

RF Characterization of Zirconia Ribbon Ceramic Using T-Resonator Method

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Abstract—Zirconia Ribbon Ceramic (ZRC) is a commercially available ceramic that can be a potential low-loss substrate for radio frequency (RF) devices suitable for high temperatures and harsh environmental conditions. In this paper, the RF characteristics of ZRC are determined in the frequency band of 0.5 GHz to 5 GHz. A T-resonator is designed and fabricated for the transmission coefficient measurements to obtain complex permittivity (dielectric constant and loss tangent) values of the material. The dielectric constant is shown to be steady at 32.2, while the loss tangent is found to be at 0.001 in the band of interest.

I. INTRODUCTION

Zirconia Ribbon Ceramic (ZRC) has gained attention recently in radio frequency (RF) and microwave applications as a low-loss substrate material due to its properties of moisture resistance, high temperature tolerance, and low thermal mass. It is a Ytria-Stabilized Zirconia (YSZ)-based ceramic with great potential in the design of various RF devices, including gas sensors and high-temperature devices [1]. However, to effectively use ZRC as a substrate for RF devices, it is necessary to determine its dielectric characteristics. Several studies have been presented in the literature regarding the dielectric properties of ZRC, and the generally accepted dielectric constant of this substrate is shown to be around 23 with a loss tangent of 0.001 [2], [3], and has been used in the design of various devices, including patch antennas [1]. However, a clear shift was seen between experimentally measured and simulated return loss in [1], where other than fabrication imperfections, the main reason could be a higher dielectric constant of ZRC. To ensure accurate modeling of the RF devices, dielectric properties of ZRC are characterized in this study.

Resonator-based methods are mostly used for determining the RF characteristics of the substrate of the devices. These methods include T-resonators, parallel plate resonators, ring resonators, and cavity resonators. Among these methods, the T-resonator technique is applied in our work to determine the dielectric constant and loss tangent of ZRC due to its ease of implementation and testing while maintaining accuracy up to 20 GHz frequency [4]. In our paper, the T-resonator structure is designed for a primary resonant frequency of 1 GHz based on the dielectric constant value of 23 for ZRC. Then, it is observed if the measured resonant frequencies deviate from the designed ones as that will indicate there is a difference between the actual dielectric constant and the value used in the design. The actual dielectric constant can be calculated based on the measured resonant frequencies and the dimensions of

the structure. After fabricating the device with the calculated dielectric constant, full-wave simulations are conducted to match experimental and simulated values of the transmission coefficient in order to ensure the calculated dielectric constant value of ZRC in the frequency band from 0.5 GHz to 5 GHz.

II. T-RESONATOR DESIGN

T-resonator consists of an open-end transmission stub and feed lines which together compose a T-pattern. It presents well-defined resonances at odd integer multiples of its quarter wavelength frequency. The resonant frequency, f_r around each resonance point can be used to extract effective dielectric constant, ϵ_{eff} as follows [4]:

$$\epsilon_{eff} = \left(\frac{nc}{4f_r L_{st}} \right)^2 \quad (1)$$

Where n is the resonance index ($n = 1, 3, 5, \dots$), c is the speed of light in vacuum, and L_{st} is the physical length of the stub. This ϵ_{eff} can then be compared with $\epsilon_{r,eff}$, which is calculated based on dimensions of the T-resonator structure and dielectric constant value used in the simulation, ϵ_r , as follows [1]:

$$\epsilon_{r,eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12h}{W_T}}} \quad (2)$$

Where h is the thickness of the substrate, and W_T is the width of the feed line of the T-resonator. After comparing ϵ_{eff} and $\epsilon_{r,eff}$, an agreement on $\epsilon_{r,eff}$ determines the relative permittivity, ϵ_r , of the ZRC substrate.

The T-resonator is modeled using Ansys HFSS on substrate of dimension 28 mm by 44 mm with full ground plane on the bottom side. At first, dielectric constant of 23 and loss tangent of 0.001 were used in the modeling of the device. Considering the substrate width, $W_S = 28$ mm, the overall T-resonator is designed to be centered on the substrate. The feeding line width, W_T would be very thin ($\sim 54 \mu\text{m}$) for a 50Ω impedance due to high relative permittivity of the substrate. This narrow 50Ω line would be impractical for fabrication and soldering of SMA connectors. Thus, a line width of 3 mm is assigned corresponding to a low impedance value around 3.5Ω . It is to be noted that this low impedance configuration of feed line will still determine electrical properties, because the main method is to match measured and simulated transmission coefficient. The stub of the resonator is then calculated as 14.5 mm to resonate around 1 GHz and fit within the dimensions of the substrate. The design is presented below in Fig. 1.

