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# Dielectric Properties of PTFE Matrix Modified with Soda Lime Silicate Glass at X-Band Frequency

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**Abstract:** The purpose of this work was to prepare and develop a low-cost polytetrafluoroethylene (PTFE) filled with recycled soda lime silicate glass (SLS). The SLS powder was prepared using a ball milling technique. PTFE/SLS composites were fabricated by dispersing 25, 45, 63, 90, and 106 μm of the SLS powder in the PTFE through the dry powder processing technique. The fabricated composites were characterised by scanning electron microscopy (SEM). The SEM images showed better filler distribution at 106 μm with SLS particle agglomeration at lower filler sizes. The results of dielectric properties characterised at 8.2 GHz indicated that the $\varepsilon_r$ and $tan\delta$ varied from 2.22, 0.0018 and 2.18, 0.0016 at 25 and 106 μm, respectively. The $\varepsilon_r$ and $tan\delta$ further decreased from 2.20, 0.0017 and 2.16, 0.0015 at 12.4 GHz, respectively. Thus, the PTFE/SLS composites exhibited low $\varepsilon_r$ and $tan\delta$ suitable for microwave substrate application.

Polymer-based substrates have received considerable attention due to their potential applications at microwave frequencies. The substrates are dielectric materials with low dielectric properties for use in microwave printed circuit boards (PCBs) [1] A polytetrafluoroethylene (PTFE) matrix filled with inorganic fillers, such as SLS glass is mostly preferred among polymers in light of its outstanding electrical properties for the substrate application [2]. The PTFE being a carbon-based, fluorinated synthetic polymer, however, has a high processing temperature (~327℃) that makes handling and blending with inorganic fillers difficult and expensive [3]. Various methods have been employed for the fabrication of

Polymer-based composites, such as the melt-blend technique [4], extrusion technique[5], and wet powder-processing technique [6]. The melt-blend technique is low-cost and easy to use, however, it has difficulty mixing highly viscous polymers such as PTFE, while the extrusion method costs a lot. The wet processing technique uses solvents like ethyl alcohol to mix the powders. Unfortunately, the solvent can be confined in the composite to reduce the matrix-filler contact area because removing a tiny amount of solvent is difficult [7]. This work utilises the dry powder processing technique over the wet process because it is easy to implement and solvent cost-free, reducing the overall budget of composites preparation.

In this work, soda lime silicate (SLS) glass bottles and PTFE powder were used as starting materials. The SLS glass bottles, obtained from a recycling site, were soaked, cleaned and dried overnight to remove impurities. After that, the bottles were crushed and loaded into a mill jar, where a powder-to-ball ratio of 20:1 was set. The powder was therefore milled for a day at 45 rpm via U.S. Stoneware Jar Mills (U.S. Stoneware, East Palestine, Ohio, USA). Particle sizes of 106 $\mu m$, 90 $\mu m$, 63 $\mu m$, 45 $\mu m$, and 25 $\mu m$ were then extracted from the powder using sieves. Furthermore, PTFE/SLS composites were obtained by dispersing different sizes of the SLS powder with the PTFE matrix via a high-speed dry mixer for 10 min, and the concentration of the SLS powder was fixed at 5% of each composite. The samples were then compacted using a hydraulic press at 10 MPa for 5 min and then sintered for particles' coalescence and void removal. The surface topology of the PTFE/SLS composites was examined through Leo 1455 variable pressure scanning electron microscope (VPSEM, Leo Electron Microscopy Group, Oberkochen, Germany), while the relative permittivity ($\varepsilon_r$) and loss tangent ($tan\delta$) of the composites were measured in the 8.2-12.4 GHz microwave frequency domain via a rectangular waveguide (RWG) measurement technique. In addition, the RWG adapters were connected to a Keysights E5063A Vector Network Analyser (VNA, Keysight Technologies, Santa Rosa, CA, USA) for the measurement.

