>Resistivity</td>
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<tr>
<td>Rs</td>
<td>Sheet Resistance</td>
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<tr>
<td>t</td>
<td>Thickness</td>
</tr>
<tr>
<td>SnO₂</td>
<td>Tin dioxides</td>
</tr>
<tr>
<td>FTO</td>
<td>Fluorine Tin Oxide</td>
</tr>
<tr>
<td>FSS</td>
<td>Frequency Selective Structure</td>
</tr>
<tr>
<td>AFM</td>
<td>Atomic Force Microscope</td>
</tr>
<tr>
<td>FE-SEM</td>
<td>Field Emission Scanning Electron Microscope</td>
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<tr>
<td>Na₂CO₃</td>
<td>Sodium Carbonate</td>
</tr>
<tr>
<td>NaOH</td>
<td>Sodium Hydroxide</td>
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<tr>
<td>XRD</td>
<td>X-Ray Diffraction</td>
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<tr>
<td>CST</td>
<td>Computer Simulation Technology</td>
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<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>CVD</td>
<td>Chemical Vapor Deposition</td>
</tr>
<tr>
<td>O₂</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Ar</td>
<td>Argon</td>
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<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>Cu</td>
<td>Copper</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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</tr>
<tr>
<td>PSPD</td>
<td>Position-Sensitive Photo Detector</td>
</tr>
<tr>
<td>Au</td>
<td>Gold</td>
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<tr>
<td>2D</td>
<td>Two Dimensional</td>
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<td>Three Dimensional</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background of Research

Malaysia is a tropical country with hot and wet weather all along the years [1]. With the weather of 34°C in average, air conditioning is basic equipment in modern buildings to release the heats to outside [2]. Thus, electrical power consumption increases with the air conditioning usage in the buildings. In addition, heavy usage of air conditioning is not good for the mother earth due to depleting of ozone layer [2]. Recently, energy saving glass has been developed to overcome this problem [3–12]. Energy saving glass could help to reduce the temperature inside the buildings by reflecting the infrared light that penetrates through the building.

The most basic energy saving glass is a glass that applied with a very thin tin oxide (SnO$_2$) film on it. This SnO$_2$ material is a semiconducting oxide that have higher band gap that are suitable in the gas sensors [13–17] due to the higher free electrons in the oxygen vacant holes and thus increased the electrical conductivity of the thin film, solar cells [18], flat panels display [19] and photo catalysis [20]. However, the disadvantage of the energy saving glass is that it reflects the important electromagnetic wave such as GSM mobile signal, GPS and Bluetooth. In order to improve the electromagnetic signal inside the building, FSS had been added into the energy saving glass [6], [8], [21–24]. This FSS structure helps to enhance the electromagnetic wave inside the building. Different FSS structure will give different transmission at various frequencies. The optimized FSS structure will give the better transmission in the particular frequency.
FSS is a structure that allows certain frequencies to pass through it while blocking other frequencies. The use of FSS in this project was to improve the microwave frequencies. In the past few years, many researchers had tried to apply different structures on the energy saving glass [6], [21–25]. Bandpass FSS that act as filters with single, double, and triple glass used to improve the transmission of RF/microwave frequencies. The sheet resistance of the film plays a vital role in the improvement of the energy saving glass with the FSS structure. From Liu et al. findings, decreased in sheet resistance will increase the shielding effect of the electromagnetics wave [26]. The material of the metal oxide had the effects towards the sheet resistance of the film. The transmission of the electromagnetic wave affects once the sheet resistance changed.

Besides that, most of the researchers were using the Pilkington energy saving glass to form the FSS structure on it with the laser technique [27]. In this thesis, fabrication of energy saving glass with FSS structure will be presented. The fundamental properties of coated SnO$_2$ thin film and its testing toward FSS applications will be discussed. These testing and analyses are needed for optimum usage of energy saving glass application at the modern design building.

Fluorine doped tin oxide (FTO) is the common material used for the energy saving glass that fabricated by Pilkington United Kingdom (UK) [28]. The technique used by Pilkington was chemical vapor deposition (CVD) technique. However, FTO material is not an environmental friendly material due to fluorine gas process which is a toxic gas. Thin film fabrication under CVD technique will require high temperature which needs more time in production.

