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HIGH FREQUENCY ELECTROMAGNETIC CHARACTERIZATION OF NEG PROPERTIES FOR THE CLIC DAMPING RINGS

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Abstract

Coating materials will be used in the CLIC damping rings (DR) to suppress two-stream effects. In particular, NEG coating is necessary to suppress fast beam ion instabilities in the electron damping ring (EDR). The electromagnetic (EM) characterization of the material properties up to high frequencies is required for the impedance modeling of the CLIC DR components. The EM properties for frequencies of few GHz are determined with the waveguide method, based on a combination of experimental measurements of the complex transmission coefficient S_{21} and CST 3D EM simulations. The results obtained from a NEG-coated copper (Cu) waveguide are presented in this paper.

METHOD

The waveguide method is used to characterize the properties of the coating materials in a range of frequencies of few GHz. The reliability of this method is first tested using standard X-band waveguides made from Cu and StSt before measuring the NEG properties in this regime. The electrical conductivity of the material is obtained from the measured transmission coefficient S_{21} using a network analyzer and 3D EM simulations with CST Microwave Studio®(CST MWS) [1].

Stainless Steel 316LN Waveguide

An X-band StSt 316LN waveguide, Figure 1, of 50 cm length was the first device under study during the experiment.

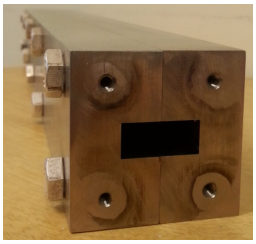

Figure 1: X-band StSt waveguide with vertical cut.

Using a network analyzer, the transmission coefficient is measured over a frequency range from 10 to 11 GHz. In Figure 2, the result of this measurement is illustrated with the blue line. The S_{21} coefficient is related to the attenuation due to the finite conductivity of the material. In the same plot, the comparison is given with the expected S_{21} parameter from CST simulations for an X-band StSt waveguide with σ = 1.35 x 10^6 S/m.

The skin depth is 4 μm at 10 GHz and roughness measurements were performed in the StSt waveguide giving an estimation of Ra = 0.6 μm. S_{21} results from measurements and simulation are in very good agreement and surface roughness is not expected to induce significantly higher losses.

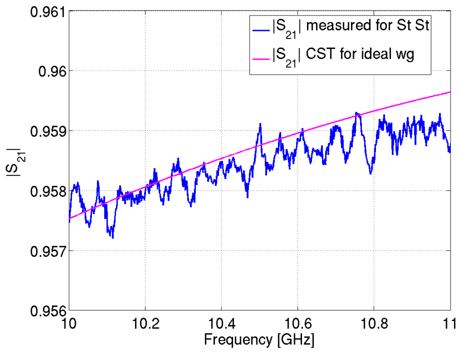

Figure 2: S_{21} for a StSt waveguide: experiment and CST simulation comparison.

For each frequency the output of the CST simulations is the S_{21} parameter as a function of conductivity. The relative permittivity ε_r and permeability μ_r are assumed to be equal to one while the conductivity σ is the unknown parameter which is scanned in simulations. By intersecting at each frequency the measured S_{21} with the CST output obtained numerically, the electrical conductivity is determined as a function of frequency.

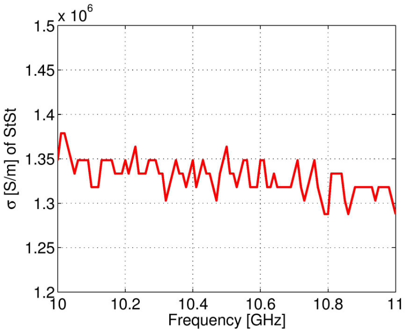

Figure 3: Electrical conductivity of StSt.

The electrical conductivity of StSt is shown in Figure 3 and the expected DC conductivity for StSt 316LN is σ = 1.35 x 10^6 S/m. The very good agreement between measurements and theory validates the waveguide method.

Copper Waveguide

An X-band annealed Cu waveguide was the second device under test for the validity of this method. Measurements of S_{21} parameter were performed with the network analyzer and the results are shown in Figure 4 compared to the expected

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S_{21} from CST for an ideal Cu waveguide with σ = 5.8 x 10^7 S/m.