Figure 1 shows the representative SEM images of 25, 63, and 106 $\mu m$ PTFE/SLS composites. It can be deduced that at 25 $\mu m$ SLS, agglomeration of the filler particles occurs. The agglomeration is attributed to the larger surface area and high surface charge of the smaller-sized fillers [8–10], making it difficult to distribute uniformly within the PTFE matrix. This adversely affected the complex permittivity of the composite. However, a fair distribution of the SLS particles is observed at higher filler sizes, suggesting a good interfacial adhesion between the filler and the matrix [11].

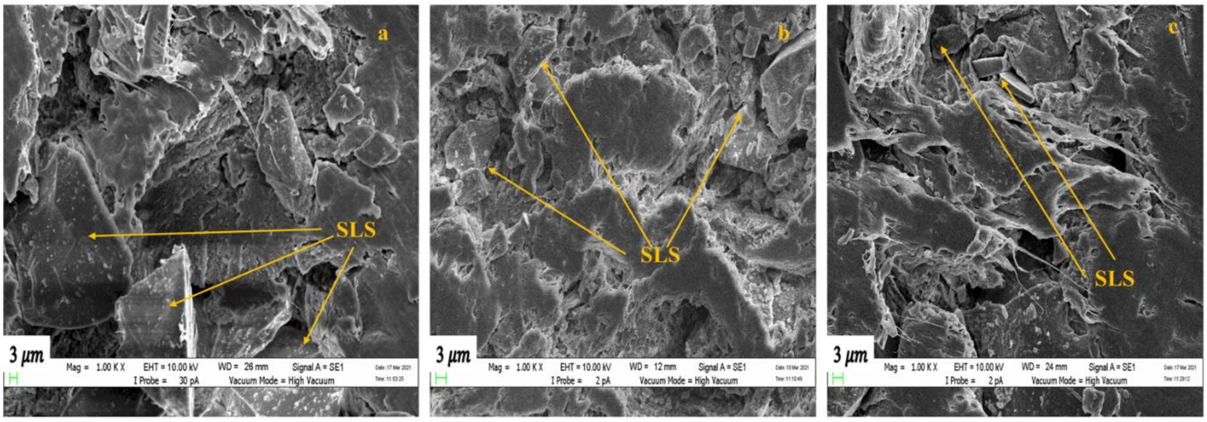


**Figure 1**: SEM micrographs of (a) 25 $\mu m$ (b) 63 $\mu m$ and (c) 106 $\mu m$ PTFE/SLS composites

Figures 2 and 3 show the variation of $\varepsilon_r$ and $tan\delta$ with different SLS filler sizes. It can be seen that the $\varepsilon_r$ and $tan\delta$ of the composites decreased steadily with a corresponding increase in frequency. This decreasing nature of $\varepsilon_r$ with frequency is due to the reduction of the interfacial polarisation effect [12–15]. Also, the lower values of $tan\delta$ at high frequencies are attributed to a drop in space charge effect and dipole-dipole relaxation [16]. At lower frequencies, however, the impact of the interfacial polarisation is strong due accumulation of charges under the influence of the electric field at the boundary between the matrix and filler, resulting in higher values of the $\varepsilon_r$ of the composites [17,18]. Similarly, the high resistivity of grain boundaries can be the cause of higher values of $tan\delta$ at lower frequencies. Careful analysis of Figures 2 and 3 revealed that both $\varepsilon_r$ and $tan\delta$ increased with SLS filler size reduction, consistent with previous studies [19–22]. Generally, when the size of the filler is reduced, the interfacial area between the filler and polymer matrix increases, leading to a stronger interfacial polarisation and hence, the dielectric properties [10,23]. Also, the increase in $\varepsilon_r$ and $tan\delta$ of the PTFE/SLS composites with the filler size reduction can be attributed to the effect of densification as the smaller-sized SLS fillers possess more particulates per unit volume [6].