Indium tin oxide (ITO) also been found in the microwave frequency application [29]. But, the ITO is an expensive material that will results in high production cost. In the present research, magnetron sputtering process will be used to fabricate SnO$_2$ thin film. The deposition was done in room temperature which had reduced the processing time and then lead to cost saving effect. Besides that, the energy saving glass available for four season country is double panels that argon gas was filled in the middle of it [6], [9], [12], [21], [28], [30] and currently none of the research was reported in Malaysia. This energy saving glass is specially designed for four season countries. While Malaysia is a tropical country that only needs a single panel of energy saving glass [31]. For single panel energy saving glass is relatively
cheaper than the double panel energy saving glass that filled with Argon gas. SnO$_2$ was used as the material for energy saving glass due to its high reflectivity towards the infrared light (IR) [32–34]. Besides that, SnO$_2$ thin film is also chemically stable that can stay long lasting [35–37].

1.2 Problem Statement and Objective

Nowadays, energy saving glass can keep the room cold at the summer and warm at the winter. But at the same time it attenuates the useful microwave frequencies such as GSM mobile signal. Because of this, a FSS structure needs to be added into energy saving glass to improve the transmission of the energy saving glass. Different design of FSS can have different of transmission on the glass. The transmission loss also been influenced by the sheet resistance of the film.

The objectives of this project are to:

1. To simulate the transmission of the microwave signal through energy saving glass with different structure of FSS.
2. To experimentally deposit tin oxide (SnO$_2$) on glass substrate using RF magnetron sputtering technique and evaluate its characteristics.
3. To evaluate the heat reduction, mobile radio signal transmission through the SnO$_2$ glass with FSS structure and without FSS structure fabricated by RF magnetron sputtering.

1.3 Scope of Research

In order to meet above objectives, this project is carried out according to below:

1. Computer simulation using CST software for different FSS structure in microwave frequencies.
2. Fabrication of FSS structure using printed circuit board technology.
3. Deposition of SnO$_2$ thin film using RF magnetron sputtering plasma.
4. Surface morphology, optical and electrical properties of SnO$_2$ thin film analyses.
5. Microwave transmission analysis in the frequency range of 0.8-2.2GHz through SnO$_2$ coated glass with FSS structures.
1.4 Outline of Thesis

This thesis is consists of 7 chapters. The first chapter describes an overview of this project. The second chapter explains the literature review of previous works and techniques used in this project. The third chapter presents the experimental setup and equipment used for analyses. The fourth chapter explains the SnO$_2$ thin film analysis on electrical, physical and optical properties. The fifth chapter describes the CST simulation with different FSS structures and sheet resistance obtains from the electrical properties of the SnO$_2$ film. The sixth chapter presents the microwave transmission analysis tested with spectrum and network analyzers. Finally, the last chapter described conclusion of the findings throughout the project and propose future work.
CHAPTER 2

LITERATURE REVIEW

Energy saving glass was widely applied in the buildings nowadays. This energy saving glass used to save the power consumption and the mother earth [38]. Malaysia is a tropical country which is hot and wet weather, throughout the year. Energy saving glass was applied a transparent metallic oxide layer on it. The metal oxide has the ability to reflect the electromagnetic radiation from penetrates into the buildings. But this metallic oxide layer also attenuates the useful signal such as GSM mobile radio signal. In order to improve the electromagnetic wave such as GSM mobile radio signal, a FSS was introduced. The main reason of applying FSS glass was to eliminate the electromagnetic radiation of infrared as much as possible and then the electromagnetic wave of GSM mobile radio signal can be passing through.

