Modeling the Relationship of Frequency, Temperature, and Resistivity of Vanadium Dioxide

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Abstract

This report investigates the relationship of resistivity and frequency of a thin film of vanadium dioxide, VO_2, on a sapphire substrate as temperature changes and implements data to simulate an antenna utilizing thin films VO_2. Six 3D models were created from the VO_2 measured. Four models, two for resistivity and two for resistance, as temperature increases from 30°C to 100°C and as temperature decreases from 100°C to 30°C were made. Another two models were created for the imaginary for the same temperature ranges. From the data present on the models, an antenna using VO_2 was simulated using IE3D and compared to prior research done on a bowtie antenna with VO_2.

1. Introduction

Vanadium dioxide, VO_2, is a phase changing material that is capable of a metal-to-insulator transition around 68°C which creates a strong change in resistance. This property has caught the attention of scientists and researchers interested in creating applications for it. Researchers Hillman C. et al experimented with thin-films of VO_2 on a sapphire substrate and demonstrated that switch capabilities are possible (1). Prior research done by prof. Dimitris Anagnostou and his graduate student Tarron Teeslink has demonstrated the potential that VO_2 has for phase-changing antennas (3). Electromagnetic simulations used for VO2 so far has only accounted for resistance, which we hypothesize may have resulted in deviations between the obtained simulated and measured antenna performance (i.e. antenna gain). The objective of this study is to model the relation of temperature, frequency, and resistivity of VO_2 to allow for better simulations of the material for use in frequency dependent applications.

2. Broader Impact

The phase changing properties of thin-film VO_2 have the potential to allow for a single antenna to have multiple resonant frequencies (3). Integrated thin films of VO_2 on an antenna with a sapphire substrate can act as an open at temperatures higher than 68°C and temperatures lower than 68°C. This can allow for an antenna to cut off a portion of its length at higher temperatures which can create a separate operating frequency. By creating a model of the frequency, resistivity, and temperature VO_2, simulations will be simpler to make which will allow for antennas using VO_2 to be designed and tested at a faster pace.

3. Procedure

3.1 Equipment

Agilent 8753ES S-Parameter Network Analyzer

Model 350B Temperature Controller

Agilent 85052D 3.5mm Economy Calibration Kit

3.2 VO_2 Antenna Specifications

The VO_2 used in this experiment was provided by Professor Nelson Sepulveda and PhD student David Torres, and it was used in a bowtie antenna in the research done by Tarron Teeslink. The bowtie was designed with a branch length of 10.26mm and an ending height of 1.3mm, and thin 20µm vanadium dioxide strips with thickness of 200nm on each branch to connect and disconnect the extensions for a total length of 11.77mm and height of 1.6mm (3).

3.3 Measurements

The impedance of the thin strip of VO2 integrated on a bowtie antenna was measured using an Agilent 8753ES S-Parameter Network Analyzer for every 2°C from 30°C to 100°C and from 100°C to 30°C. 201 number of points were set on the vector network analyzer with a frequency range of 30 KHz to 6 GHz. Fig. 1 below shows the setup used to take measurements of the VO_2.

