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

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To my beloved late father *(Lim Seng Ong),*
mother *(Gan Mui Eng)*, brothers
and sisters

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ABSTRACT

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 being 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 allows the transmission of GSM mobile signal penetrate in the buildings while blocking the infrared light with the SnO_2 film properties.

ABSTRAK

Penggunaan kaca yang boleh menjimatkan tenaga adalah sangat popular dalam bangunan moden masa kini. Konsep kaca penjimatan tenaga boleh dihasilkan dengan menggunakan timah oksida (SnO_2) yang sangat nipis dan disalut pada satu permukaan kaca. Lapisan ini akan menebat haba dengan baik pada bangunan-bangunan, iaitu dengan menghalang sinaran inframerah daripada telus ke dalam bangunan. Salah satu kelemahan salutan SnO_2 ini adalah ia akan melemahkan penghantaran isyarat yang berguna seperti gelombang telefon daripada melalui salutan SnO_2. Penggunaan struktur frekuensi terpilih (FSS) adalah dicadangkan untuk mengatasi masalah ini. Di dalam projek ini, lapisan SnO_2 dan struktur FSS dibentuk dengan menggunakan RF *magnetron sputtering* dan teknologi papan litar tercetak. Mikroskop tekanan atom (AFM) dan mikroskop imbasan elektron – pancaran medan (FE-SEM) telah digunakan untuk menganalisis morfologi permukaan dan kekasaran filem nipis SnO_2. *Two point probe* digunakan untuk menentukan rintangan filem nipis SnO_2. Ketebalan filem nipis diukur menggunakan *surface profiler*. Perkaitan yang baik di antara sifat-sifat permukaan dan sifat elektrik SnO_2 filem nipis telah ditemui. Ketebalan filem ini juga sangat berhubung kait dengan sifat-sifat elektrik filem. Kadar penembusan gelombang mikro melalui salutan SnO_2 berserta struktur FSS dikaji menggunakan *network analyzer*. Hasil simulasi komputer telah disahkan dan konsisten dengan hasil kajian *network analyzer* yang menunjukkan peningkatan dalam penembusan gelombang melalui kaca bersalut SnO_2 dengan struktur FSS. Hasil kajian suhu juga mendapati struktur FSS telah meningkatkan penghantaran isyarat GSM dengan menembusi dalam bangunan manakala menyekat pemanasan inframerah.

CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

d - Distance
θ - Bragg angle
λ - Wavelength
l - Length
A - Area
w - Width
R - Resistance
Rho - Resistivity
Rs - Sheet Resistance
t - Thickness
SnO_2 - Tin dioxides
FTO - Fluorine Tin Oxide
FSS - Frequency Selective Structure
AFM - Atomic Force Microscope
FE-SEM - Field Emission Scanning Electron Microscope
Na_2CO_3 - Sodium Carbonate
NaOH - Sodium Hydroxide
XRD - X-Ray Diffraction
CST - Computer Simulation Technology
RF - Radio Frequency
CVD - Chemical Vapor Deposition
O_2 - Oxygen
Ar - Argon
DC - Direct Current
RF - Radio Frequency
Cu - Copper

PSPD	-	Position-Sensitive Photo Detector
Au	-	Gold
2D	-	Two Dimensional
3D	-	Three Dimensional

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 allow the certain frequencies to passed through it while block other frequencies. The used of FSS in this project was to improve the microwave frequencies. In the past few years, many researchers had tried to apply different structure on the energy saving glass [6], [21–25]. Bandpass FSS that act as filter 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].

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