Energy saving glass had been widely explored by many researchers to obtain better transmission in microwave frequency range in the past few years [5], [9], [27], [39]. For example, Irfan et al had successfully design an energy saving glass with dual bandpass FSS by hard coating technique [23]. From his findings, the FSS structure able to attenuates 92.7% IR radiation. While Syed et al had reported that combination of low pass and high pass FSS glass had 30dB transmission improvement in the microwave frequency range [6]. Besides that, Mats et al reported that the transmission improvement of 10dB had been achieved with FSS window [12]. Then, Rafique et al had successfully designed a dual band circular loop FSS with the improvement in transmission of 26.4dB [24]. Last but not least, Ghaffer et al had reported that cross dipole FSS had transmission improvement in the microwave frequency range of 11.3dB [27].
FSS had broadly used in many other applications such as antenna, building and transportation. From the findings, Philippakis et al had reported that FSS structure can applied on the wallpaper for better transmission [21]. Besides that, Russo et al had successfully design FSS structure on the application of beam steering [40]. Then, Ragan et al had reported that FSS structure in millimeter wave integrated circuits application [41]. The application of FSS in millimeter astronomy had reported by Ge et al [42]. Lastly, Lee et al had reported that FSS structure can improve the WLAN application in his findings [43].

2.1 Energy Saving Glass

Energy saving glass had widely been developed in the past few years. The energy saving glass applied in the country which has four seasons is good that could maintain the temperature in winter or summer. But in Malaysia, energy saving glass can helps to reduce the high temperature inside the buildings even though Malaysia do not have four season. With the energy saving glass applied on the buildings will help to save a lot of the electricity bill for long term usage.

Energy saving glass is divided into two types, which are tinted film and thin film. Tinted film is well known in the market today that have the properties to reflect heats and infrared light in the automotive application. In the tinted film category, there are few types that consist of percentage of visible light and infrared transmission.

The thin film deposited on the glass with any material can defined as thin film that thickness of the film was ranging in nanometer. The differences of tinted film and thin film are on the visibility of the glass and features on it. One can feel with hand for tinted film but not for thin film. In this project, RF magnetron sputtering technique was chosen for the thin film deposition. RF sputtering is a technique that has high deposition rate, good reproducibility and good adhesion [44–46]. Kim et al had done his project with investigate electrical properties of SnO$_2$ film deposited by RF magnetron sputtering [44]. In his research, low resistivity and high mobility was found in SnO$_2$ thin film for gas sensor application. Shinzo et al reported that SnO$_2$ film prepared by DC magnetron sputtering applied on optoelectronics devices [45]. In the research, lowest resistivity was established at low
temperature in organic film substrates. Dan et al had deposited SnO$_2$ by RF magnetron sputtering for solar cells application [46]. In his project, oxygen partial pressures were investigated towards the resistivity of the SnO$_2$ film as the buffet layer of the solar cells. The findings obtain from this project was when increased the oxygen partial pressure, the resistivity of the film decreased.

Tin oxide thin film had been deposited by RF magnetron sputtering. SnO$_2$ film is a transparent conducting oxides that usually found in the gas sensor and solar cells application [14], [16], [18], [47–48]. From Selin et al findings, amorphous films has the water permeation resistance [49]. For the window in the buildings, the water resistance ability is very important to ensure that the SnO$_2$ film towards the heat insulation properties is maintained. Besides that, SnO$_2$ film also chemically stable, low resistivity and high optical transmittance that is suitable for energy saving glass applications [36], [50].

FSS is an aperture that only allows certain of frequency band to pass through it [51–52]. Different FSS structure will brings different effects on the transmission along the frequencies range. FSS structure can be added in wallpaper [21], [53] and antenna application other than energy saving glass application [8], [22–24], [30], [33], [40–42], [54–72]. FSS structure added will help to improve the electromagnetic wave such as GSM mobile signal, wireless network, GPS and bluetooth signal in the certain area [43]. The interest of frequency range in this thesis is the microwave frequencies which range between 0.8GHz to 2.2GHz.

The concept of FSS has a long history of development over years. Several applications of FSS can be applied on marketable things and military sectors to enable multiple frequency band operation. For an example, FSS concept had been applied in microwave oven which reflects at 2.45GHz microwave energies but allowing light to pass through it [73].

CST is a tool that used to simulate the FSS structure on the glass towards the transmission in the frequency range of 0.8GHz to 6GHz. It helps to analyze the transmission from the transmitter to receiver with different design and different sheet resistance to figure out the most suitable parameter or material to be used in the energy saving glass application. It will save time and cost with the pre simulation before the experimental deposition. But all the simulation in this tool is taking perfect situation that without any losses.
In the CST simulation, several shapes of the FSS had been simulated and analyzed for better transmission of the electromagnetic wave that focuses on 900MHz which is GSM mobile radio signal. The selected structure was analyzed by transmission loss, bandwidth, and the center frequency of the transmission in the microwave range.

