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Dielectric Properties of Soda Lime Silica Glass at Microwave Frequencies for Substrate Application

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Abstract

Soda lime silica (SLS) powder was extracted from SLS glass waste for reinforcing polytetrafluoroethylene (PTFE) for microwave substrate application. A ball milling technique was used to prepare the SLS powder with different particle sizes (106 - 25) µm. Scanning electron microscope (SEM) analysis of the SLS powder representative particle size revealed an irregular shape, while energy dispersive X-ray (EDX) spectra indicated the purity of the SLS powder. The dielectric properties of the SLS powder were measured using an open-ended coaxial probe (OCP) technique connected to a vector network analyser in the 1 GHz to 12 GHz microwave frequencies. The results obtained from the OCP technique exhibited a decreasing trend with higher particle sizes of the powder and the frequency of operation. In addition, the ε_r *of the 106 µm SLS powder decreased from 3.52 to 3.48, while the loss tangent*($\tan\delta$) *reduced from 0.0052 to 0.0047 in the 1 GHz to 12 GHz, respectively. For the 25 µm SLS powder, the* ε_r *and* $\tan\delta$ *varied from 3.59 - 3.55 and 0.0059 - 0.0057, respectively. These results indicated the suitability of the SLS powder for filling the PTFE for microwave substrate application.*

Keywords: SLS glass; recycling; relative permittivity; dielectric loss

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Introduction

The proliferation of wireless communication devices for consumer and military use has elicited a lot of interest in suitable materials for microwave substrate application. For a practical application, substrate materials are required to possess low relative permittivity (ε_r) and loss tangent ($tan\delta$) in addition to good thermal and mechanical properties. Polymer-inorganic composites are usually employed for this purpose. Polymers have appropriate dielectric properties, with poor thermal properties that impede their potential use as stand alone materials for the microwave substrate application. The inorganic materials, such as ceramic and glass, have moderate ε_r and $tan\delta$, excellent mechanical and acceptable thermal properties, however, high processing temperature and fragility hamper their usage. Hence the blend of the polymers and inorganic materials to produce composites with optimum properties is required for the substrate application.

Several inorganic materials have been reported to reinforce polymers for the microwave substrate application (Cai *et al.*, 2020; Calabrese *et al.*, 2022; Tan *et al.,* 2022; Varghese *et al.,* 2015; F. Zhang *et al.,* 2020; K. Zhang *et al.*, 2022). However, these materials were obtained commercially, contributing to the cost of the composites. The obstacle can be mitigated by recycling some inorganic materials, such as soda lime silica glass (SLS) for large-scale composite production. The SLS is the most common glass available. It is used in windowpanes, lightbulbs, and beverage bottles. It comprises approximately 70%-75% silica (SiO_2), 5%-10% CaO, 13%-17% Na_2O and a small percentage of other glass-modifying materials such as Al_2O_3 (Hasanuzzaman *et al.*, 2016). It has moderate dielectric properties, and strong mechanical strength, in addition to possessing moderate thermal properties for microwave substrate application. Moreover, the glass constitutes a significant chunk of household and industrial waste, which takes a long time to decay. Thus, recycling it for substrate application can reduce production costs as well as environmental waste (Ashby, 2012; Hisham *et al.,* 2021; Khazaalah *et al.,* 2022; Wahab *et al.,* 2021).

Although the SLS glass has found applications in optoelectronics, glass-ceramics, and cement production (Francis Thoo *et al.,* 2013; Ismail *et al.*, 2020; Saparuddin *et al.,* 2020), its usage in microwave substrate application has never been reported. Furthermore, a detailed study on its dielectric properties at microwave frequencies has not been conducted, considering its beneficial properties, in addition to being non-toxic and cheaper. Thus, this work intends to extract SLS powder of different particle sizes from the SLS glass through ball milling and sieving procedure, and then characterise it for its dielectric properties (ε_r and $tan\delta$).

The characterisation would be carried out using the OCP measurement technique in1 GHz - 12 GHz microwave frequency range.

