Broadband Dielectric Characterization of Glasses and other Silicates up to the THz Frequencies.

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***Abstract*—The dielectric characterization of silicate materials up to 2.5 THz is presented in this paper, to try to fill up the THz gap between electrical and optical measurements. Several measurement techniques have been employed to provide a broadband response. Materials in the silicate family can be classified as amorphous or crystalline. The internal structure, as well as the composition of the material, influences the dielectric properties. The loss of a material depends on its crystallinity, with higher crystallinity exhibiting lower loss.**

I. Introduction

The 5^{th} generation of mobile communications (5G) has emerged with a number of new frequency bands complementing the sub-7 GHz former ones. Some of these bands are placed in the millimeter-wave (mm-wave) spectrum, on which the wavelengths are around one order of magnitude lower. This can be translated as more obstruction for the waves propagation [1], [2]. For the sixth generation (6G) more spectrum from 100 GHz to several THz is under assessment [3], [4]. The new frequency bands included in the mm-wave spectrum have brought a renovated interest in glass substrates, as they limit outdoor to indoor coverage in the mm-wave spectrum [5], [6]. Apart from that, the front and back covers of the phones are made with Gorilla glass, and large intelligent surfaces on glass (LIS) have been proposed for 6G [7].

However, there is a measurement gap between the electric and optical frequencies, and the reported data is limited. In [2], the attenuation of typical building materials is given at 28 GHz, 73 GHz and 91 GHz. The window attenuation at 38 GHz is given in [8]. In [9]–[11], the measurements of some dielectrics and semiconductors are given until 110 GHz. Paper [11] compares the loss of three different glasses at 10 GHz, 77 GHz and 110 GHz. In [12], the dielectric properties of alkali and alkali-free aluminoborosilicate glasses are shown until around 100 GHz.

In this paper, we aim not only to characterize the materials in the silicate family up to 2.5 THz, but also to understand why some of them have higher loss than others.

II. Silicate Materials

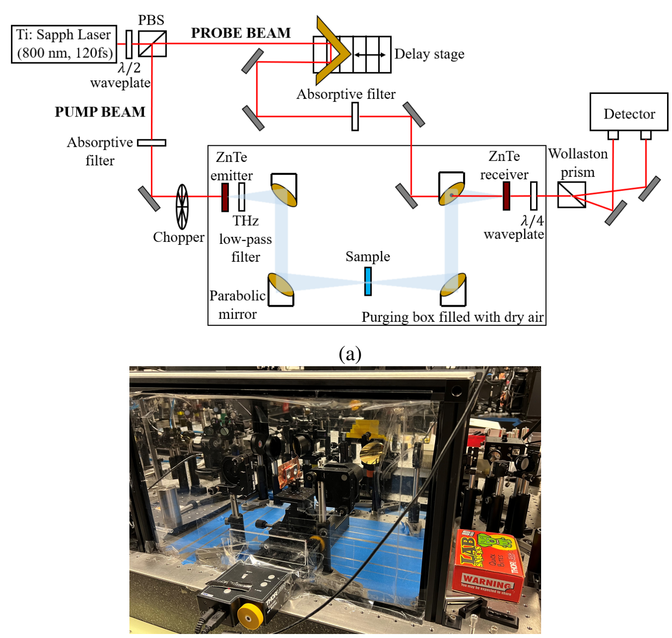
The silicate materials are divided in two groups according to their internal structure: crystalline and amorphous materials. The latter group can be divided in fused silicas and glasses, with a higher and lower level of crystallinity, respectively.

In the amorphous case, the addition of alkali and alkaline-earth modifiers into silica contributes to the depolymerization of the SiO_2 network. Each molecule of alkaline oxide causes the breakage of a $Si-O-Si$ bridge, resulting in two non-bridging atoms. Depending on the amount of modifiers, the depolymerization can lead to five different silicon microstructures, also known as $Q^{(n)}$ species, with n the number of bridging oxygens [13].

