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Glass Characterization for Designing Frequency Selective Surfaces to Improve Transmission through Energy Saving Glass Windows

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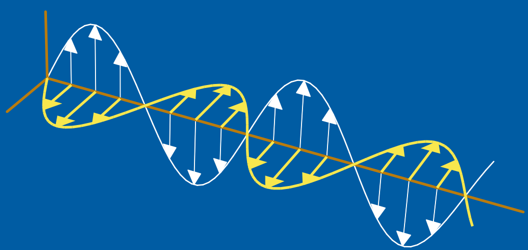

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Abstract

This paper reports initial work on creating frequency selective surfaces (FSS) on modern day glass windows to improve the transmission of wireless communication signals through the glass. The manufacturers of these glass windows apply very thin layers of metallic oxides on one side of glass to provide extra thermal insulation. These coatings block the infrared and ultraviolet waves to provide thermal insulation, but they also attenuate communication signlas such as GSM 900, GSM 1800/1900, UMTS and 3G mobile signals. This creates a major communication problem when buildings are constructed using mostly such type of glass. A bandpass FSS can provide a solution to increase the transmission of useful bands through the coated glass. In order to design an appropriate FSS, the relative permittivity and conductivity of glass should be measured accurately. Moreover, electrical properties of the coated layer must also be known in order to obtain a resonance in the desired band. In this work, we used two different methods of measuring the permittivity and conductivity of glass. Electrical properties of one of the common glass windows (Optitherm^{TM} SN) are presented. Simulations of Optitherm glass shows about 35 dB transmission loss over 900 - 2200 MHz frequency band.

1 Introduction

Energy saving techniques are very popular in glass used in modern buildings. These are called low-emissivity or energy- saving widows since the metallic oxide coating on one side of the glass can reflect most of the incident infrared power [1, 3, 5, 7]. This coated glass acts as a filter for electromagnetic radiations in the infrared region, while being totally transparent to the visible part of the spectrum. Due to this property of coated glass, thermal insulation is obtained inside the buildings. Therefore, in winter, buildings can be kept warm by thermal insulation for longer period of time without significant heat loss. The opposite is true in summer as it will block the heat to enter inside the building and therefore reducing the cost of cooling.

One major problem related to such energy saving glass is that it effectively attenuates the wireless communication signals (e.g. GSM 900, GSM 1800/1900, GPS, UMTS and 3G). Therefore, buildings using most of such glass in their design will have a subsequent problem with the transmission of the useful wireless communication signals, especially in the band of 900 to 2200 MHz. However, these windows can act as a screen to provide good security for 2.45 GHz and 5 GHz wireless local area network (WLAN) inside the building and may help to create different WLAN zones for frequency reuse [2].

A frequency selective surface (FSS) can provide a solution to above mentioned problem [4]. A bandpass FSS with 1.4 GHz bandwidth can be etched on the coated side of glass to provide improved transmission from 900 to 2200 MHz frequency band. Since this FSS has to be aperture type, it has to be designed carefully in such a way that least amount of the metal oxide layer is removed from the glass surface to reduce the degradation of thermal insulation. Before the design procedure of FSS is initiated, one has to measure the precise values of relative permittivity and conductivity as opposed to what was approximated in [1]. Moreover, to obtain a practical FSS design, the electrical properties of the metallic oxide layer has to be carefully calculated. Due to the presence of oxide in the coating layer, a strong resonating FSS is not possible in this case, and therefore full transmission of the band of interest is impossible, but a considerable improvement in transmission can be achieved by careful design. In this paper, we present the measurement techniques for relative permittivity and conductivity of glass and discuss the electrical properties of metallic oxide layers used in glass manufacturing.

2 Measurement of Relative Permittivity and Conductivity of Glass

In this section, two different methods are presented to measure the relative permittivity and conductivity of glass. The first method uses a parallel plate capacitance measurement technique using wheatstone bridge in which only the relative permittivity and conductivity are obtained at lower frequencies. The second method uses a waveguide measurement technique to determine both permittivity and conductivity in an X-band waveguide. Both methods are described below:

2.1 Parallel Plate Capacitor Method

The permittivity and loss tangent of float glass were measured in a classical setup for reference. A Rohde & Schwarz VKB 3250 Dielectric Test Bridge with the KMT 5411 Guard Ring Capacitor were connected with a low frequency generator as the signal source and an oscilloscope as the detector [6]. This allowed measurements of both permittivity and loss tangent at 1 KHz and 10 KHz. The measurement setup is shown in Figure 1.

First the capacitance and loss tangent were measured with the glass as dielectric. Then the glass was removed and the measurements were made again. The relative permittivity is then calculated by using equation:

$$\epsilon_r = \frac{C_{glass}}{C_{air}}$$

The procedure was repeated twice at both frequencies and the mean values of the results were obtained. For the frequencies less than 10 KHz the measurements gave an average permittivity of 7.0 ± 0.05 and the upper bound for the conductivity was 10^{-4} S/m. Since the conductivity is very low and the relative error in its different measurements is quite large as compared to the permittivity, only an upper bound is given.