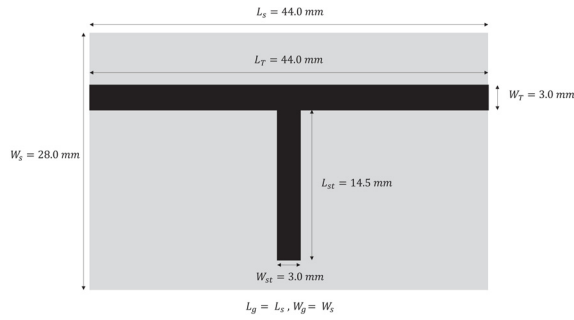


Fig. 1. T-resonator configuration

III. RESULTS AND DISCUSSION

The T-resonator is fabricated on the ZRC substrate by clean-room sputtering method, with a combination of Cobalt (Co) and Aluminum (Al) resonant layer. Here, Al served as the top and main resonating layer. The overall metal-layer thickness of the ground and design layer are $0.23 \mu\text{m}$ and $0.4 \mu\text{m}$, respectively. Transmission coefficient (S_{21}) measurement of the T-resonator is conducted using a Keysight FieldFox Microwave Analyzer N9952A. The results here are compared with the simulation in HFSS to estimate dielectric constant, ϵ_r and loss tangent, $\tan(\delta)$ of the ZRC substrate. Simulated and measured transmission coefficient, S_{21} are given in Fig. 2. Using (1), the primary resonance of the T-resonator should be at around 1.06 GHz. However, from the figure, the resonance is measured at around 0.96 GHz. This clear shift of resonance to lower frequencies indicates that ZRC indeed has a higher dielectric constant. Then, in the simulation, the dielectric constant is gradually updated to shift resonance frequency of simulation closer to that of measured in the network analyzer. From Fig. 3, it is seen that at ϵ_r of 32.2, the first resonant frequency of simulation is at 0.96 GHz which matches with measured value in the experiment. In (1), taking $f_r = 0.96$ GHz for the first resonance results in ϵ_{eff} to be 29.03. This ϵ_{eff} may be shown by using (2). Replacing ϵ_r in (2) with our predicted dielectric constant of 32.2, along with $h = 0.15$ mm and $W_T = 3$ mm, $\epsilon_{r,eff}$ is determined to be 28.93, leading to a difference of 0.35% between ϵ_{eff} and $\epsilon_{r,eff}$. For this very small percent difference between them, dielectric constant, ϵ_r of ZRC is determined to be 32.2. It is to be mentioned that although a higher dielectric constant is obtained for ZRC, the loss tangent is found to be 0.001 in this study aligning with previous studies [2], [3].

IV. CONCLUSION

In this paper, the dielectric properties of ZRC material have been revisited so that RF devices using this substrate can be modeled accurately. To do so, a T-resonator is modeled using previously determined characteristics of the substrate. After that, the resonator is fabricated to conduct experimental measurements. Then, after observing a significant difference between the simulation and experiment, the simulation is updated to match the experimental measurement and thus

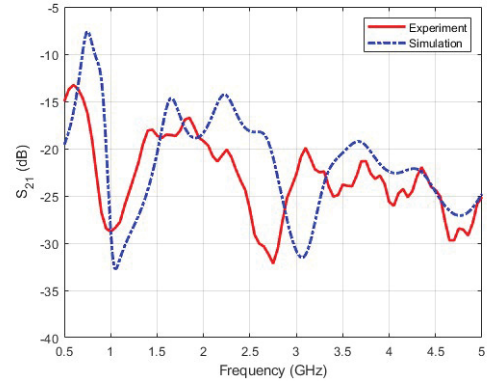


Fig. 2. Experimental and simulated S_{21} results for $\epsilon_r = 23$

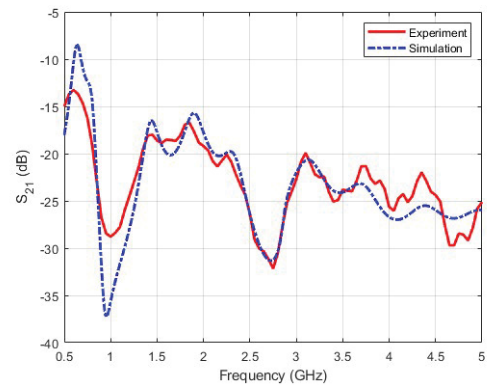


Fig. 3. Experimental and simulated S_{21} results for $\epsilon_r = 32.2$

determine the characteristics shown by the ZRC substrate. The dielectric constant and the loss tangent of ZRC are shown to be 32.2 and 0.001, respectively, in the band of 0.5 GHz to 5 GHz.

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