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Optimizing Transmission of RF/Microwave Signal through SnO_2 Thin Film of Energy Saving Glass using Frequency Selective Surface

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Abstract: Energy saving glass is commonly applied in the modern building. Energy saving glass is applied with a thin metallic oxide such as silver oxide or tin oxide on a side of the ordinary float glass. SnO_2 thin films were deposited by rf-magnetron sputtering on glass substrates using high purity (99.99%) SnO_2 target. Working pressure in the system was kept at 8.25 mTorr with a source-substrate distance of 13 cm and deposition time of 20 minutes. Argon and oxygen flow rate were fixed at 25 sccm and 8 sccm, respectively. The sputtering powers were changed from 150 W to 300 W with the intervals between 25 W and 50 W. The sheet resistance was measured using 2 point probe setup. From the analysis, sheet resistance value decreased from 21.37 Ω/square at dissipation power of 150 W to 12.82 Ω/square at dissipation power of 300 W. Later, the sheet resistance values were used in the CST simulation to characterize the transmission of GSM signal. The optimum transmission lost was at 300 W. Full width half maximum (FWHM) and peak frequency increased with the dissipation power. These works suggest that experimental parameter is important in order to get the optimized transmission through the glass.

Keywords: Frequency selective surface (FSS), magnetron sputtering technique, GSM and sheet resistivity.

1. Introduction

Tin oxide (SnO_2) is one of the semiconductors that been widely investigated over past decades. The characteristics of SnO_2 thin films are it has low electrical resistance and highly optical transparency in the visible range of the electromagnetic spectrum. Besides that, tin oxide thin films possess an interesting structural and electrical properties that suggest for useful applications such as solid state gas sensor, photovoltaic cells, transparent electromagnetic shielding materials and infrared reflector [1–2].

In addition, SnO_2 is suitable as a hard film material for applications that require higher refractive and reflective properties. SnO_2 is a transparent conducting oxides (TCOs) material that has high chemically and environmentally stable [3]. Several techniques that have been used to fabricate tin oxide thin films such as sol-gel [4], thermal deposition [5], spray pyrolysis [6], chemical vapor deposition [7] and sputtering techniques [8].

Low emissivity properties of energy saving glass are the glass prefers used in the modern building nowadays [9]. A thin SnO_2 was applied to one side of the ordinary glass to form an energy saving glass. Energy saving glass rejects the heat from outside during summer while kept warmer during winter. This energy saving glass can blocked the infrared but at the same time it attenuates useful microwave signal such as GSM signal. To overcome this problem, frequency selective surface (FSS) is being introduced to improve the transmission of the glass. In our previous study, we found that the FSS with a combine structure of circle and cross dipole has the most suitable property for GSM signal transmission. It is noted that the electrical properties of the films and conductivity of the glass are very important parameters in the simulation of CST Microwave Studio. From the previous research has been stated that the dielectric constant for the float glass was 6.9 and conductivity was 0.0005 S/m. The surface resistance was fixed at 6 ohm/square [10]. In present study, SnO_2 thin films were fabricated by vary the dissipation power. Sheet resistance of the films was measured by 2 point probe setup. Sheet resistance values obtained from the analysis were used in the CST simulation to investigate transmission through GSM signal.

2. Experimental Setup

Fig. 1 displays the deposition setup. SnO_2 thin films were deposited by rf-magnetron sputtering on glass substrates using high purity (99.99%) SnO_2 target. The background vacuum condition was less than 1.0 x 10^{-5} Torr. The mixture gases of argon and oxygen atmosphere were used during deposition. Prior to the deposition, glass slices were cleaned ultrasonically using acetone for 5 minutes and rinse under DI water and dry it using nitrogen gas. During deposition, high purity oxygen was used as a reactive gas while argon as a sputtering gas. Deposition was turned on after 10 minutes pre-sputtering for cleaning the target surface and stabilizing the sputtering process. Working pressure in the system was kept at 8.25 mTorr with a source-substrate distance of 13 cm and deposition time of 20 minutes. Argon and oxygen flow rate were fixed at 25 sccm and 8 sccm, respectively. The sputtering powers were changed from 150 W to 300 W with the intervals between 25 W and 50 W. The deposition process was done at room temperature where no additional heating was introduced to the substrate holder.