III. Measurement techniques

For the measurements in the lower part of the mm-wave spectrum, the following techniques have been used: split-post, split-cavity, open resonator and MCK from SWISSto12. The first two can only measure one frequency point (below 5.17 GHz and below 20 GHz, respectively), while the last ones provide multiple frequency points. For the open resonator, the frequency range is $15-67$ GHz. For the MCK, the frequency range is $70-115$ GHz.

This contribution is focused on the measurement above those frequencies, in the THz spectrum. THz time-domain spectroscopy (THz-TDS) has been employed and the transmission set-up is plotted in Fig. 1a.



(a)

(b)

Fig. 1: (a) Simplified illustration of the THz time-domain spectroscopy set-up. (b) Real set-up.

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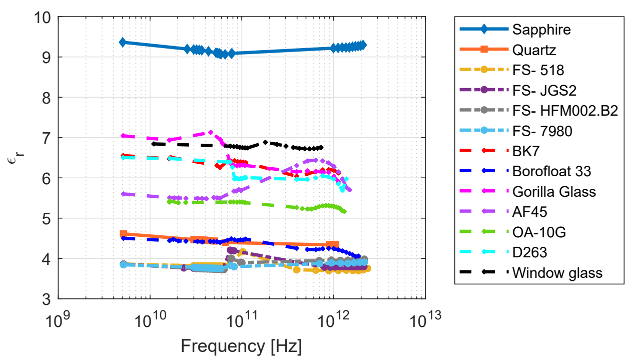
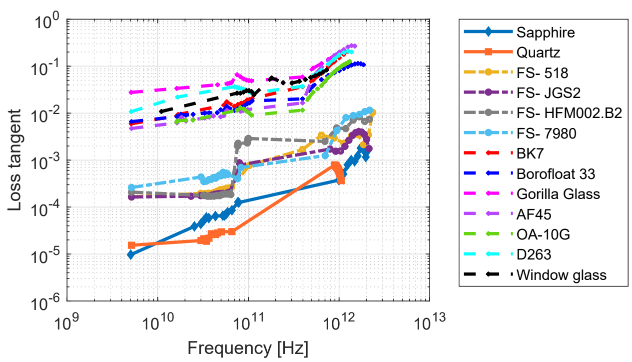
IV. Measurement Results

The dielectric constant of the measured materials is plotted in Fig. 2a. The thickness of the materials vary between $0.3-1$ mm (2.3 mm for window glass). The results from 5 GHz to 115 GHz have been included to show the tendency. The glasses have a dielectric constant between 5 and 7, except for Borofloat 33, which has a permittivity of 4.2 due to the lower polarizability of the boron ion [14]. The fused silicas have a typical permittivity below 4.3, while for quartz, the value is around 4.4. Sapphire is not part of the silicate family and has been added as a reference, and its permittivity is around 9.2.

The loss tangent results can be found in Fig. 2b. It is clear in the figure how the samples are separated in three different regions that depend on their internal structure. Glasses are the most lossy materials, with a loss tangent reaching 10^{-1} at the THz frequencies. Fused silicas are one order of magnitude below, and the crystalline materials have even lower loss. However, the values obtained for the crystalline materials should be just taken as a reference, since they reach the techniques' loss floor.



(a)



(b)

Fig. 2: Measured results. (a) Dielectric constant. (b) Loss tangent.

V. Conclusion

The internal structure of a silicate material affects the polarizability of its molecules under an electric field. The purest sample, i.e. quartz, is only formed by Q^4 structures. However, in highly-modified glasses, the percentage of Q^3 and Q^2 is large. The lower amount of bridging oxygens gives the molecules extra mobility, which translates in higher loss.

The measurement results are obtained from 5 GHz until 2.5 THz. The upper limit of the measurement band is limited by the response of the zinc-telluride crystal.

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