![Figure 2.1: Illustration of energy saving glass with the FSS structure.](image)

Figure 2.1 shows the energy saving glass that coated with SnO$_2$ film that FSS structure had been added in it. The FSS structure is specially designed to bypass the GSM mobile signals that pass through the buildings. In the energy saving glass fabrication is divided into two which are hard coating and soft coating. Hard coating means that the glass been manufactured at high temperature near 1000°C that material of energy saving glass was added in the coating process. This hard coating glass can be directly applied to buildings as windows once it had been done. While for the soft coating, the coating process is separated from bare glass process. The coating was done on the surface of the bare glass. The difference between the hard coating and soft coating is the FSS structure can be formed in soft coating and not in the hard coating. Both hard and soft coating can produced energy saving glass. In this project, the aims are to investigate property of SnO$_2$ film with FSS in energy saving glass application. In this thesis, soft coating process was used with magnetron sputtering technique to fabricate the energy saving glass. In soft coating process, various parameters can be studied to characterize the optimum SnO$_2$ thin film for energy saving glass application. Hard coating means that the material is embedded in the glass when the manufacturing of the glass. While for the soft coating, it is the off-line process with the glass manufacturing. Various parameters can be changed for soft
coating process such as layer of the coating, material, deposition time to study the properties of the glass to suit the energy saving glass or other applications.

In this project, PCB technique was used to deposit FSS structure on glass. Besides that, PCB technique is widely seen in fabricating electronic devices. This PCB technique was the cheapest and fastest way in fabrication. This same technique was applied on this project with copper sheet changed to glass substrate. With that, the production cost of the energy saving glass will be cut down.

2.2 Thin Film Deposition

SnO$_2$ material is a tetragonal n-type semiconductor having high band gap energy ($\approx$3.6eV) [74]. Tin oxide thin film has been reported for various applications mostly on optics, solar, transistor and gas sensor [16], [75–78]. Chemical vapor Deposition (CVD), sol-gel, electrode deposition and magnetron sputtering techniques are familiar as deposition technique used for thin film deposition. In this project, magnetron sputtering technique has been chosen due to its highly reproducible, chemically stable and high deposition rate [44], [79]. In addition, the deposition occurs at room temperature condition which is much cheaper in cost. In general, there are two sources power in magnetron sputtering technique which is Radio Frequency (RF) and Direct Current (DC). Radio frequency source is suitable for most of the target material while direct current source is more suitable for metal target material. In this project, SnO$_2$ was chosen as target material thus RF source power supply was chosen for magnetron sputtering deposition. Tin oxide is a fragile material, therefore the copper backing plate is required on tin oxide target. In this project, RF source power supply was chosen instead of DC source power supply was because of tin oxide is a breakable material that is not suitable for to apply DC source power supply. In RF source power supply, the power will go to auto matching box before reach the target material. While the DC source power supply, the power will directly go to target material without any auto matching box. The purpose of auto matching box was to control the power supply source constantly in the process of deposition.

From this chapter, the energy saving glass properties was studied. Soft coating method was selected because FSS structure can be formed on it. RF
magnetron sputtering technique was chosen for the SnO₂ thin film deposition. The CST simulation, FSS forming process and thin film characterization will be discussed in next chapter.
As mentioned in previous chapter, SnO$_2$ thin film was prepared using magnetron sputtering machine. Several analyses were carried out such as surface profiler, FESEM and AFM. The analysis is required to find the suitable parameter to fabricate an energy saving glass that can reflect most of the infrared while maintains good GSM signals. Besides that, sheet resistance of the thin film also takes into account to simulate the transmission along the GSM mobile signals. Different sheet resistance will brings effect to the transmission of microwave frequencies.

Figure 3.1: Flow chart to fabricate energy saving glass.
Figure 3.1 shows the process flow in fabricate energy saving glass. First, changing sheet resistance and shape of FSS was varied in the CST simulation. After that, FSS structure was formed by printed circuit board technique. The fabricated FSS structure on glass was deposited by magnetron sputtering to form SnO$_2$ thin film. Several analyses were used to analyze SnO$_2$ thin film such as surface topography, surface roughness and electrical properties. The deposited glass tested using spectrum and network analyzer to check the magnitude and transmission along the microwave frequencies.

