Update on NEG electromagnetic properties characterization at high frequencies

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Overview

1. EM material properties measurements in X-band
   - Stainless steel waveguide
   - Copper waveguide
   - 9 μm NEG coated-Cu waveguide
   - 20 μm NEG coated-Cu waveguide
2. On the road to high frequencies measurements
   - High frequency measurements
3. Summary and future plans

Use of NEG coating and motivation

- The performance of the CLIC DR is likely to be limited by collective effects due to the unprecedented brilliance of the beams
- Coating will be used in both electron (EDR) and positron damping rings (PDR) to suppress effects like electron cloud formation or ion instabilities
- NEG coating is necessary to suppress fast beam ion instabilities in the electron damping ring (EDR)
- The impedance modeling of the chambers must include the contribution from the coating materials
- A correct characterization of the EM material properties of NEG in a high frequency range is therefore necessary and still widely unexplored

Material EM properties characterization

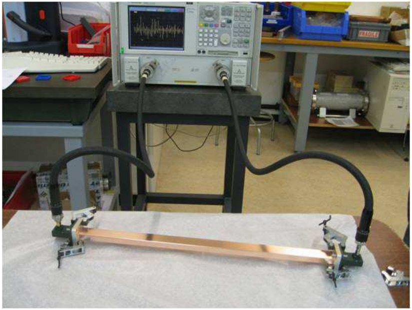
Waveguide method

The EM properties 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

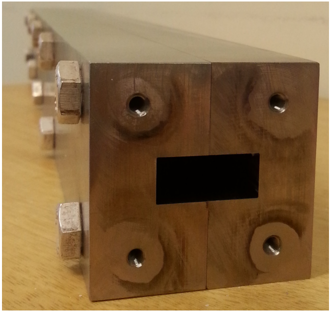
Measurements in X-band

- An X-band waveguide is connected to a vector network analyzer (VNA) to measure the S_{21} parameter across the 10 - 11 GHz single-mode band of the WR-90 waveguide
- S_{21} is related to the attenuation due to the material finite conductivity, therefore related to the unknown properties
- The S-parameters can also be obtained numerically from 3D simulations using CST

Measurements setup and waveguides for testing the method

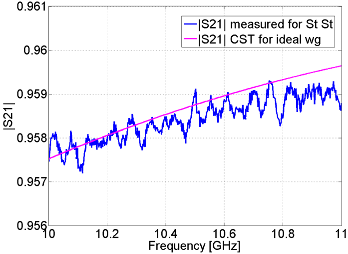


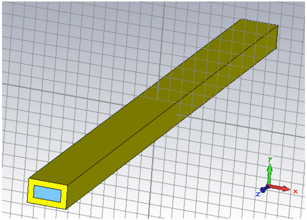
(a) Measurements setup with VNA and a Cu WR-90 waveguide.



(b) Split-block StSt WR-90 waveguide with vertical cut (interior dimensions of 22.86 x 10.16 mm)

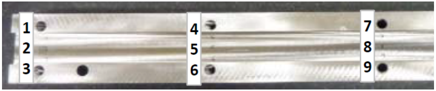
Benchmark of the method using a well known material: stainless steel 316LN waveguide (1)

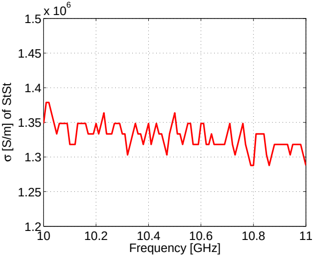




- Measured and simulated S_{21} for a StSt waveguide (conductivity used in CST simulation σ=1.35 x 10^6 S/m)
- CST assumes no surface roughness. Results in good agreement

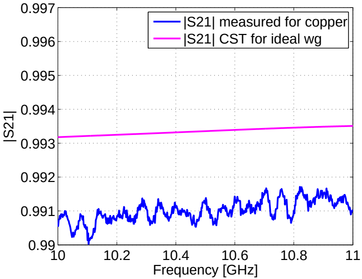
Benchmark of the method using a well known material: stainless steel 316LN waveguide (2)

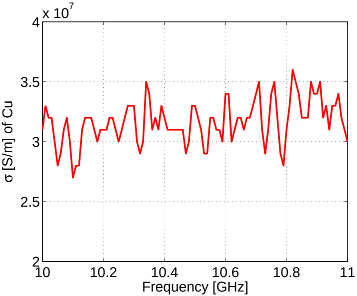




- Measurements of the Ra roughness parameter along the waveguide were performed (*by J.P.Rigaud*). Calculating the average, R_a = 0.6 μm. At 10 GHz, δ = 4.3μm. Surface roughness is not expected to induce significantly higher losses. Extracted StSt conductivity in good agreement with the expected one.