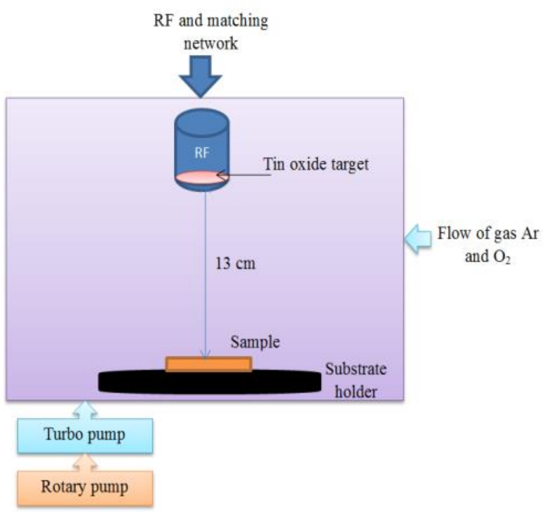

Fig. 1 Experimental setup for SnO_2 thin film deposition using rf-magnetron sputtering system.

Thickness of each SnO_2 thin film was analyzed by Alpha Step IQ Surface Profiler. The electrical resistivity and sheet resistance of the films was calculated from I/V graph measured by 2-point probe setup. The distance between two probes was approximately 1 mm.

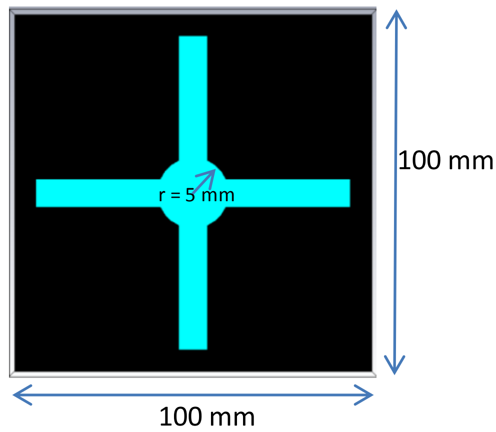

Fig. 2 Simulation setup for transmission lost in different sheet resistance using CST software.

Fig. 2 indicates the cross and circle dipole unit cell simulated using Computer Simulation Technology (CST) Microwave Studio. The polarization used are perpendicular (TE) polarization during the simulation. Glass with different sheet resistances was simulated. The glass sample has the length and width in 100 mm. Unit cell of the cross dipole has length and width in 44 mm and 4 mm, respectively. While, the unit cell of the circle has the radius, r of 5 mm.

Frequency domain solver in CST was chosen for simulating the FSS unit cell. Tetrahedral mesh was used for simulation rather than hexahedral mesh. It is because tetrahedral mesh has high quality mesh compare with hexahedral mesh. The frequency range used for simulation was 0.8 – 6.0 GHz. But, in this study, GSM signal that ranging from 0.8-2.2 GHz was used for analysis.

3. Results and Discussion

Thickness of each films fabricated were measured using surface profiler as display in Table 1. From Table 1, it can clearly seen that the thickness of the SnO_2 thin film increased with the dissipation power. The thickness of thin film increased from 230 nm to 416 nm upon the increased in dissipation power.

Table 1 Thickness SnO_2 thin film deposited at various dissipation powers. Measured using surface profiler.

Power (W)	Thickness (nm)
150	230
200	272
225	300
250	356
300	416

Fig. 3 shows the sheet resistance and electrical resistivity influenced by the dissipation power. The sheet resistance, R_s, and resistivity, R, were calculated from below equations:

$$R_s = 4.532 \times (V/I) \qquad (1)$$

$$R = R_s \times \text{thickness } (t) \qquad (2)$$

It is clearly understood from equation (2), that sheet resistance is inversely proportional to the film thickness. Fig. 3 shows that the sheet resistance of SnO_2 film decreased with the dissipation power. Sheet resistance of the SnO_2 thin film decreased from 21.37 Ω/square to 12.82 Ω/square when SnO_2 thickness increased from 230 nm to 416 nm. Therefore, the resistivity of SnO_2 thin film was much dependent on the thickness of the film. The resistivity of the film is increased with the increased of film thickness. But the resistivity of the film was decreased slightly at the power of 250 W. This is because, although the thickness increased with the dissipation power, the resistivity was almost saturated due to the decreased of sheet resistance as shown in equation (2).

Similar results have been published by Tadatsugu *et. al.*, where they have reported higher sheet resistance obtained at thinner film when deposited by rf magnetron sputtering at room temperature condition [9].

The measured sheet resistance value is important in order to simulate the GSM signal in CST software. The software was used to simulate the desired transmission of GSM signal through energy saving glass with the minimum transmission lost.