### 3.1 Radio Frequency (RF) Magnetron Sputtering Deposition

![SnO$_2$ target material](image)

**Figure 3.2**: Tin oxide (SnO$_2$) target material.

![FTO target material](image)

**Figure 3.3**: Fluorine Tin Oxide (FTO) target material.
Figure 3.2 shows the SnO$_2$ target material that used for magnetron sputtering deposition. This target had 3” diameter in size with thickness of 0.5” and the color of the target is nearly white. The copper backing is needed for the compound and fragile material. Figure 3.3 displays the FTO target that used for deposition process. The color of the FTO target was seen darker than SnO$_2$ target. For the FTO material, the coating on the glass will be less transparent than SnO$_2$ film. For the windows application in the buildings, transparency of the glass is a very important.

In sputtering process, a target is bombarded by energetic ions generated in glow discharge plasma. The bombardment process caused the removal of target atoms, which condense on a substrate as a thin film. Besides that, ion bombardment process also produced secondary electrons from the target surface. This secondary electron plays an important role in maintaining the plasma. Magnetrons are the concept of magnetic field configured parallel to the target surface can constrain secondary electron motion to the vicinity of the target. In the magnetron sputtering deposition, various parameters can be varied such as substrates bias voltage, substrate temperature, dissipation power, oxygen flow rate, deposition time and working pressure of the chamber. Vary parameters can be affects towards the film properties [46], [80–81].

![Diagram of magnetron source](image-url)

Figure 3.4: Schematic diagram of magnetron source [82].
The base pressure was kept at below 5.0x10^{-6} mTorr before the deposition started to ensure the film quality. Due to SnO$_2$ is a fragile material, the deposition was done in changed the dissipation power between 150W to 300W. Gas pressure used in the system was 8.25mTorr when the deposition of SnO$_2$ film on the glass substrate. Two gases were used in the deposition process which is argon (Ar) and oxygen (O$_2$) gas. The gas flow rate for Ar was 25sccm with the various oxygen flow rate was changed. The oxygen flow rate changed in between 0sccm, 4sccm, 8sccm and 16sccm. Figure 3.4 shows the schematic diagram of the magnetron sputtering system used in this project. In the system, the ground shield is representative as anode while SnO$_2$ target as cathode. The system was connected to the chiller that acts as cooling water into it. Permanent magnet connected to SnO$_2$ target creates magnetic field when dissipation power applied on it.

![Magnetron sputtering system](image)

**Figure 3.5: Magnetron sputtering operation system.**

Figure 3.5 displays the illustration of the RF magnetron sputtering system. In the system, the target was placed 11cm from the glass substrate. The angle of the SnO$_2$ target was around 45° to the glass substrate. Before the deposition started, high vacuum condition is required to produce high quality SnO$_2$ film. In order to achieve high vacuum, rotary pump and turbo pump had been used. Deposition process happened with the Ar and O$_2$ gas that supply into the chamber. Other than gases,
dissipation power and gas pressure also need to be set before the deposition process start.

![Figure 3.6: Overview of RF magnetron sputtering setup.](image)

Ion bombardment influenced the films produced on the substrate by structure and electrical properties. Besides that, the energy of the bombardment ions can be increased by increasing the negative bias applied to the substrate. However, when the negative bias increased it can bring defects in the film and decreased the overall film properties [83]. Figure 3.6 shows the RF and DC sputtering system that available at MiNT-SRC UTHM.

### 3.2 Computer Simulation Technology (CST)

![CST Studio Suite 2013](image)

Figure 3.7: CST studio suite 2013 used for simulation.
Computer Simulation Technology (CST) simulation is 3D electromagnetic simulation software that can design and optimize the operating devices in a wide range of frequencies. Frequency domain solver was chosen over transient domain solver due to it is suitable for periodic structures application such as FSS. Besides that, CST microwave studio features a special periodic boundary implementation that creates for unit cells shaped. Floquet mode port was used in the port mode that produces higher accuracy and fast simulation to ease the polarization analysis and mode type. CST simulation was used Finite Integration Technique (FIT) that can simulate two materials together as metal oxide layer that stack above the glass that used in this project. In this project, CST simulation was used due to the mesh size required was two mesh. Figure 3.7 shows the CST studio suite 2013 used in simulation for this project. In the CST simulation, there are two solver to solve the problems, transient and frequency simulation. Transient solver is used in order to obtain accurate broadband results in the frequency domain where the electromagnetic energy in the computational domain needs to be sufficiently decayed. Basically, transient solver is use to solve electrically medium and large sized problems. It is suitable for broadband analysis.