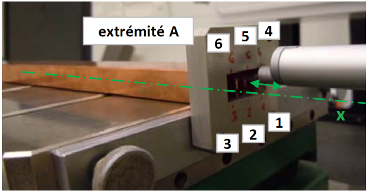
Benchmark of the method using a well known material: annealed copper waveguide

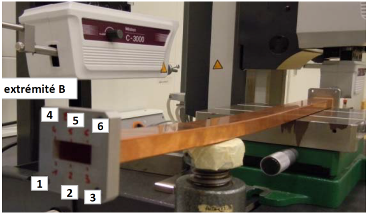




1. Real losses higher than CST prediction for σ=5.8 x 10^7 S/m ($\delta = 0.66\mu$m at 10 GHz). Theoretical losses for Cu: 0.108 dB/m at 10 GHz. Measured: 0.16 dB/m.
2. Extracted σ_{Cu} is lower than the expected DC value, representing a higher-loss waveguide due to roughness effects. CST agrees with this estimated effective conductivity of Cu if roughness is assumed to be R_q=0.4 μm.

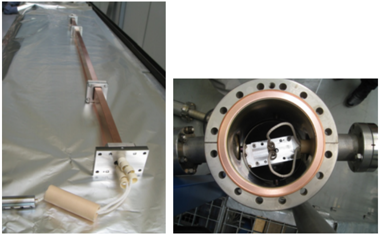
Roughness measurement on the copper waveguide

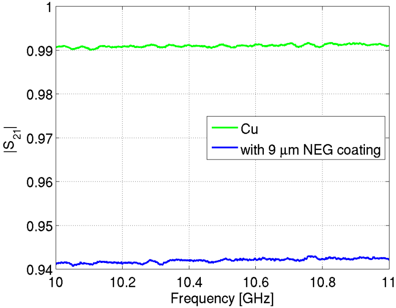




1. R_q measurements were performed at the 2 extremities of the waveguide (6 points each) (*by J.P.Rigaud*)
2. Average value of R_q=0.3 μm
3. Successful benchmark of the method

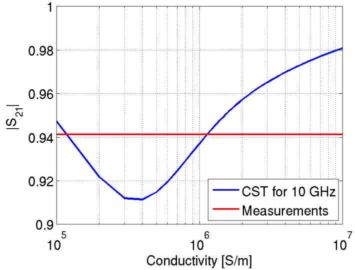
S_{21} measurements for a copper and a 9 μm NEG-coated copper waveguide





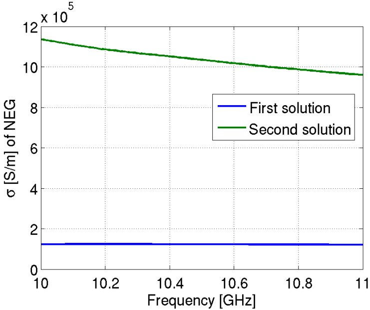
1. Coating by *P.Costa Pinto* from TE/VSC group at CERN
2. EM interaction with NEG induces more losses

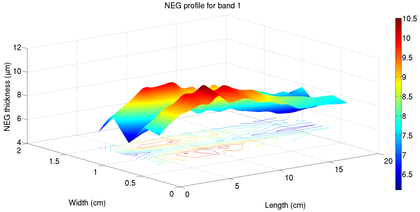
S_{21} from CST simulations and intersection with measurements- ambiguity in the solution

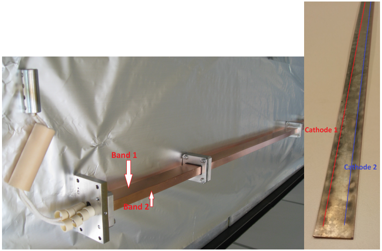


- CST computes S_{21} at a certain frequency as a function of conductivity (parameter sweep)
- At a certain frequency, intersect CST and measured value to find conductivity. Two possible solutions due to the 2-layers structure

NEG effective conductivity

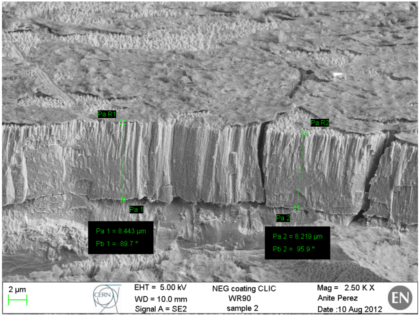


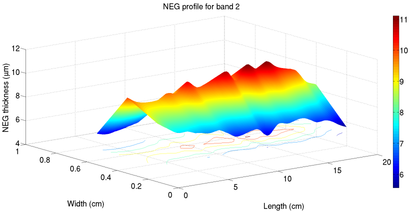


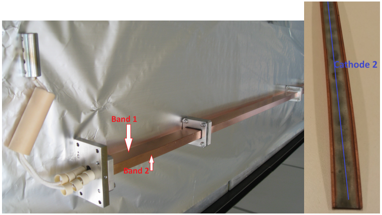


- First solution gives a stable but too low value of 1.2 x 10^5 S/m
- Non uniform coating from XRF (*by M. Malabaila*)