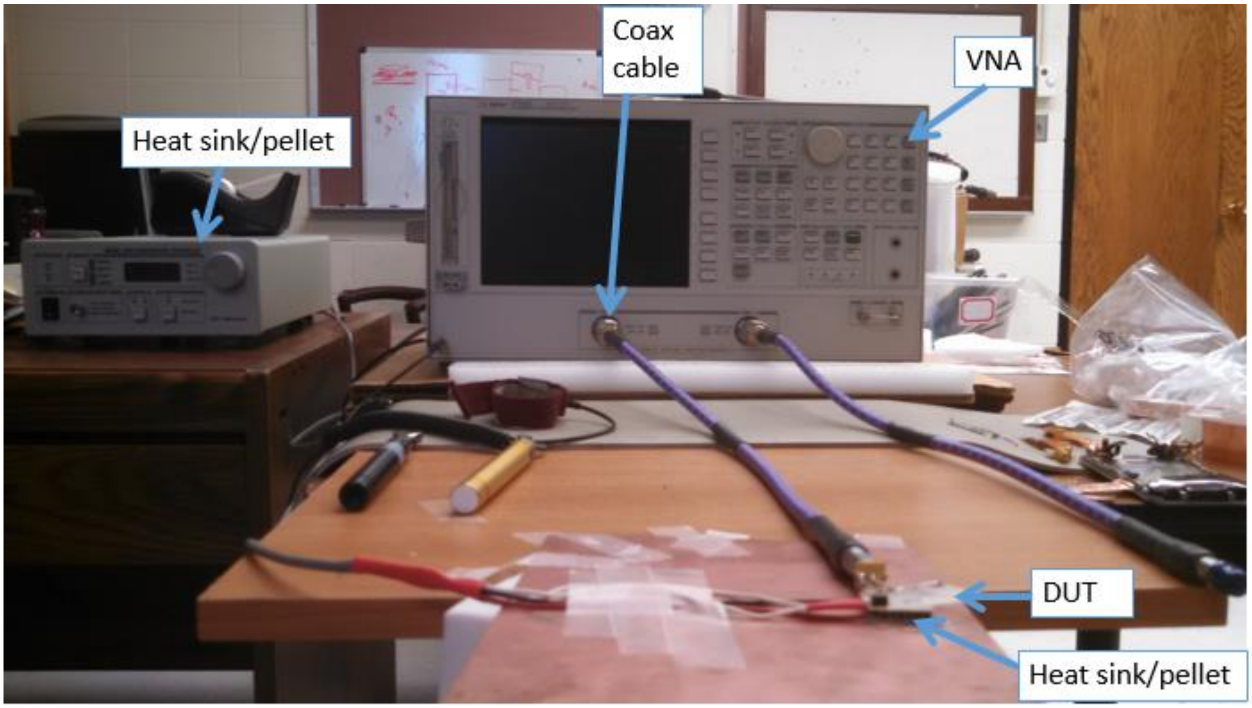

Figure 1: Equipment setup.

4. Results and Discussion

4.1 3D Models

The data obtained from the vector network analyzer was exported to Excel and organized for use in MATLAB. Four 3D plots were created of the resistance and imaginary of VO_2 in relation to frequency and temperature. These models can be seen in fig. 2.