2.2 Waveguide Technique

A waveguide technique was used to measure the permittivity and conductivity at high frequencies. The block diagram for the setup is depicted in Figure 2. An X-band waveguide with cross-section $a \times b = 22.86$ mm $\times$ 10.16 mm was used with

Figure 1: Photograph showing the setup of the parallel plate guard ring capacitor measurement method

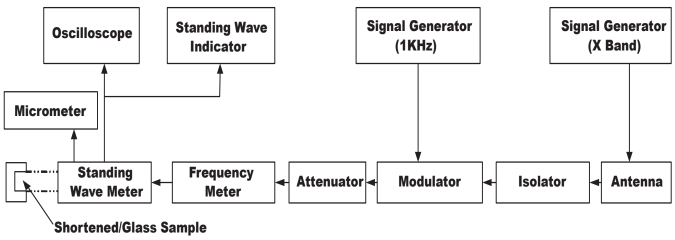

Figure 2: Block diagram showing the waveguide measurement method

TE_{10} as the fundamental propagating mode. The frequency band of such a system is 6.6 to 13.1 GHz, corresponding to the frequency band where only the fundamental mode is propagating. The accuracy of the measurements is important and for this reason measurements were only done in the frequency band of 9 to 10 GHz. It is difficult to obtain good accuracy outside this band [6].

In the waveguide measurements it is crucial that the device under test is shaped such that it fits exactly into the waveguide. A small air gap between the glass and the waveguide deteriorates the results. The glass sample is placed in the waveguide, well pressed against the shortening plate. A standing wave meter is used for measuring the location of the voltage minima with and without a glass sample. It is also used for measuring the corresponding 3 dB widths of the voltage minima. Here a method was used to measure high values of VSWR (>10), that circumvents the problem of determining a precise value of a deep minimum. The VSWR is defined as:

$$S = \frac{V_{max}}{V_{min}} = \sqrt{\frac{P_{max}}{P_{min}}} = \sqrt{\frac{I_{Dmax}}{I_{Dmin}}}$$

when measured with an ordinary quadratic detector diode (where I_{Dmax} and

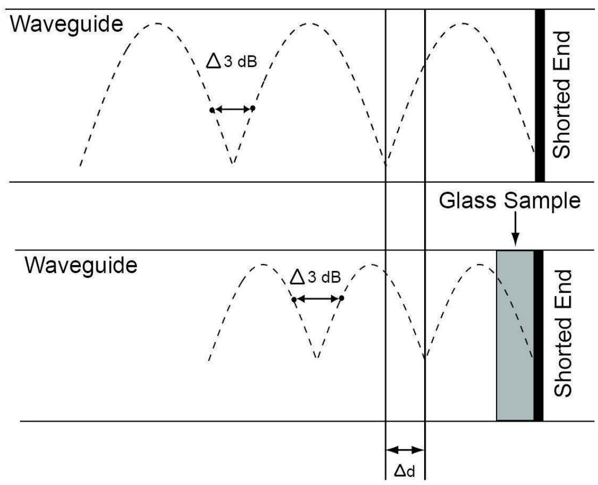

Figure 3: Standing wave patterns with and without glass sample. The distance Δd and the difference in distance between two corresponding $\Delta 3\ dB$ values give the conductivity and permittivity of the glass sample.

I_{Dmin} are maximum and minimum diode currents). If studied on a linear scale, the SWR pattern is described by $\cos 2\beta z$. This pattern, thus, is sinusoidal and can be represented on a circle with circumference $\lambda_g/2$. Utilizing the theorem of intersecting chords and some other geometric theorems, VSWR can be calculated as $\lambda_g/\pi d$, d being the distance along the circle between the two points where the diode current is twice its minimum, and λ_g is the guided wavelength. This is equivalent to finding the distance between the points where the power is $2P_{min}$ or 3 dB above the minimum. These are easily found with a common slotted line, rather than the deep minimum itself [6].

From these measured values the permittivity and conductivity of the glass can be calculated. The measurements in the frequency band of 9 to 10 GHz gave $\varepsilon_r = 6.9 \pm 0.15$ and $\sigma < 5 \cdot 10^{-4}$ S/m. It is possible to reduce the errors in these measurement by manufacturing even better shaped samples but for this project the accuracy is enough. The conductivity of glass is very small and hence the relative error in its measured value is quite high. The permittivity was approximately constant in the frequency band.

The measured values of the permittivity at frequencies from 9 to 10 GHz coincide with those at $f \leq 10$ KHz. In both of these frequency bands the measured conductivity is very small. From these observations the assumption is made that the permittivity is constant and that the conductivity is very small for all frequencies less than 10 GHz. This is in accordance with the frequency dependence of ε_r and σ for most insulating solid materials.

