ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPHA002

ELECTROMAGNETIC CHARACTERIZATION OF NEG PROPERTIES ABOVE 200 GHz FOR THE CLIC DAMPING RINGS

E. Koukovini-Platia*, G. Iadarola, G. Rumolo, C. Zannini, CERN, Geneva, Switzerland

Abstract

Non-Evaporable Getter (NEG) will be used in the CLIC Electron Damping Rings (EDR) to suppress fast beam ion instabilities due to its effective pumping ability. The electromagnetic (EM) characterization of the NEG properties up to high frequencies is required for the correct impedance modeling of the Damping Ring (DR) components. The properties are determined using WR-3.4 and WR-1.5 rectangular waveguides, based on a combination of experimental measurements of the complex transmission coefficient S_{21} with a Vector Network Analyzer (VNA) and CST 3D EM simulations, for the frequency ranges of 220-330 GHz and 500-750 GHz. The results obtained from NEG-coated Aluminum (Al) waveguides are presented in this paper.

METHOD

The impedance modeling of the DR chambers must include the contribution from coating materials applied for ultra-low vacuum pressure. This advocates for the correct characterization of this impedance in a high frequency range. The short DRs bunch length of 1.8 mm rms, translates into a frequency spectrum up to hundreds of GHz, therefore the characterization of NEG is necessary up to those frequencies.

The proposed method requires the use of a rectangular waveguide connected to a VNA and the 3D CST [1] simulation of the exact geometry waveguide. The waveguide is a 2-port network that can be described by means of the S-parameters as a function of frequency. The transmission coefficient S_{21}, from the scattering matrix, is related to the waveguide's attenuation, which depends on the effective conductivity.

The exact geometry waveguide can be simulated with CST and S_{21} is calculated assuming a certain conductivity of the coating material. However, assuming that conductivity is the unknown, several simulations can be done sweeping this parameter. Intersecting the measured data with the CST simulation, the conductivity that matches the measured losses is extracted at a specific frequency. By repeating the intersection over the whole frequency range of interest, the conductivity can be extracted as a function of frequency.

The method has been successfully benchmarked with known materials like copper and stainless steel and was used to characterize NEG at frequencies between 10 and 11 GHz [2].

MEASUREMENTS AT 220-330 GHz

Four rectangular waveguides, of type WR3.4, were used for measurements between 220 and 330 GHz. The waveguides were purchased from Virginia Diodes (VDI) [3] and are produced in 2-split blocks made of Al with a thin gold plating (see Figure 1).

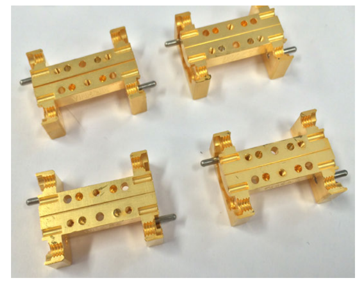

Figure 1: WR3.4 and WR1.5 waveguides from VDI made of Al with thin gold plating, with 25 mm length.

The waveguides were coated at CERN by magnetron sputtering, targeting at 3 μm NEG thickness. In Figure 2, the transmission S-parameters are plotted for the four waveguides (labeled as 1, 5-12, 5-15 and 5-16) as a function of frequency. In the same figure, the simulated S_{21} from CST is shown, assuming DC conductivity of NEG equal to 0.57×10^6 S/m and a uniform profile of 3 μm thickness.

The DC value was extracted from resistance measurements on NEG-coated glass samples with known coating thickness. From the measurements, the DC conductivity of NEG was scattered between 0.5×10^6 S/m and 0.7×10^6 S/m with an uncertainty of 15%. A factor of 1.5-2 difference with older measured values of the DC conductivity (1×10^6 S/m) is observed. This is attributed to the different coating setup used, and consequently due to the different cathode used for the NEG deposition.

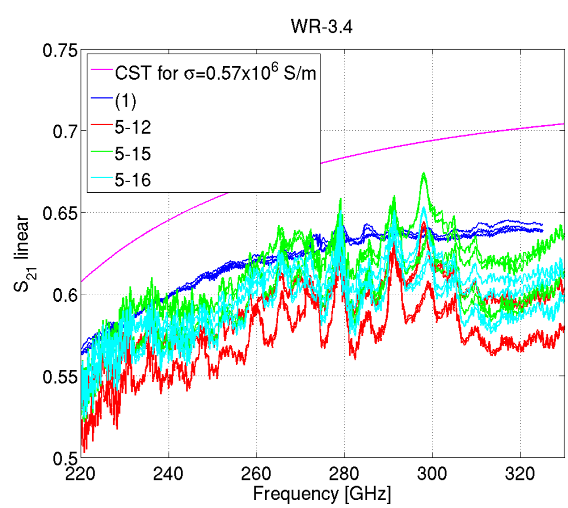

Figure 2: S_{21} comparison between CST (magenta) and measurements using the four WR3.4 waveguides.

