Non-destructive evaluation of ceramic porosity using terahertz time-domain spectroscopy

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THz radiation can be employed to characterize the dielectric constant and loss tangent of ceramic materials widely used for industrial applications. However, a key parameter in ceramic material production concerns the control of the porosity since it is directly related to the ceramic properties. The evaluation of the ceramic porosity can be achieved by mercury injection. However, THz radiation can propose an alternative effective contact-less and non-destructive approach. In this communication, we focus our attention on alumina (Al2O3), the most important, widely used and cost effective oxide ceramic material [1]. We investigate the THz dielectric properties of alumina ceramic samples with porosity fractions from 0% to 20%. Samples are prepared by pressing and sintering 1 µm grain sizes. Sample porosity was first characterized by the mercury porosimetry technique. Then, THz spectra were obtained with a commercial THz time-domain spectrometer.

For different porosity fractions, Fig. 1 shows the evolution of both the permittivity (a) and the loss tangent (b) from 0.3 to 2 THz. Main interesting feature is that we observe a clear 20% decrease of the sample permittivity as the porosity fraction changes from 0% to 20%. Simultaneously, the dielectric loss strongly increases for samples with higher porosity fractions. At macroscopic scale, the effective properties of a multi-phase composite material can be accurately computed using the properties and the relative fractions of its components. Using the effective medium theory with most common models, we predict the sample permittivity for all porosity fractions from 0% to 20% with a good agreement with the experiment (Fig. 1c). Assuming a spherical aspect for the pores (empty spaces between alumina inclusions), we conclude that the inclusions have also a quasi-spherical shape with an aspect ratio estimated to 0.87.

In the communication, we will also demonstrate that THz time-domain spectroscopy can differentiate alumina samples fabricated with different grain sizes, or reveal a small fraction of impurities, such as 5% ZrO2, embedded in non-porous alumina. These results demonstrated the potential of THz radiation for non-destructive characterization of low loss high dielectric constant ceramics.

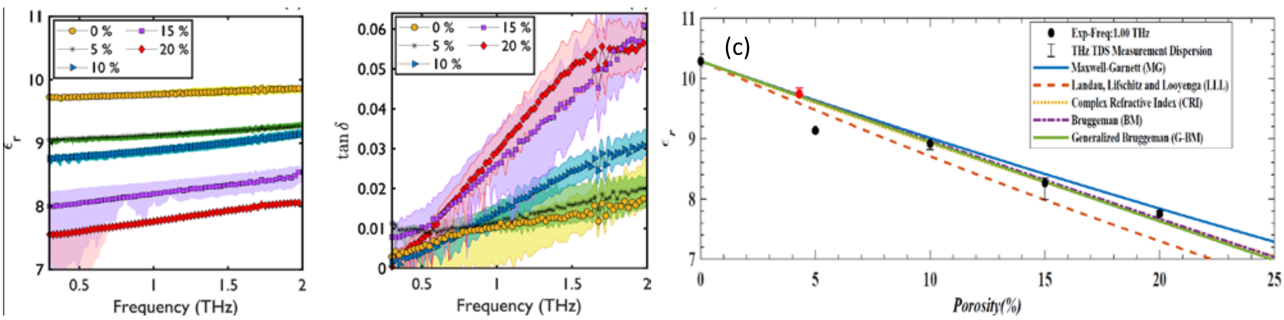

Fig. 1: Dielectric properties of d_{50} =1 µm grain size alumina samples with different porosity fractions. (a) Relative permittivity. (b) Loss tangent. (c) Comparison between experimental relative permittivity of the samples (black dots) and the one predicted from EMMs (solid lines), at 1 THz and as a function of the sample porosity fraction.

[1] K.Z. Rajab et al., "Broadband dielectric characterization of aluminum oxide (Al2O3)", J. Micr. El. Pack, 5 (1), 2-7 (2008).