Materials and Methods

SLS glass bottles were sourced from a landfill location at Taman Sri Serdang, Selangor, Malaysia. The bottles were thoroughly washed, before being cleaned and left to dry indoors. After 24 h, the bottles were processed into glass powders of different sizes. The process of the extraction is shown in Figure 1.

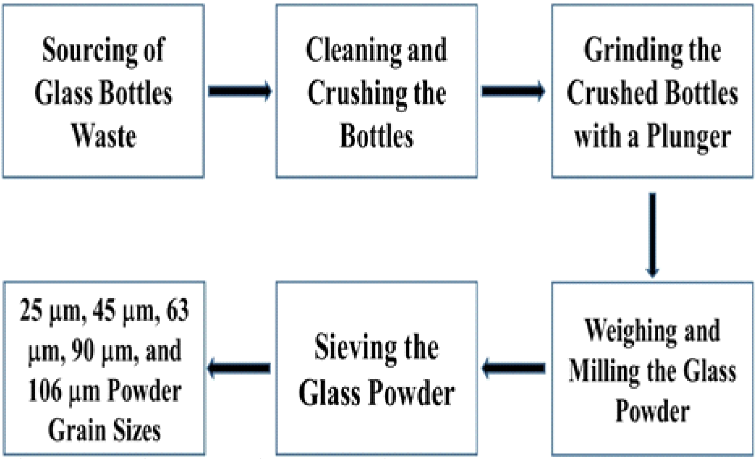

Figure 1: Glass powder extraction process

The morphology and elemental composition of the representative powder particle size were characterised using SEM and EDX analysis. Variable pressure SEM from Leo Electron Microscopy Group, Oberkochen, Germany, was utilised in the SEM analysis. In addition, the EDX analyser from Oxford Instruments, Buckinghamshire, England, connected to the Leo system was used for the collection of the elemental composition of the sample.

The dielectric properties of the glass powder were characterised to obtain its relative permittivity (ε_r)and loss tangent ($tan\delta$) at microwave frequencies (1 GHz - 12 GHz). An open-ended coaxial probe (OCP) technique coupled with a vector network analyser from Agilent Technologies, Santa Clara, CA, USA, was used for the characterisation. After calibration of the measurement apparatus, a standard polytetrafluoroethylene (PTFE) material was first characterised to confirm the accuracy of the measurement setting. Also to avoid air gaps in the sample that might affect the measurement precision, the glass powder was compacted before the characterisation.

Results and discussion

The SEM image of SLS powder and its corresponding EDX spectra are illustrated in Figure 3. The SLS glass exhibits an arbitrary geometry with an average particle size of 52 μm The particle size of the glass powders was determined using Image J software (Schindelin et al., 2015).

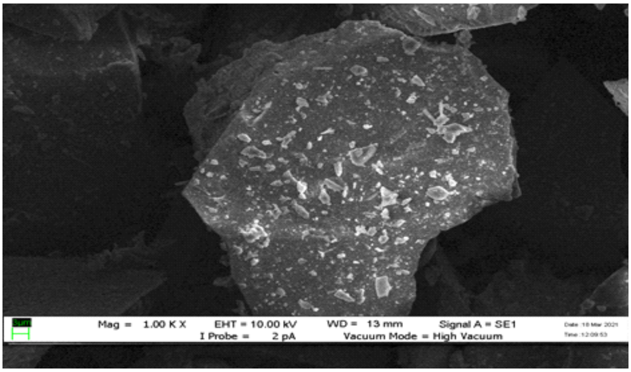

Figure 2: SEM micrograph of a 63 μm SLS powder

Figure 3 shows that the elemental composition of the SLS glass powder consisting of calcium, oxygen, sodium, and silicon at 0.2 keV, 0.4 keV, 1.0 keV, and 1.6 keV. Furthermore, calcium appears again at 3.6 keV and 4 keV. These multiple appearances are due to the excitation of the atomic energy level of the calcium under the incident energy of the SEM. All the elements expected from SLS glass were detected with no contaminant of any sort in the spectra, indicating the purity of the SLS powder. The corresponding weight and atomic percentages are illustrated in Table 1.