The steady state behavior of a model simulated using frequency domain simulation is calculated at different frequency points. It is suitable to run the simulation in narrow band or single frequency. This frequency domain is normally applied on electrically small or medium sized problems. Frequency domain is simulating in periodic structures with Floquet port modes. The step by step in CST simulation part was in Appendix A.

### 3.2.1 Electromagnetic Simulation Workflow

![Electromagnetic Simulation Workflow Diagram](image)

Figure 3.8: Basics procedure in CST simulation.
Figure 3.8 shows the basic procedure in running the CST simulation. In the CST simulation, the transmission of the signal between transmitter and receiver can be obtained in perfect condition without any loss.

3.3 Printed Circuit Board Technology and Fabrication of FSS Structures

Figure 3.9: Process flow of the FSS formation.
Printed circuit board (PCB) technique was chosen in this project due to its simplicity and low cost in fabricating the FSS structure. Besides that, this technology can easily found in the electronic labs that ease for the experiment. The advantage of the PCB technique compare to the laser technique was the process of fabrication. The PCB fabrication process was easier than laser fabrication process due to the laser etching required CO\textsubscript{2} gas.

![Diagram of the fabrication process]

Figure 3.10: Procedure on frequency selective structure (FSS) printed on the glass.

Regarding the fabrication accuracy, there were around 80% successfully with handling every process carefully. For laminating part, bubbles were not allowed on the glass. Time control in the UV expose was one of the key points for the fabrication process. Glass with the FSS structure developed need to be under the sun heating for strengthens the attraction force. After that, fabrication process was done
in high vacuum condition to avoid contamination of film. For the etching film, the
film will not been degrade as the RF deposition technique had the strong adhesion as
other deposition technique. The repeatability of the PCB fabrication process was
quite high around 95%. The difference process on this experiment is usually copper
or aluminum board will be used in etching purposes to form the structure on it and
this project is using glass to replace it. Glass is using due to the energy saving glass
application in this project. Figure 3.10 shows the process flow chart of the FSS
fabrication on the glass substrate and can best describe the FSS fabrication on the
glass.

Figure 3.11: Front illustration for the glass before and after coating.

Figure 3.11 shows the glass before and after coating for the energy saving glass
fabrication.

### 3.4 Thin Film Characterization

Several technique have been used in the thin film analysis such as field emission
scanning electron microscopy (FESEM), atomic force microscopy (AFM) and 2
point probe. Thickness of the film was analyzed by surface profiler. Electrical
properties were analyzed by 2 point probe. Sheet resistance and resistivity of the
SnO$_2$ film can be obtained from the electrical properties analysis. This sheet
resistance is the key parameter that will effect to the transmission of electromagnetic
wave.

FESEM analysis was to investigate the structure and grain size of the SnO$_2$
particle. While AFM analysis was to analyzed film roughness. The difference with
the FESEM and AFM is 2D and 3D images obtained. Transparency of the glass is very important for the window application in the buildings. UV-Vis is a tool that used for the glass transparency measurement. Physical composition of the SnO$_2$ film was analyzed by X-Ray Diffraction (XRD) technique. This analysis was to determine the changes state of the SnO$_2$ film with various parameters. All the analyses about will be relate to the result of the thermal insulation properties and the transmission of the electromagnetic wave. Details of this equipment will be discussed in research methodology.

3.4.1 Surface Profiler and Two Point Probe

Figure 3.12: Surface profiler Alpha Step IQ.

Thickness of the thin film is important in order to characterize it in energy saving glass application for this project. With the measurement of the thin film thickness, sheet resistance of the thin film can be calculated. Sheet resistance is an important key to improve the GSM transmission in the energy saving glass [27]. Picture of the surface profiler is show in Figure 3.12.