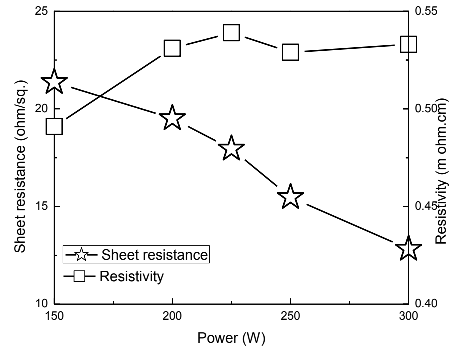

Fig. 3 Influence of dissipation powers towards sheet resistance and resistivity.

The sheet resistance obtained from Fig. 3 was used in the CST simulation to investigate the transmission lost through it as in Fig. 4. From Fig. 4, there is slightly difference on the transmission lost at different dissipation power. The transmission lost is optimum when it approaches to 0 dB. When transmission lost is 0 dB, its means that all the signals are fully transmits to the receiver. Until today, there are no parameter or design that can fully transmit the entire signal without any lost. Minimum transmission lost was analyze from Fig. 4 are displayed in Fig. 5. The transmission lost through the energy saving glass is improved when the dissipation power increased in around 1.5 GHz. The simulated frequency range in Fig. 4 had showed two peak frequencies but in this paper only GSM signal ranging from 0.8-2.4 GHz is taken into account.

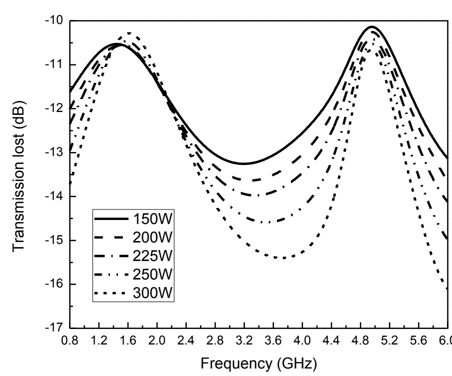

Fig. 4 Transmission lost under different dissipation power.

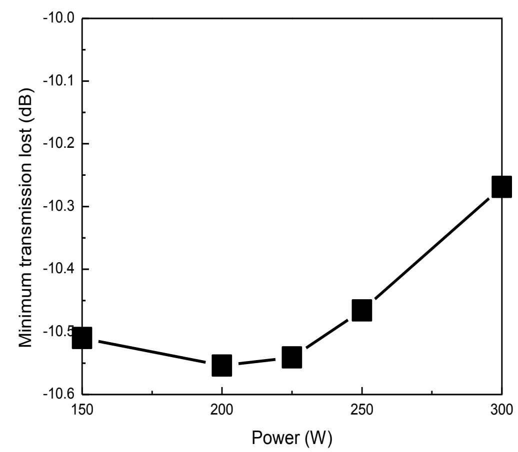

Fig. 5 Minimum transmission lost through different dissipation power.

Fig. 6 shows the peak frequency and FWHM analysis through different dissipation power. For the FWHM analysis, our focus is to study the bandwidth of the GSM signal that can pass through FSS surface. FWHM values increased with the dissipation power. When the FWHM value increased, it shows that larger bandwidth and more signals can pass through at the desire frequency range.

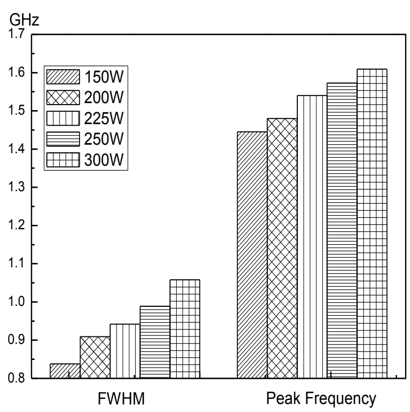

Fig. 6 Effect on different dissipation power through FWHM and peak frequency analysis.

Peak frequency analysis was to study suitable parameter to suit the GSM signal. Desire peak frequency for the GSM signal fall at 1.4 GHz. Peak frequency increased with the dissipation power increased. From Fig. 6, 150 and 200 W had shown the desire peak frequency that suit for the GSM signal.

In overall, analysis from minimum transmission lost, peak frequency and FWHM had shown that 300 W is most suitable for GSM signal application.

4. Summary

Different dissipation power during fabrication of SnO_2 thin films were successfully carried out. Effect of sheet resistance under different dissipation power had been studied. Analyses on the FWHM, transmission loss and peak frequency of the transmission along microwave frequencies were also successfully carried out. Results suggest that dissipation power plays an important role in order to improve transmission of signal through the energy saving glass. Optimized power, sheet resistance and metal oxide thickness are essential in order to improve the usage of metal oxide coating for energy saving glass application.

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