* also affiliated at EPFL

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPHA002

Measured losses are higher by around 10% than the CST prediction for a smooth waveguide. A 10-15% sample-to-sample variance characterizes the S_{21} measurements that comes from the VNA itself. The effective conductivity versus frequency is obtained from the intersection of measured data and simulations. The results between 220 and 330 GHz are shown in Figure 3.

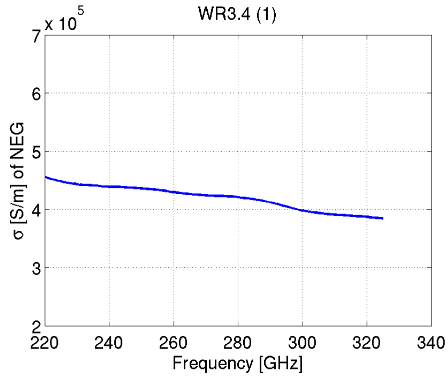

Figure 3: NEG effective conductivity between 220 and 330 GHz.

For lower frequencies, around 220 GHz, a 20% difference is observed between the DC conductivity and the extracted value. A 6-7% reduction can be explained from the CST model due to roughness. Measurements with an optical profilometer revealed an average Rq of 0.3 μm, while the skin depth varies between 1.4 μm and 1.15 μm across the frequency range. The observed difference at lower frequencies lies within the uncertainty of the experimental method and the error of the DC conductivity measurement itself. However, at higher frequencies, up to 330 GHz, this difference is further increased to around 45%.

MEASUREMENTS AT 500-750 GHz

Measurements were also conducted for frequencies between 500-750 GHz with two WR1.5 waveguides, which can be seen in Figure 4. S_{21} measurements are compared

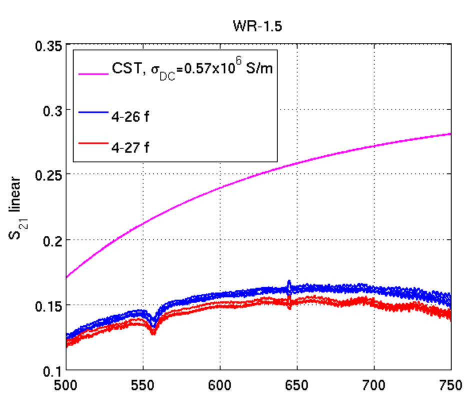

Figure 4: Comparison of S_{21} CST prediction (magenta) with measurements along the two WR1.5 waveguides (4-26 and 4-27).

to CST simulation for a smooth 3 μm NEG-coated waveguide with DC conductivity of 0.57×10^6 S/m. The effective conductivity, as extracted from the intersection, is shown in Figure 5. A 35% difference from the DC conductivity is

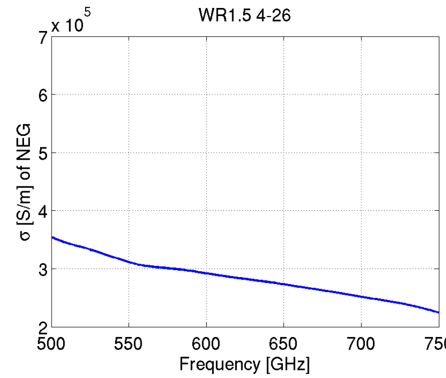

Figure 5: NEG effective conductivity at 500-750 GHz.

observed at 500 GHz. Roughness of Rq=0.3 μm (measured with the profilometer) can explain a reduction of around 22%, while the measurements accuracy is not better than 15%. However, once more, the conductivity seems to reduce as frequency increases.

EFFECT OF THE NON-UNIFORM PROFILE

The extracted conductivity at lower frequencies agrees within 20% with the DC value, while a certain reduction is expected due to roughness. However, a significant reduction of conductivity has been observed as frequency increases, around 45% at 330 GHz and 60% at 750 GHz. Such big reduction cannot be explained by roughness, while relaxation effects are not expected below 10^{14} Hz for metals.

A systematic feature that was neglected in the CST simulations is the non-uniformity of the coating profile. So far, it was assumed to be constant, however Scanning Electron Microscope (SEM) analysis revealed very non-uniform profiles in all waveguides. SEM analysis on a WR3.4 waveguide, showed a variation between 5 and 10 μm along the wide part of the groove (with 10 μm in the center and 5 μm in the corners) and between 1 and 3 μm on the side walls, which is the least preferential direction during the coating process. The targeted thickness was 3 μm, but in reality we can see that the profile varies significantly.