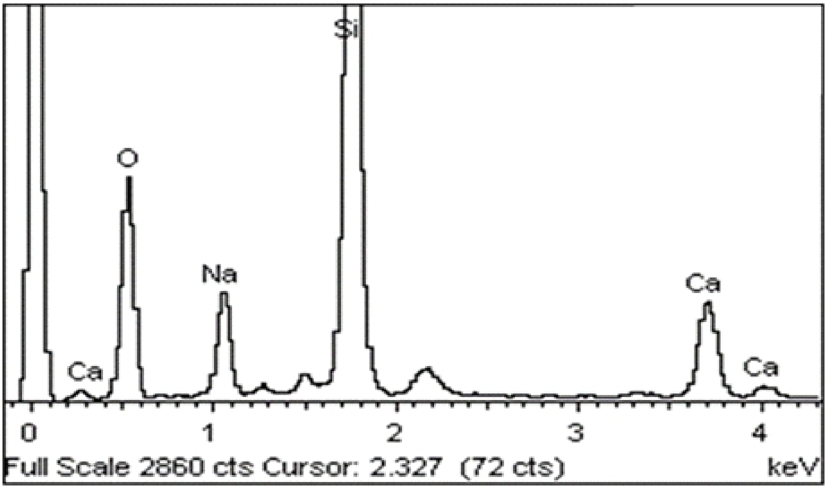

Figure 3: EDX spectra of a 63 μm SLS powder

Table 1: Weight and atomic percentages of SLS composition

Element	Weight (%)	Atomic (%)
O	55.50	68.76
Na	8.76	7.55
Si	28.47	20.09
Ca	7.27	3.60
Total	100.00	100.00

Figures 4 and 5 show the effect of size variation as well as the frequency dependence on the dielectric properties of SLS powder. It can be seen that both ε_r and $tan\delta$ decrease with frequency (Rayssi *et al.,* 2018). The reduction in ε_r and $tan\delta$ with frequency is due to the decrease in the interface polarisation as ion hooping could not keep phase with the rapidly changing applied field at higher frequencies (Meli *et al.,* 2019). However, the ε_r and $tan\delta$ record higher values at lower frequencies due to a stronger space charge polarisation effect (Xue *et al.,* 2021). Moreover, the ε_r and $tan\delta$ decrease from 3.52 - 3.48 and 0.0052 - 0.0047 for 106 µm powder size, respectively. Similarly the ε_r and $tan\delta$ vary from 3.59 – 3.55 and 0.0059 – 0.0057 to 3.55, respectively, for 25 µm powder size in the 1 GHz to 12 GHz frequency range.

Furthermore, it is observed that ε_r and $tan\delta$ decrease when the powder size reduces from 106 µm to 25 µm (Ahmad *et al.,* 2019). As such the ε_r and $tan\delta$ achieve mean values of 3.50, 3.52, 3.54, 3.56, 3.57 and 0.0050, 0.0052, 0.0055, 0.0057, 0.0058, respectively, for 106 µm, 90 µm, 63 µm, 45 µm, and 25 µm SLS powder sizes, respectively. The higher values of ε_r and $tan\delta$ at smaller filler sizes is due to a stronger interfacial polarisation. Since the surface area possessed by particles is indirectly proportional to their sizes, thus, smaller-sized particles tend to have a larger surface, increasing the particle-particle interaction that leads to more interfacial polarisation, which contributes to higher ε_r and $tan\delta$ in the material (Jiang & Yuan, 2018). In addition, the powder with smaller-sized particles has more particles per unit volume, leading to higher densification, which also increases the ε_r and $tan\delta$ of the powder (Mensah *et al.,* 2019).