**Conclusion**: A low-cost PTFE composite filled with SLS glass has been developed for microwave substrate application. The composites were prepared using the environmentally friendly dry powder processing method. The composites showed excellent microwave dielectric properties. SEM analysis indicated a good filler dispersion at the maximum filler size of 106 μm. At the same highest filler size of 106 μm, the composites exhibited a mean $\varepsilon_r$ of 2.17 and $tan\delta$ of 0.00153 suitable for substrate application.

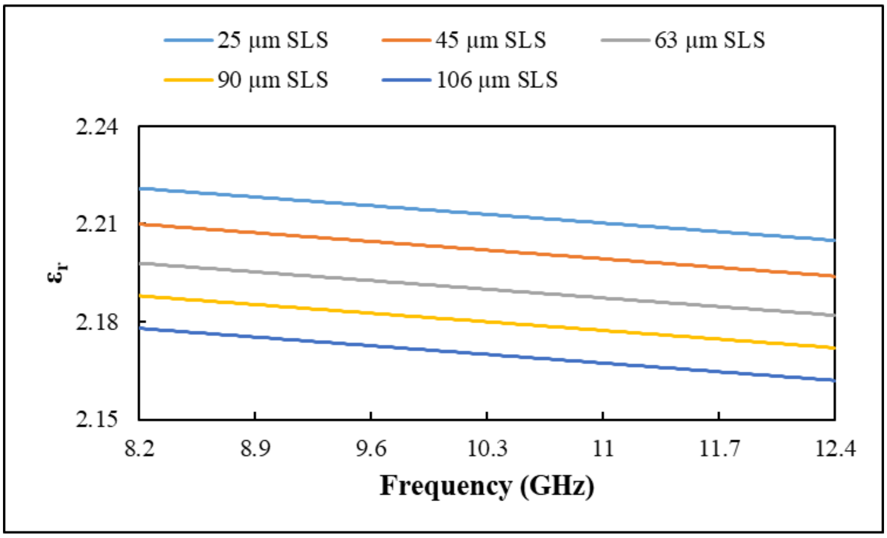


**Figure 2**: Variation of relative permittivity with frequency and filler size

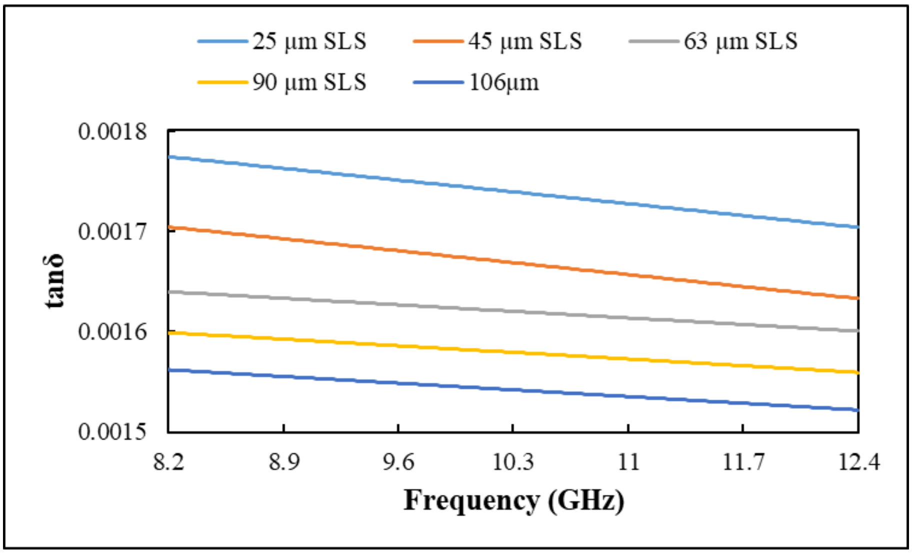


**Figure 3**: Variation of loss tangent with frequency and filler size

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