Investigation of permittivity of SiC substrate integrated waveguides at mm wavelengths

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Abstract

Substrate integrated waveguides (SIWs) give us desirable properties when used for the next generation of telecommunications. Furthermore, SiC proves to be promising material for these applications due to its properties such as a high dielectric constant. By using HFSS simulations, we fit experimental data to simulated data, allowing us to extract a dielectric constant of 10.4 at frequencies of 123, 134, and 153GHz. Additionally, we conducted a sensitivitiy analysis and found that as size of resonators increased, the sensitivity of resonsators decreased with respect to TSV diameter and relative permittivity.

Introduction

Substrate integrated waveguides (SIWs) are seen as the way forward in terms of the next generation of telecommunication, 6G. This is because they can integrate multiple circuit elements onto the same chip, resulting in low losses, minimum crosstalk, and high-power capacities when compared to more conventional microwave monolithic integrated circuits (MMICs) [1]. Additionally, SiC promises to be a good material for this application due to its high dielectric constant, breakdown strength, low coefficient of thermal expansion, and loss tangent [1].

Knowing this, this material still has not had extensive study in the mm wavelength range, and there is an overall lack of reported data for important properties, namely the dielectric constant in this range. With this study, we aim to begin to fill in this gap of knowledge so that we have a better understanding of SiC electrical properties before applying the material to this use case.

Methods

Simulations from the software HFSS of one-port resonators (fig. 1) will be used to generate reflection data. This data will then be fitted to previously obtained experimental results [1]. Based on the fitting parameters (relative permittivity and TSV diameter) of the simulation, we can extract the real portion of the permittivity by fitting the resonant frequency of the resonators. This will be done for 3 different sizes of resonator, 400, 500, and 600 μm resonators.

Results

When measured using SEM, we find that the diameter of the TSVs is approximately 45 μm. Based on this, we obtained the best fit, seen in figure 2, using a relative permittivity value of 10.4.

In addition to this, we also conducted a sensitivity analysis to determine the extent to which resonant peak location changes with respect to TSV size and relative permittivity. The results from this are show in figures 3 and 4.

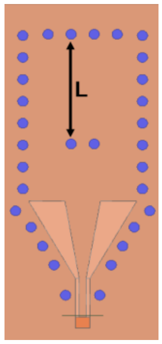

Figure 1: Diagram of a 1-port resonator consisting of a port (dark orange), SiC substrate (orange), transition region, and through substrate vias (TSVs)(blue). Length L corresponds to the size of the resonator.

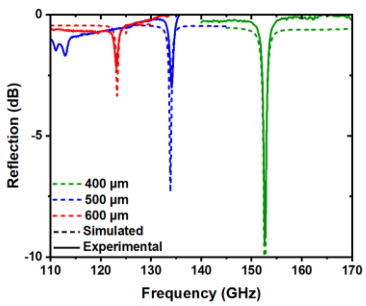

Figure 2: Experimental [1] and simulated data of 1-port resonators. Fitting parameters used are TSV diameter of 50μm and ε_r=10.4.

Based on these results, we conclude that in both cases, the 400-micron resonators are the most sensitive, and the 600-micron resonators the least sensitive. Furthermore, as expected, the resonant peak location will increase with TSV size, and decrease with permittivity.

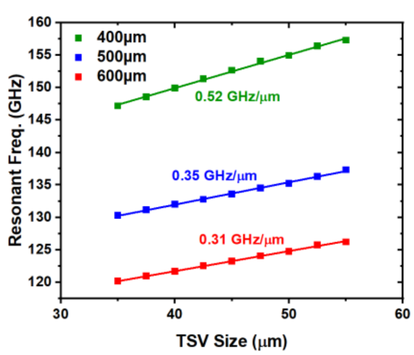

Figure 3: Sensitivity analysis of resonant frequency with respect to TSV diameter.

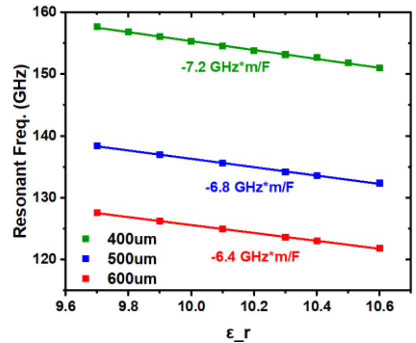

Figure 4: Sensitivity analysis of resonant frequency with respect to relative permittivity.

Conclusions & Future Work

During the project, we were able to extract the real part of the permittivity at frequencies of 123, 134, and 153 GHz, the result being 10.4. Additionally, we conducted a sensitivity analysis and found that smaller resonators were more sensitive to changes in TSV size and relative permittivity. Likewise, the larger resonators were less sensitive to these changes.

Moving forwards, we aim to also characterize the imaginary part of the permittivity for the experimental data by fitting the unloaded Q-factors of the simulations to the experimental data. Ultimately, we aim to apply these techniques to Si SIWs once we can obtain experimental data on such SIWs.

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References

[1] M. J. Asadi *et al.*, "SiC Substrate-Integrated Waveguides for High-Power Monolithic Integrated Circuits Above 110 GHz," *2021 IEEE MTT-S International Microwave Symposium (IMS)*, 2021, pp. 669-672, doi: 10.1109/IMS19712.2021.9574845.