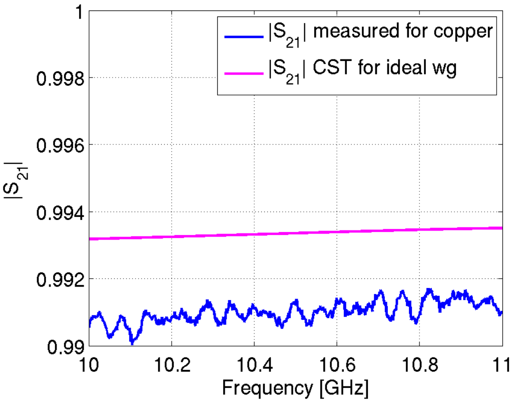

Figure 4: S_{21} for a Cu waveguide: experiment and CST simulation comparison.

In the case of the Cu waveguide, the value of the measured S_{21} is lower than the simulation for the ideal (no roughness effects) waveguide. The theoretical losses for Cu are 0.108 dB/m at 10 GHz [2] while the measured losses are 0.16 dB/m at the same frequency (real losses are expected to be slightly higher).

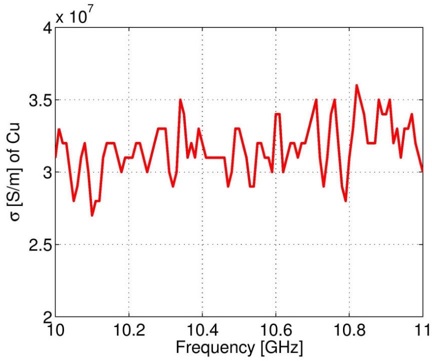

Figure 5: Effective conductivity of Cu.

At frequencies where the skin depth approaches the surface roughness, higher losses occur. For this reason the extracted conductivity of Cu in Figure 5, is lower than the expected DC value of 5.8 x 10^7 S/m, representing a higher-loss waveguide due to roughness effects. CST agrees with this Cu conductivity if roughness is assumed to be Rq = 0.4 μm. Rq measurements were realized at the extremety of the waveguide and the average value was estimated to be 0.3 μm.

NEG COATING

The same Cu X-band waveguide was coated with a Ti-Zr-V thin film using magnetron sputtering [3], targeting at 9 μm thickness. This is a much higher value compared to what is usually found in accelerators (1 or 2 μm) trying to maximize the EM interaction inside the NEG. Measurements of the S_{21} coefficient were performed on the NEG-coated waveguide and compared to the results from the Cu waveguide. The lower measured S_{21} coefficient indicates that the skin depth is small enough compared to the NEG thickness allowing the EM interaction with NEG [4], therefore more losses occur.

From the intersection of measured data with CST results, the conductivity of NEG is extracted as a function of frequency. But from the intersection, two possible solutions occur for all the freguency range, shown in Figure 6, where the S_{21} calculated from CST as a function of conductivity is intersected with the measured value at that certain frequency.

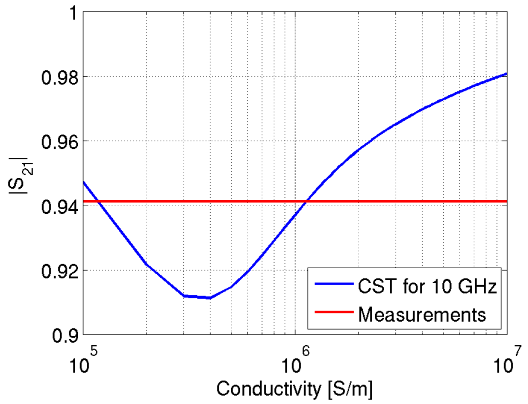

Figure 6: Example of intersection of simulated S_{21} as a function of conductivity with the measured value at 10 GHz.

The plot displayed in Figure 7 shows the NEG effective conductivity and the two different curves correspond either to the first or the second solution. The first solution gives a stable value of 1.2 x 10^5 S/m while the second solution is in the order of 10^6 S/m.

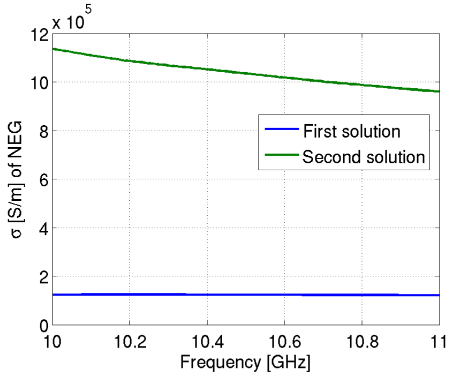

Figure 7: Effective conductivity of NEG.