3 Coating Properties

There are two main types of coatings used in low emittance (low-e) glass windows to provide thermal isolation, namely hard coating and soft coating. In hard coating

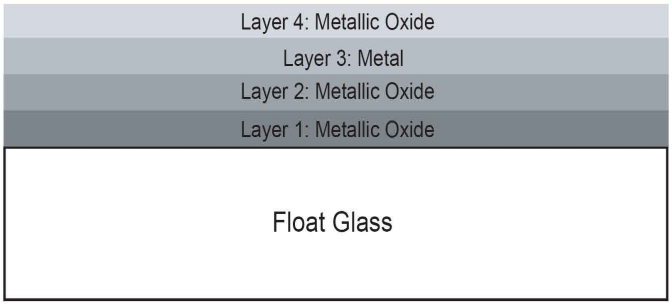

Figure 4: A typical arrangement of the soft coat layers on the float glass

low-e glass, a very durable pyrolytic coating is sprayed at a high temperature on the glass surface during the float glass process. This coating is relatively durable and allows ease of handling and tempering. On the other hand, the soft or sputter coating utilises a technique in which very thin metallic oxide layers are deposited on the glass surface in a vacuum chamber to provide high thermal insulation. This configuration is shown in Fig. 4 in which four very thin layers of the order of nanometers are applied on a float glass to provide high thermal insulation. This technique provides a more expensive but high performance alternative to the hard coat glass.

In this paper we deal with soft coat low emittance glass manufactured by Pilkington. Pilkington Optitherm^{TM} SN glass windows are very popular for providing high performance thermal insulation. It has three very thin metallic oxide coatings with a silver layer sandwiched between them. In order to design an aperture type FSS on this coating for improved transmission through glass window, the electrical properties of the coating must be known. Due to commercial confidentiality, we are unable to provide any further details about properties of layers. In this case, all four layers have been modelled as a surface impedance of 4 Ω per square. This value of surface impedance is provided by Pilkington and we are in the process of measuring it to authenticate the value.

4 Simulation Results

In this section, simulation results for soft coated Pilkington Optitherm^{TM} SN glass are presented. Fig. 5. shows the transmission response of glass having a soft coated layer of about 100 nano meters thick. The thickness of the glass is 3.82 mm and the coated surface is modelled as an impedance boundary in CST MW Studio. The surface impedance of the coating is 4 Ω per square. The relative permittivity of the glass is 7 while the conductivity is of the order of 10^{-4} S/m. It can be seen that a theoretical transmission loss of 33.8 dB occurs in the desired frequency band (900 - 2200 MHz). The results are presented for both parallel (TM) and perpendicular (TE) polarizations at normal incidence.

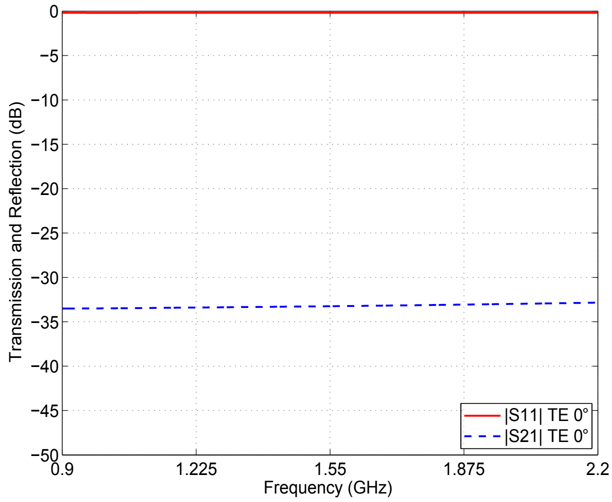

Figure 5: Theoretical transmission and reflection of soft coated Optitherm^{TM} SN glass from Pilkington

5 Frequency Selective Surface Parameters

In order to improve the transmission through energy saving glass, an aperture type bandpass frequency selective surface (FSS) has to be etched on the coated side of glass window to provide extra transmission at the required band. The main challenges in the design of bandpass FSS are as follows: (a) It should provide a stable frequency response at normal and at oblique incidence for both parallel (TM) and perpendicular (TE) polarizations (b) The width of the aperture of FSS should be as narrow as possible to keep the thermal insulation high (c) It should have fairly large bandwidth to cover the whole band of interest (d) To devise a way of etching FSS on the coated side without degrading the aesthetic aspect of the glass. Various options are under consideration at the moment, and we hope to present the results at the conference.

6 Conclusion

In this paper, our initial work on creating FSS on commercially available glass windows is reported. It presents methods for measuring relative permittivity and the conductivity of glass by two different methods. It has been observed that both methods show very similar results. These values are very important in the ultimate design of FSS on the glass. Moreover, different types of glass and coatings are discussed and typical description of Pilkington Optitherm^{TM} SN glass is given. A 33.8 dB theoretical transmission loss is observed in the band of interest for Optitherm^{TM} SN having 4 Ω per square surface resistance. The challenges in design of FSS are discussed and work is underway to devise a suitable solution. We hope to present design results at the conference.

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