Submillimeter-wave properties of Zn_2SiO_4 ceramics

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***Abstract* — Zinc silicate ceramics have been prepared by using conventional ceramic technology. Morphological, structural, and dielectric characterizations of the samples were performed using scanning electron microscopy, X-ray diffraction, and terahertz time-domain spectroscopy. The achieved absorption properties of zinc silicates make them very attractive solutions for submillimeter-wave applications.**

I. INTRODUCTION

LOW-LOSS dielectric materials [1] influence decisively both terrestrial and space communications and monitoring infrastructure. These are very efficient for equipment's weight and size reduction which integrate components such as lenses, waveguides, filters, antennas, photonic crystals, metamaterials etc. Due to permanent requirement for cost reduction, the conventional ceramic technology is the most widely employed procedure for large-scale production of dielectric materials.

Many sources of dielectric loss exist in the polycrystalline materials, but all of them can be grouped into two major classes: i) intrinsic, corresponding to phonons loss in single crystals [2] and ii) extrinsic, related to imperfections, which can be reduced by proper processing parameters [3].

Since the modern telecommunications are moving towards microwave bands due to the crowding of the electromagnetic spectrum [4-6], material's characterization in millimeter-wave (MMW) and submillimeter-wave (SMMW) bands is required. The Terahertz Time-Domain Spectroscopy (THz-TDS) is a very accurate measurement technique which can be used for that purpose. When compared to the conventional Fourier Transform Infrared Spectroscopy (FTIR), THz-TDS provides not only the spectral intensity, but also the intrinsic phase shifts of the propagating THz signal allowing the direct finding of the complex dielectric permittivity without the use of the Kramers–Kronig relations [7].

II. RESULTS

Zn_2SiO_4 (ZSO) ceramics were synthesized by conventional ceramic technology. High purity ZnO and SiO_2 oxides have been ball-milled in distilled water. In order to determine the temperature of the solid-state reaction, the homogenized mixture was subsequently investigated by thermal analysis and X-ray diffraction. The ZSO powders calcined in air at 1100 ºC / 2h were mixed with 2 % polyvinyl alcohol and uniaxial pressed into cylindrical mould to about 50 % of their theoretical bulk density. ZSO sample were sintered in air for 4 at 1300 ºC.

The ZSO sintered samples were polished in order to remove the superficial zone and their bulk densities were measured by using Archimedes method. After sintering process, ZSO sample with bulk density higher than 95 % of theoretical density have been obtained.

The structural characterization of ZSO samples was performed in Bragg-Brentano geometry with a Bruker D8 Advance diffractometer, equipped with copper X-ray tube and LynxEye detector. The X-ray diffraction patterns (Fig. 1) confirm the formation of the Zn_2SiO_4 willemite-type structure (space group R-3). All the diffraction lines were indexed with respect to the ICDD file 01-070-1235 and no secondary phases have been detected.

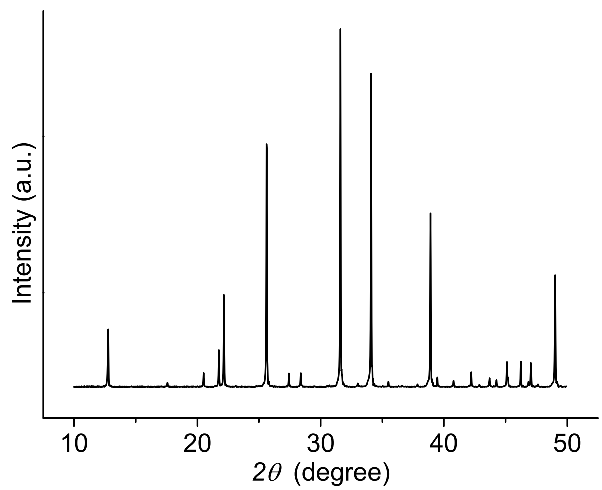

Fig. 1. X-ray diffraction pattrens of Zn_2SiO_4 sample sintered at 1300 ºC / 4h.

The microstructure of ZSO ceramics was analyzed by using a Zeiss Evo 50 XVP scanning electron microscope (SEM). The SEM micrographs recorded on sample's fracture (Fig. 2) put in evidence a distribution of spherical grain with size in the 1 - 5 μm range. The porous structure is represented by submicron intergranular pores.