In order to distinguish which of the two solutions correspond to the real one, measurements were performed in a new Cu waveguide that was NEG-coated first at 6 and then at 20 μm. The S_{21} coefficient measurements are shown together with the 9 μm coated waveguide in Figure 8.

For the 20 μm NEG-coated waveguide, there is only one solution in this conductivity range, shown in Figure 9.

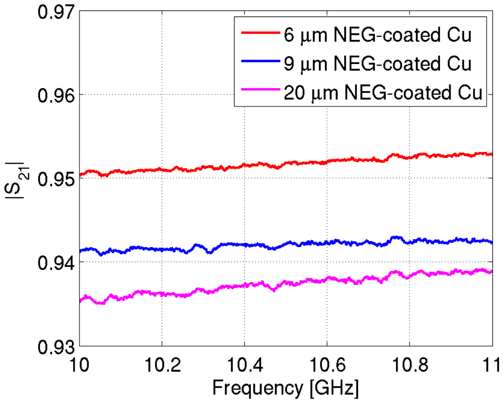

Figure 8: S_{21} measurements for the new waveguide coated first at 6 and then at 20 μm together with the old waveguide coated at 9 μm.

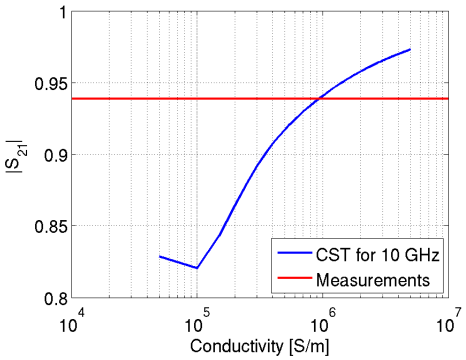

Figure 9: Example of intersection of simulated S_{21} as a function of conductivity with the measured value at 10 GHz.

The extracted NEG conductivity is plotted in Figure 10 compared to the result of the previous 9 μm NEG-coated waveguide (black curve).

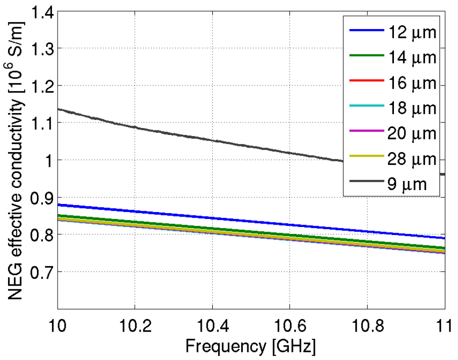

Figure 10: Effective conductivity of NEG.

The small difference between the 9 μm and the 20 μm case is probably due to the fact that for the 9 μm waveguide, still not all losses occur inside the NEG film. It is clear that assuming 12 up to 28 μm, all the curves are in good agreement indicating that losses are now only inside the NEG coating film.

Two different waveguides with different NEG coatings conclude to NEG conductivity values of the order of 10^6 S/m indicating that the second solution should be accepted. CST can only simulate a uniform NEG coating while x-ray analysis on the coating profile revealed a very non-uniform coating. Further studies are planned to investigate the effect of the profile's non-uniformity on the results obtained so far that would possibly explain the frequency dependent behavior of the NEG conductivity.

Calibration Comparison

Two different calibration methods that are commonly used were compared in order to investigate if that could introduce some errors in the measurements but the results were very close. The comparison is shown in Figure 11.

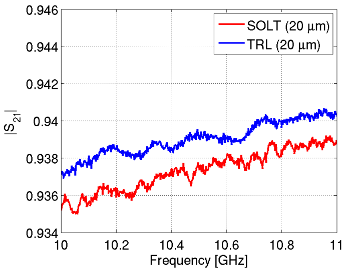

Figure 11: S_{21} results for the SOLT and TRL calibration.

CONCLUSION

The validity of the waveguide method was demonstrated for the case of StSt and Cu waveguides that were used as benchmark for this method. Applying the same method in order to characterize NEG, the estimation of conductivity predicts a value in the order of 10^6 S/m. Further studies should be performed to understand the error introduced from the non-uniform NEG coating.

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