For the two point probe method, the current and voltage are measured in the same wire. In this case, the measured voltage is added with the potential difference created into wires. While for the four point probe, current is sent in two probes and voltage is measured by two other probes. So, the measured voltage is circulating into the sample without current. Meanwhile, it means that the potential difference into wires and area of contact and spreading resistances are not high. In this project, two point probing is used for the electrical properties of the thin film.
Figure 3.13: Electrical properties measured using 2 point probing.

Figure 3.13 shows the two point probing that used to measure electrical properties of the thin film. From the IV graph obtained from the two point probing, resistivity can be calculated by Equation 3.1. Sheet resistance of the film can be calculated by Equation 3.2 with the resistivity obtained from Equation 3.1. Besides than the thickness and the sheet resistance of the film, dielectric constant of the glass also take into the account when the CST simulation.

\[
\text{Resistance, } R = \text{Resistivity, } \rho \times \frac{\text{Length}}{\text{Area, } A} = \left( \frac{\rho}{\text{Thickness, } t} \right) \times \left( \frac{1}{\text{Width, } w} \right) \quad (3.1)
\]

\[
\text{Sheet resistance, } R_s = \frac{\rho}{t} \quad (3.2)
\]

3.4.2 Field Emission Scanning Electron Microscope (FESEM) and Atomic Force Microscope (AFM)

Figure 3.14: Image of the FESEM (JEOL JSM-7600F) operation system.
Figure 3.15: Configuration of the FESEM (JEOL JSM-7600F) operation system [84].

FESEM is a microscope that operates with electrons to form the morphology image for the surface object [84]. Dry sample is required to achieve high vacuum condition in scanning process. This system has two electrons operated which are primary and secondary electrons. Primary electrons can be achieved at high vacuum condition and then been focused and deflected to scanning unit to produce a narrow beam that will have bombardment on the object [84]. Surface structure of the thin film is affected by angle and velocity of the secondary electron. Electron detector detects the secondary electron and sent the information to scanning unit. Morphology of the thin film can be seen in computer screen after digital signal processing process the data in the scanning unit. The operation system of the FESEM analysis is clearly showed in Figure 3.14 and 3.15.

Figure 3.16: Image of the Park System AFM (model XE-100) operation system.
The measurement of the AFM is in three dimensions, which are x and y in horizontal with z in vertical direction. In atomic force microscopy (AFM) are divided into three, which are contact, non-contact and tapping mode. For contact and tapping mode, the cantilever had touched the sample that will damage the sample. While, non-contact AFM is a laser beam is used to deflect the cantilever passes over a sample that will go through the position sensitive photo detector (PSPD) and come out with topological surface of the sample [85]. The system used is non-contact AFM that cantilever vibrate near resonant frequency that ranging between 100 kHz and 400 kHz [85]. Roughness of the film can be obtained with the AFM measurement. The advantages of the AFM compare to FESEM were AFM has 3D image and FESEM has 2D image for the film structure. Figure 3.16 shows the picture and operation of the AFM measurement. Figure 3.17 shows the operation system for AFM.

### 3.4.3 X-Ray Diffraction (XRD) and UV-Vis

X-Ray Diffraction (XRD) used in this project to differentiate the chemical formula that change during changes of parameter in the deposition. XRD is a non-destructive analytical technique for identification and quantitative determination of the solid sample. Glazing incidence diffraction (GID) is used in analyzed thin film due to its
small diffracting volumes that caused low diffracted intensities [86]. When analyzing thin film, parallel beam geometry is combined with glazing incidence angle to obtain the spectrum peaks. The detector is rotates through the angular range while others is remain constant in the collecting of the spectrum diffraction [86]. The XRD analysis was best described by Bragg’s Law as Equation 3.3.

\[
n\lambda = 2dsin\theta \tag{3.3}
\]

Where \( n \) represents integer, \( \lambda \) symbolize the wavelength of the incident X-ray beam, \( d \) is the distance between the atomic layers in crystal and \( \theta \) is the incident angle of the X-ray beam.

![Figure 3.18: Glazing incidence diffraction experimental setup [86].](image)

![Figure 3.19: Picture of the Panalytical X’Pert Pro-MRD used for the measurement.](image)
REFERENCES