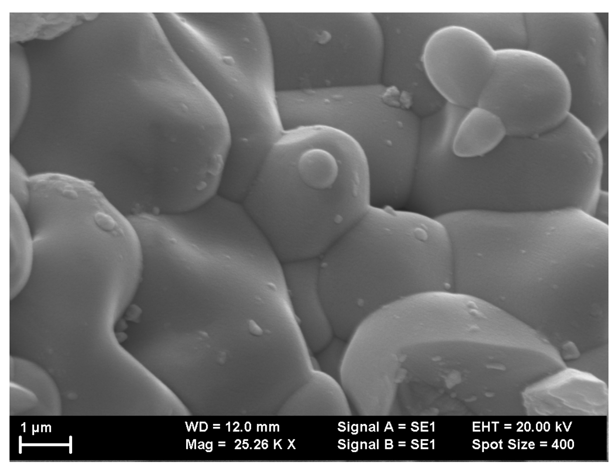

Fig. 2. SEM image of Zn_2SiO_4 sample sintered at 1300 ºC / 4h.

The THz-TDS measurements were carried out on 0.5 mm thick disks in transmission set-up. In Fig. 3 is presented the frequency dispersion of the absorption coefficient for ZSO ceramics. The data have been computed from time-domain results by using TeraLyzer commercial software. As it can be seen from Fig. 3, below 2 THz the zinc silicate ceramics exhibits low absorption coefficient value. On the other hand a strong absorption peak, which corresponds to the lowest-frequency phonon mode, was evidenced at 2.3 THz.

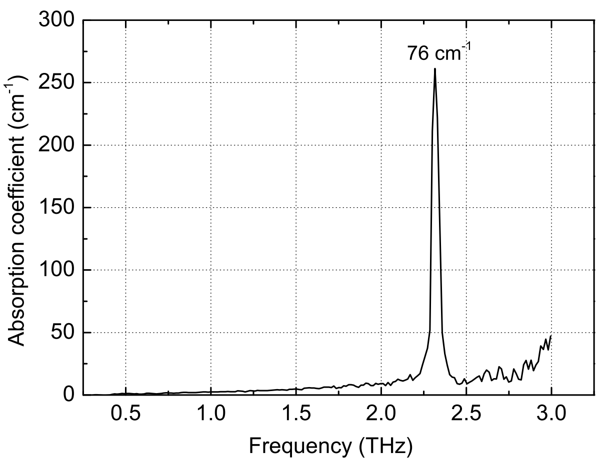

Fig. 1. Absorption coefficient versus frequency of Zn_2SiO_4 sample.

The ZSO samples sintered as dielectric resonators have been characterized in microwave domain by using Hakki–Coleman method [9]. The typical results obtained for these resonators were 6.4 for dielectric constant and 140 THz for Q x f product, where Q represent the inverse of dielectric loss and f is the resonance frequency. For defects-free dielectric resonator materials Q x f product is constant [3] over MW and MMW domain. Due to this fact, this is more used as resonator parameter rather than dielectric loss. The ZSO disks investigated by THz-TDS were cutted from resonators with lowest microwave dielectric loss. The computed data at 1 THz show that the dielectric constant is 6.4, which is in good agreement with microwave data. On the other hand, values of about 220 THz were estimated from THz-TDS data for Q x f product, which are much higher than those measured in MWs.

Many attempts have been made if the past for the estimation of the microwave dielectric loss by using FTIR technique [10-14]. This enables the identification of most important (low-frequency) polar phonon modes, which contribute most strongly to the microwave permittivity and whose damping is usually related to MMW and MW losses. The extrapolation of losses from the SMMW down to the MW range using a simple proportionality between dielectric loss and frequency was frequently used to estimate intrinsic MW loss. However, due to the extrinsic contributions, but many times the losses did not match, especially for polycrystalline materials.

The extrinsic dielectric loss of the ceramic materials can be reduced by proper processing parameters, such as purity of raw materials, calcination and sintering temperatures, shaping method, etc. For this reason, THz-TDS is a very versatile technique for estimation of intrinsic losses, hence for finding the limit achievable by tailoring of the synthesis parameters.

III. Summary

Zinc silicate ceramic materials with low absorption coefficient in THz domain were obtained by solid-state reaction. THz-TDS is an accurate technique for estimation of intrinsic dielectric loss of the low absorption materials. The low dielectric loss obtained for Zn_2SiO_4 ceramics recommend them for SMMW applications.

Acknowledgments

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