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Published in:
IEEE publication

Publication date:
2024

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Rodriguez-Cano, R., Lanagan, M., Clark, N. L., & Mauro, J. C. (in press). Novel Glass Material with Low Loss and Permittivity for 5G/6G Integrated Circuits. *IEEE publication*.

Novel Glass Material with Low Loss and Permittivity for 5G/6G Integrated Circuits

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***Abstract*—A new borosilicate glass with lower loss and permittivity than any commercial glass has been proposed in this contribution as a substrate or interposer for mm-wave and THz integrated electronics. The glass is composed of a microstructure enclosing high-purity boron rich areas and silicon rich areas. This phase-separated areas are several orders of magnitude smaller than the wavelength at 1 THz.**

***Index Terms*—characterization, dielectric, glass, loss, material, measurements, substrate, 5G, 6G.**

I. Introduction

The fifth generation of mobile communications (5G) has caused a paradigm shift with the addition of new frequency bands in the millimeter-wave (mm-wave) spectrum. The higher propagation losses found at higher frequencies have fomented the quest for low loss materials. Besides, lower permittivity enables faster electromagnetic wave propagation, since the speed is inversely related to the dielectric constant [1]. Lower permittivity also decreases the capacity coupling between adjacent conductors [2]. Glass is a promising material to decrease signal loss in semiconductor chip interposers for integrated circuits. This is because glass has inherent low loss, low manufacturing costs, and provides high signal isolation [3]–[6].

Silicates are the most common and widely used commercial glass compositions, as silicon dioxide (silica) is an extremely abundant material on the Earth, making up over half of the crust's composition [7]. Among non-crystalline silicates, fused silica has the highest purity. As a consequence, it has exceptionally low loss and low dielectric constant. To decrease it manufacturing cost, alkali (Li, Na, K) and alkaline-earth modifiers (Mg, Ca, Sr, Ba) are incorporated in the silica network, as they reduce the high melting point in fused silica. The higher ionic polarizability of these additives increases the dielectric constant and loss tangent. Other elements, which can act as network formers, are also added to the silica network in commercial glasses. Boron and aluminum are examples of network formers.

The dielectric properties of materials are ruled by the relaxation mechanisms. They are processes by which charges and dipoles in a material rotate or move when exposed to an oscillating electric field, causing the materials to dissipate or absorb energy. However, there is a lack of dielectric characterization data in the mm-wave spectrum and low-THz, known in literature as the THz measurement gap [8]. At these frequencies, the tails from the ionic resonance could have an important impact on the dielectric properties. The authors have presented the measurement data of several silicates until 2.5 THz in [9], [10], but the ionic resonance is not present at that frequency band.

A key metric to understand the connection between the molecular structure and the dielectric characteristics of a material is the ionic polarizability. The Clausius-Mossotti equation allows to estimate the permittivity of a material, by knowing the polarizability values of the ions composing the material and its density. In [11], Shannon compiled and published the polarizabilities of different ions in crystalline materials. It can be seen that boron has the lowest value, viz., $0.05\ \AA^3$. By comparison, the polarizability of silicon is $0.87\ \AA^3$ and $2.01\ \AA^3$ for oxygen. In [12], it was shown that the polarizability of ions in the non-crystalline state (e.g. glass, fused silica) is higher than in the crystalline state (e.g. quartz). The degree of divergence between the ionic polarizability in a material's crystalline phase versus its amorphous phase shows a proportional relationship to the level of dielectric loss measured from GHz to THz bands.

In this paper, we propose a new silicate glass composition with high boron percentage. Boron's inherent low polarizability, along with the immiscibility of the glass formers B_2O_3 and SiO_2 [13], leads to a phase-separated microstructure that exhibits lower dielectric constant and loss compared to any commercial glasses in the mm-wave to THz frequency range. The immiscibility has been confirmed with X-ray spectroscopy.