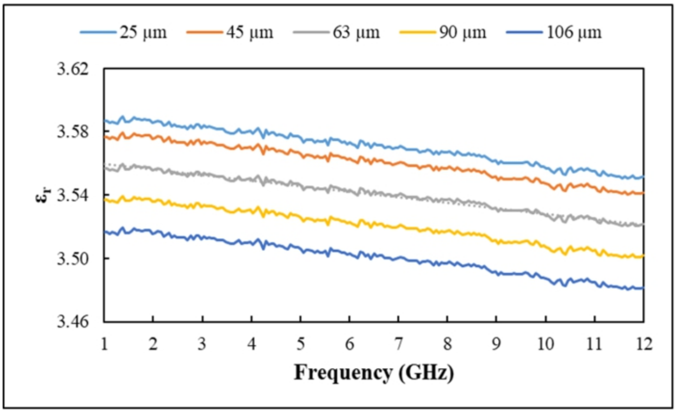

Figure 4: Variation of ε_r with different SLS powder size

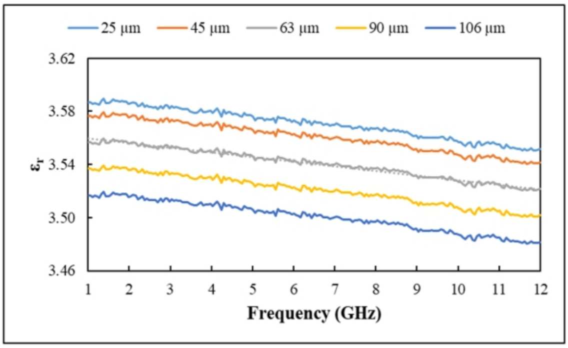

Figure 5: Variation of $tan\delta$ with different SLS powder size

Conclusion

SLS powder has been processed from SLS glass waste for inclusion as reinforcement in a PTFE-based microwave substrate. The powder was extracted by crushing, plunging, milling, and sieving process. Furthermore, the SLS powder was characterised for its morphology, composition, and dielectric properties at microwave frequencies. SEM analysis revealed the arbitrary shape of the powder particles, while EDX studies showed the presence of all elements in the SLS glass and hence, the purity of the recycled powder. The results for dielectric properties indicated the increasing nature of $\varepsilon_r$and $tan\delta$with decreasing powder particles size. In addition, the SLS powder exhibited low dielectric properties at all frequencies. Thus, the usage of macro-sized SLS powder with optimum dielectric properties could reduce environmental waste as well as reduce the cost of PTFE-based microwave substrate.

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References

Ahmad, P., Rao, A. V., Babu, K. S., and Rao, G. N. (2019). Particle size e ff ect on the dielectric properties of ZnO nanoparticles. Materials Chemistry and Physics, 224(2019), 7984.

Ashby, M. F. (2012). Materials and the Environment. Butterworth-Heinemann.

Cai, X., Dong, X., Lv, W., Ji, C., Jiang, Z., Zhang, X., … Zhang, X. (2020). Synergistic enhancement of thermal conductivity for low dielectric constant boron nitridepolytetrafluoroethylene composites by adding small content of graphene nanosheets. Composites Communications, 17(November 2019), 163169.

Calabrese, R. E., Bury, E., Haque, F., Koh, A., and Park, C. (2022). Effects of filler composition, loading, and geometry on the dielectric loss, partial discharge, and dielectric strength of liquid metal polymer composites. Composites Part B: Engineering, 234(January), 109686.

Francis Thoo, V. W., Zainuddin, N., Matori, K. A., and Abdullah, S. A. (2013). Studies on the potential of waste soda lime silica glass in glass ionomer cement production. Advances in Materials Science and Engineering, 2013.

Hasanuzzaman, M., Rafferty, A., Sajjia, M., and Olabi, A.-G. (2016). Properties of Glass Materials. In Reference Module in Materials Science and Materials Engineering (pp. 112). Elsevier Ltd.