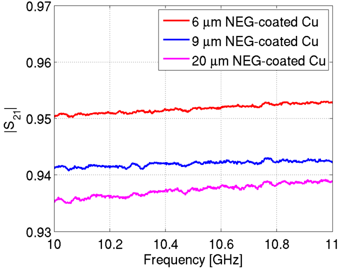
NEG effective conductivity

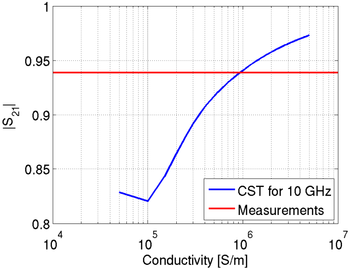






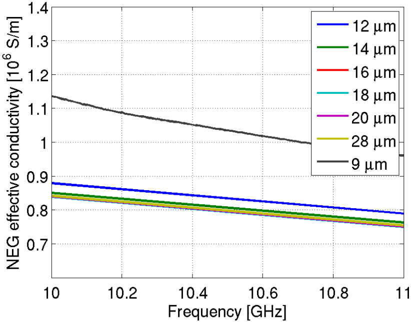
S_{21} measurements in a 20 μm NEG-coated Cu





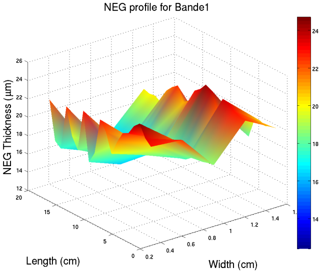
- One solution over this conductivity scan
- To accept the first solution, $\sigma_{NEG} < 10^4$ S/m

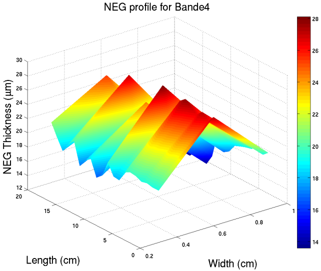
NEG effective conductivity for 9 and 20 μm coating



- Measurements with two different waveguides give close results. Indication to accept this second solution 10^6 S/m (in agreement with measurements of NEG resistivity, see *S.Calatroni talk*)
- Frequency dependent behavior. But still low frequencies to see relaxation effects. Very non uniform coating also in this case that could explain this behavior (see *S.Calatroni talk*)

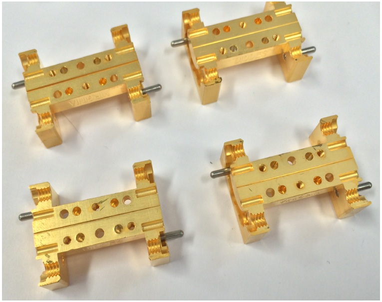
XRF profile analysis

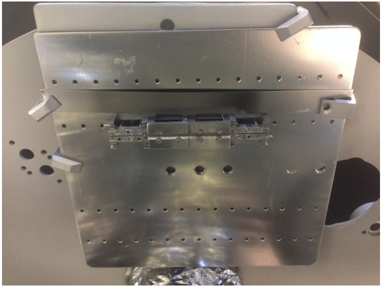




- Variation of profile between 12 and 28 μm

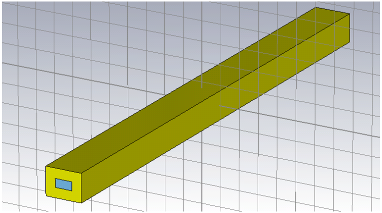
Preparation for measurements with WR3.4 220-330 GHz and WR1.5 500-750 GHz waveguides from VDI

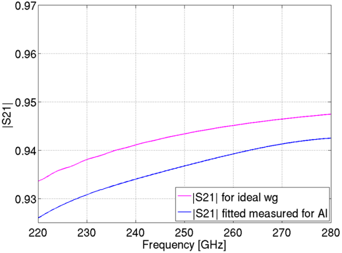




- WR3.4: 0.864 x 0.432 mm, WR1.5: 0.381 x 0.191 mm
- Challenging coating due to the very small aperture (*by W.Vollenberg*)

S_{21} measurements with Al gold plated WR3.4 waveguide





- Comparison of measured S_{21} for a WR3.4 Al gold plated waveguide and simulated with CST Al waveguide

Conclusions

- Successful benchmark of the waveguide method in X-band
- Investigate the effect of non uniform coating
- Promising beginning for the high frequency measurements
- October 2014: measurements at VDI of Al (gold plated) NEG-coated waveguides (WR 3.4 and WR 1.5) at 220-330 GHz and 500-750 GHz