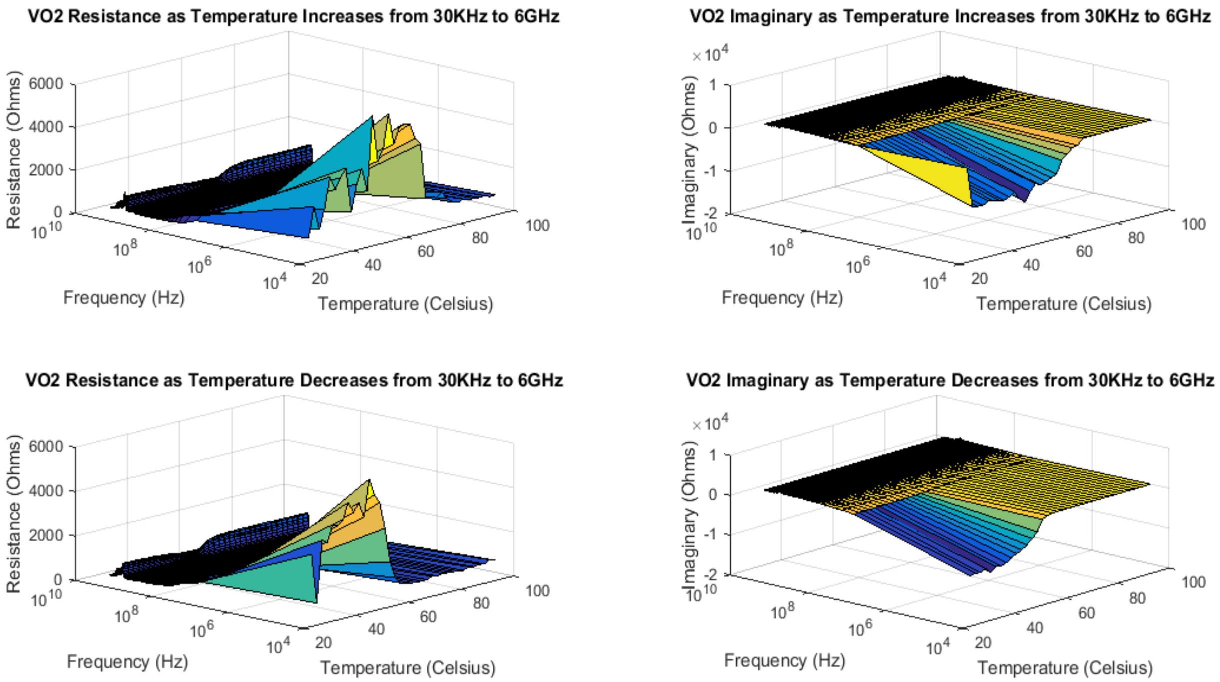

Figure 2. 3D models created in MATLAB for resistance and imaginary in relation to temperature and frequency as the temperature increased and decreased. Results match the expected outcome for an integrated thin strip of VO_2 between thicker metal.

The resistance was converted to resistivity using the equation for resistance of thin film resistors, *R=pL/A*, where L is the length of the patch, p is the resistivity, and A is the cross sectional area seen by the current (3).

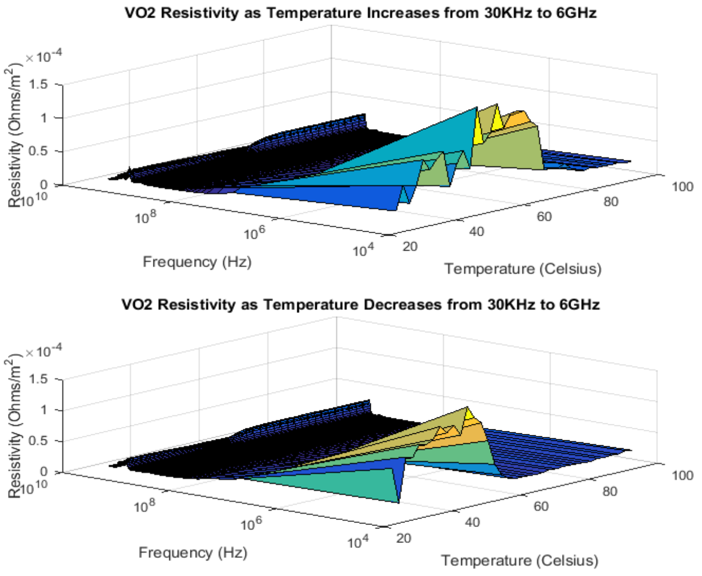

Figure 3 3D models for resistivity in relation to temperature and frequency.

As seen in the 3D models of resistance from fig. 2 and resistivity in fig. 3 on the next page, the resistance of VO_2 drops as temperature increases. This matches the insulating property of VO_2 (1). The resistance also featured a gradual decline as frequency increased. This is explained by the structure of the VO_2 and the metal plates of the antenna acting as a planar integrated capacitor. As the frequency increases, the capacitor acts more like an inductor which would decrease the resistance by allowing electrons to move more freely. This decrease in capacitance as frequency increases can be seen in the imaginary 3D models in fig 2. The imaginary in fig. 2 also shows the VO_2 becoming less capacitive as temperature increases. This agrees with the research done by Yang Z., et al which found that the capacitance of VO_2 decreases with an increase in temperature (2).

4.2 Simulation

A return loss simulation was made for a bowtie antenna with VO_2 using the data collected in this experiment and the prior antenna model provided by Tarron Teeslink (3). This was plotted in IE3D along with the measured and simulated data of a bowtie antenna using thin films of VO_2.