Hisham, N. A. N., Zaid, M. H. M., Aziz, S. H. A., and Muhammad, F. D. (2021). Comparison of foam glass-ceramics with different composition derived from ark clamshell (ACS) and soda lime silica (SLS) glass bottles sintered at various temperatures. Materials, 14(3), 114.

Ismail, N. Q. A., Saat, N. K., and Zaid, M. H. M. (2020). Effect of soda lime silica glass doping on ZnO varistor ceramics: dry milling method. Journal of Asian Ceramic Societies, 8(3), 909914.

Jiang, Z., and Yuan, Y. (2018). Effects of particle size distribution of silica on properties of PTFE/SiO2 composites. Materials Research Express, 5(6).

Khazaalah, T. H., Mustafa, I. S., Sayyed, M. I., Rahman, A. A., Zaid, M. H. M., Hisam, R., … Khalib, N. C. (2022). Development of Novel Transparent Radiation Shielding Glasses by BaO Doping in Waste Soda Lime Silica (SLS) Glass. Sustainability (Switzerland), 14(2), 111.

Meli, A. D., Abbas, Z., Mohd Zaid, M. H., and Ibrahim, N. A. (2019). The effects of SLS on structural and complex permittivity of SLS-HDPE composites. Advances in Polymer Technology, 2019.

Mensah, E. E., Abbas, Z., Azis, R. S., and Khamis, A. M. (2019). Enhancement of complex permittivity and attenuation properties of recycled hematite (α-Fe2O3) using nanoparticles prepared via ball milling technique. Materials, 12(10), 113.

Rayssi, C., El Kossi, S., Dhahri, J., and Khirouni, K. (2018). Frequency and temperature-dependence of dielectric permittivity and electric modulus studies of the solid solution Ca0.85Er0.1Ti1-: XCo4 x /3O3 (0 ≤ x ≤ 0.1). RSC Advances, 8(31), 1713917150.

Saparuddin, D. I., Zaid, M. H. M., Ab Aziz, S. H., and Matori, K. A. (2020). Reuse of eggshell waste and recycled glass in the fabrication porous glass-ceramics. Applied Sciences (Switzerland), 10(16).

Schindelin, J., Rueden, C. T., Hiner, M. C., and Eliceiri, K. W. (2015). The ImageJ ecosystem: An open platform for biomedical image analysis. Molecular Reproduction and Development, 82(78), 518529.

Tan, Y., Liu, Y., Yan, X., Lu, G., Xie, K., Tong, J., and Meng, F. (2022). Functionalized Al2O3 fillers/glass fibers cloth/PTFE composites with excellent thermal properties. Journal of Materials Science: Materials in Electronics, 33, 88158821.

Varghese, J., Nair, D. R., Mohanan, P., and Sebastian, M. T. (2015). Dielectric, thermal and mechanical properties of zirconium silicate reinforced high density polyethylene composites for antenna applications. Physical Chemistry Chemical Physics, 17(22), 1494314950.

Wahab, R. A. A., Mohammad, M., Mazlan, M., Razali, M. A. M., Rusni, N. A. M., Sharisun Asma, W. A. N., … Zaid, M. H. M. (2021). Physical properties of low energy consumption fired industrial waste-clay bricks from cockle shells and soda lime silica glass. AIP Conference Proceedings, 2332(2021).

Xue, P. J., Liu, S. L., and Bian, J. J. (2021). Effects of polymorphic form and particle size of SiO2fillers on the properties of SiO2-PEEK composites. Journal of Advanced Dielectrics, 11(4), 18.

Zhang, F., Zhang, J., Zhu, Y., Wang, X., and Jin, Y. (2020). Microstructure and properties of polytetrafluoroethylene composites modified by carbon materials and aramid fibers. Coatings, 10(11), 120.

Zhang, K., Zhao, D., Chen, W., Zheng, L., Yao, L., Qiu, Y., and Xu, F. (2022). Three-dimensional woven structural glass fiber/polytetrafluoroethylene (PTFE) composite antenna with superb integrity and electromagnetic performance. Composite Structures, 281(2022), 115096.