In order to investigate the effect of the non-uniform profile, another simulation with CST was set up. The idea is to divide the rectangular structure in CST into smaller blocks and apply coating of different thickness on the various blocks. In the wider part of the groove, 5 and 10 μm are considered. For the side walls, 1.5, 1.7 and 2 μm are assumed. The structure can be viewed in Figure 6. The result from the intersection of the simulation with measurements is shown in Figure 7.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPHA002

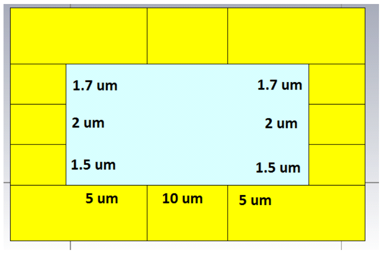

Figure 6: Front view of a WR3.4 waveguide in CST, separated in various blocks to consider NEG coating with different thickness. On the wider part of the groove, 5 and 10 μm are assumed, while on the side walls 1.5, 1.7 and 2 μm.

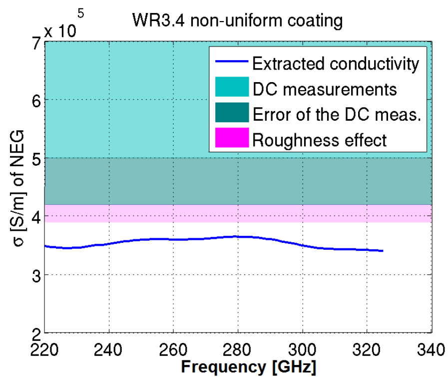

Figure 7: NEG effective conductivity between 220 and 330 GHz for a non-uniform profile implemented in CST simulations.

Conductivity is varying by around 7%, while a milder frequency dependent behavior of conductivity is observed, compared to the 45% variation found in Figure 3. We can conclude therefore, that the implementation of the non-uniform profile plays a crucial role in the seeming conductivity behavior.

This behavior is subject to the systematic error that occurs from the intersection of simulation with measured data. The error originates from the assumption that the film thickness was constant. The CST simulation with the structure of Figure 6, proved that the apparent conductivity drop versus frequency obtained so far (assuming a constant coating thickness in CST) is subject to change, once the profile is set to non-uniform.

EFFECT ON THE TRANSVERSE IMPEDANCE BUDGET

Previous estimation of the transverse impedance budget of the DR, assumed that the DC conductivity of NEG is 1×10^6 S/m. The budget under these considerations, was found to be 16 and 4 MΩ/m in the horizontal and vertical plane for zero chromaticity [4].

The budget is now re-evaluated assuming a worst case scenario for the NEG effective conductivity, that is 0.3×10^6 S/m, in order to study the possible effect. The relative tune shift in the y plane with respect to the zero-current tune and normalized to the synchrotron tune Q_s is plotted, for zero chromaticity, as a function of the transverse shunt impedance in Figure 8. A 1 MΩ/m reduction is observed in the budget

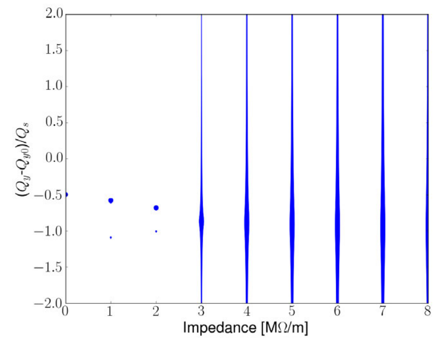

Figure 8: Mode spectrum of the vertical coherent motion for zero chromaticity, as a function of the transverse shunt impedance. A Transverse Mode Coupling Instability (TMCI) is observed at 3 MΩ/m.

estimate in both transverse planes. It is important therefore at such high frequencies, to consider a lower conductivity than the DC for beam dynamics simulations, taking into account the effect of roughness and the non-uniformity of the profile.

CONCLUSION

The experimental method was used to characterize NEG effective conductivity over few hundreds of GHz for the first time. The extracted conductivity can be lower than the DC one (a factor of 2) due to roughness effects and non-uniformity of the coating profile, according to the results obtained with this method. Therefore it is important to consider a lower conductivity than the DC in beam dynamics simulations, for frequency spectrum over few hundreds of GHz.

ACKNOWLEDGEMENT

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD-2, grant agreement no.312453.

The authors would like to thank A. Arsenovic and J. Hesler from VDI for the waveguides and the use of the VNA. We also thank W. Vollenberg for the NEG coating, A. Fontenla and F. Leaux for the SEM analysis, J.P. Rigaud for the roughness measurements, M. Taborelli and S. Calatroni and I. Syratchev for the useful discussions.

REFERENCES

[1] CST Microwave Studio- Getting Started (2003)

[2] E. Koukovini-Platia, G. Rumolo, C. Zannini. WEPME050, IPAC14

[3] Virginia Diodes, http://vadiodes.com/index.php/en/

[4] E. Koukovini-Platia, G. Rumolo. TUPRI057, IPAC14