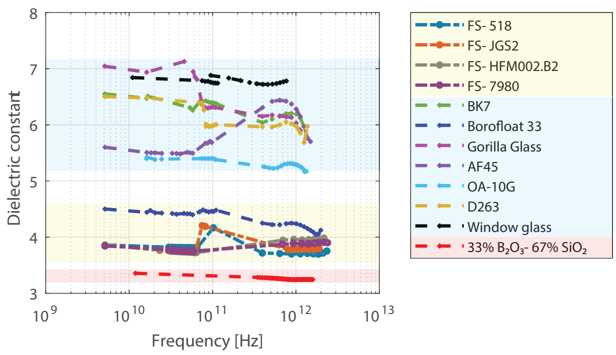
II. Samples preparation

The glass samples were prepared by manually mixing SiO_2 and B_2O_3 powders, with a range of compositions $xB_2O_3 - (1-x)SiO_2$, where $33\% < x < 100\%$. In order to remove excess water and avoid foaming in the melt, the mix was calcined in a furnace for 1.5 hours at $200°C$. After the calcination, approximately 60g batches were melted at $1600°C$ in a platinum crucible in a furnace for 3 hours. The melt was poured on a metal plate, where it quenched at room temperature.

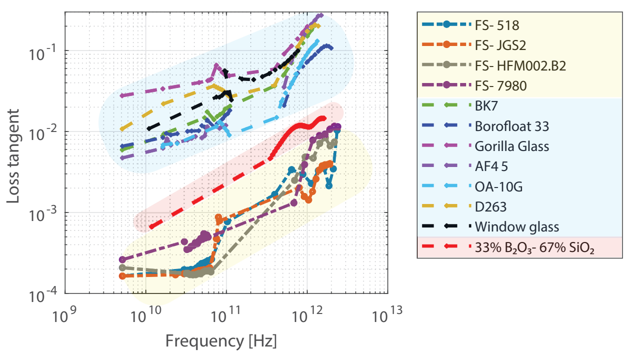
Borosilicates have been previously employed in literature, but with B_2O_3 percentages lower than 13% (e.g. Duran, Pyrex). Vycor uses around 4% mol B_2O_3, but it is dissolved after treatment.

III. Results

The measured dielectric properties of the fabricated glass and some other commercial glasses are shown in Fig. 1. The real part of the permittivity is shown in Fig. 1a. The response of the majority of the silicates remains flat over several decades. Glasses have the highest dielectric constant, above 5, due to their higher percentage of modifiers (the composition of several commercial glasses has been obtained with inductively coupled plasma (ICP) analysis and it is shown in [9]). Fused silicas (FS) have permittivity values around 4. The borosilicate glass proposed in this paper has permittivity values around 3.4, even lower than the fused silicas. The composition shown in the figure is the one with the lowest percentage of boron. Increasing the amount of boron decreases the dielectric constant even more. This permittivity of this glass is also lower than Vycor, which has a dielectric constant of 3.8.



(a) Dielectric constant



(b) Loss tangent

Fig. 1. Dielectric properties of different materials in the silicate family. Fused silicas are shaded in yellow, commercial glasses in blue and our proposed borosilicate, in red.

The loss tangent is plotted in Fig. 1b. In two decades, the loss tangent grows an order of magnitude for all the silicates. There is also around an order of magnitude difference between the fused silicas and the commercial glasses. Our proposed glass lies in between the two groups, closer to the fused silicas.

IV. Conclusion

The concepts of low ionic polarizability and immiscibility have been employed in this paper to propose a new glass with ultra low loss and lower permittivity than any commercial glass and even fused silica. These properties make it a great solution for mm-wave and THz integrated circuits.

Acknowledgment

This work was supported in part by the National Science Foundation through the Center for Dielectrics and Piezoelectrics under Grant IIP-1841453 and Grant IIP-1841466, and in part by the VILLUM FONDEN under Grant 41389.

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