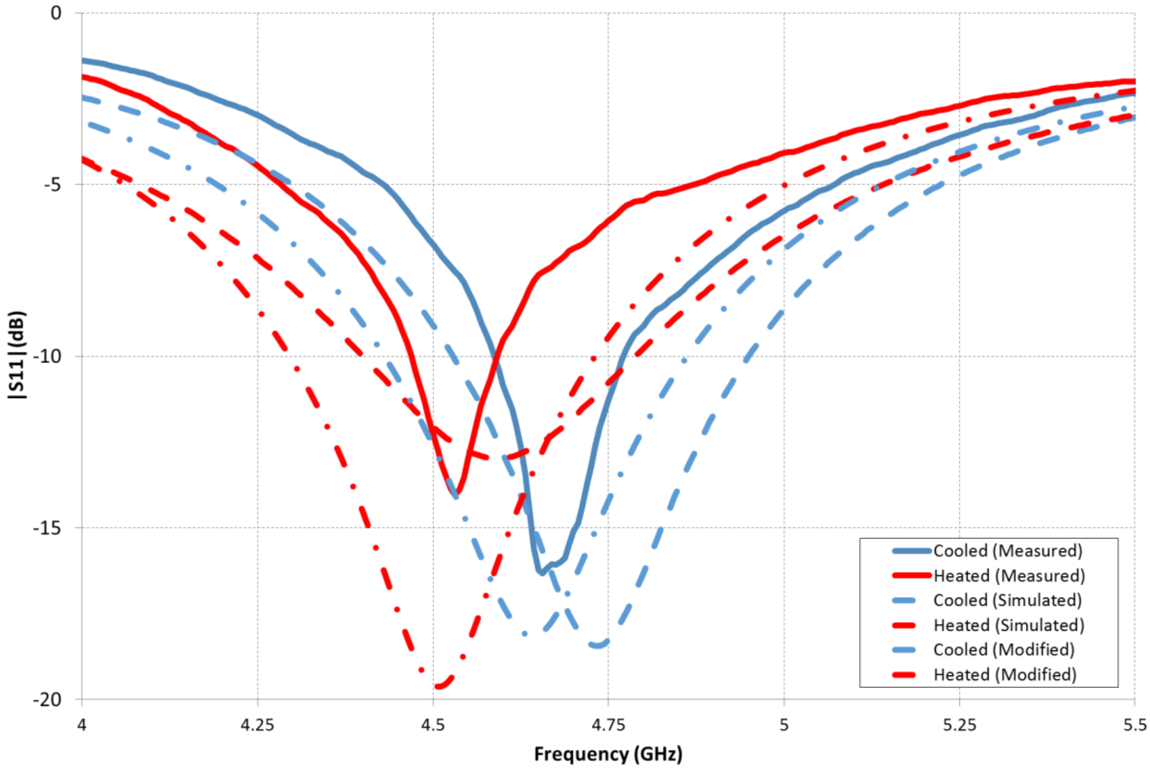

Figure 4. VO_2 bowtie antenna return loss measurement and simulation results from [3], superimposed with the simulated data obtained from the 3D models using the complex impedance values

The modified simulation using data from the real and imaginary 3D models matched the frequencies for the antenna's actual gain closer than the simulation for the gain that only accounted for resistance. However, the modified heated simulation's gain was significantly off compared to the original heated simulation. The modified, original, and actual gains can be seen plotted together in Figure 5.

5. Conclusions and Future Work

The 3D models for the relationship of frequency, temperature, and resistivity produced results that matched the properties of the integrated VO_2 strips on the antenna surface. From this data, more accurate simulations for the frequency response of antennas using VO_2 were created.

Additional measurements will need to be made to account for the VO_2 complex impedance at frequencies under 30 KHz and above 6 GHz. This data explained the reactive behavior (energy storage and slightly reduced gain) of the developed bowtie antenna. Also, this research can be extremely useful in modeling future antennas that employ VO_2 in their design. More data will need to be tested (e.g. using a VO_2–only wafer to extract models for larger VO_2 surfaces).

References

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