Electromagnetic characterization of coatings for accelerators

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Coatings and resistive wall impedance

Coatings required (as examples) for reducing surface degassing or for secondary electron yield mitigation…but layers of coating materials significantly increase the **resistive wall impedance**

- Low conductivity, thin layer coatings (NEG, a-C)
- Rough surfaces (LESS)

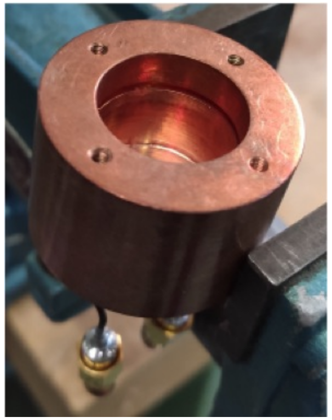
Surface impedance of the beam pipe depends on electromagnetic properties of *coatings.*

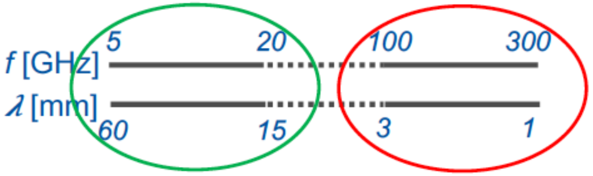
Electromagnetic characterization of “coating materials” is fundamental to evaluate accelerator performance limitations and build up a machine impedance model.

Two different methods

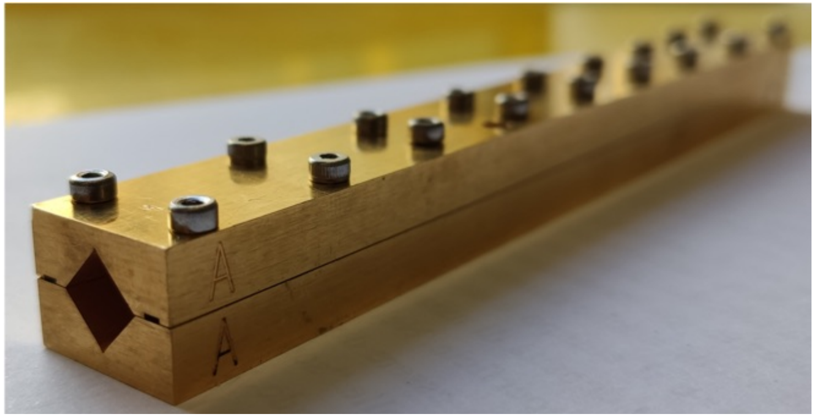
Electromagnetic characterization of Coating materials

Dielectric resonator
• high sensitivity

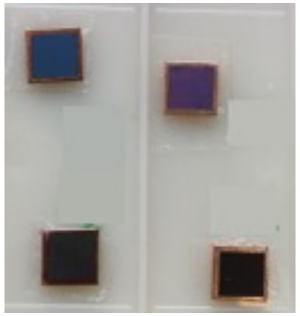




Sub-THz waveguide
• small skin-depth



LESS(Laser engineered surface structures)
• conductivity compared with copper
• small samples (10x10mm)



NEG(Non-Evaporable Getter)
• homogeneous coating

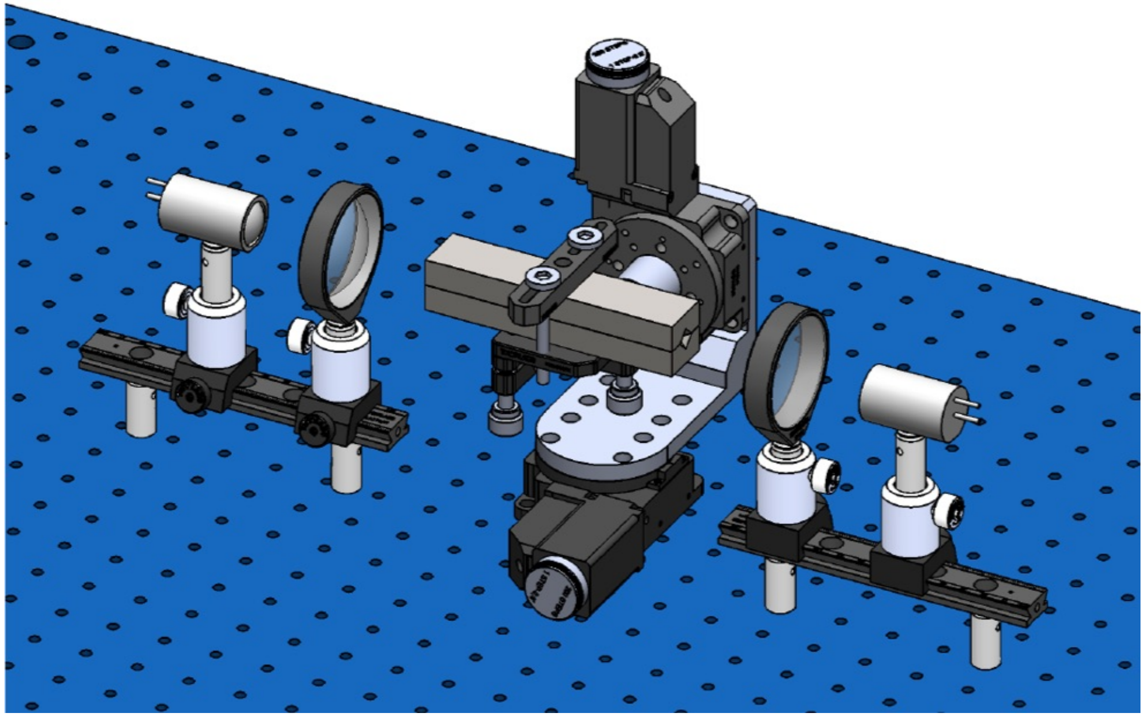
a-C (Amorphous carbon)
• coating thickness issues

Sub-THz waveguide attenuation: the proposed method

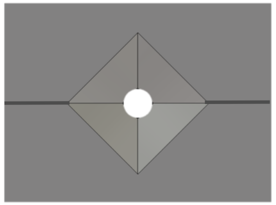
Evaluation of the **signal attenuation** inside a DUT with coating deposited.

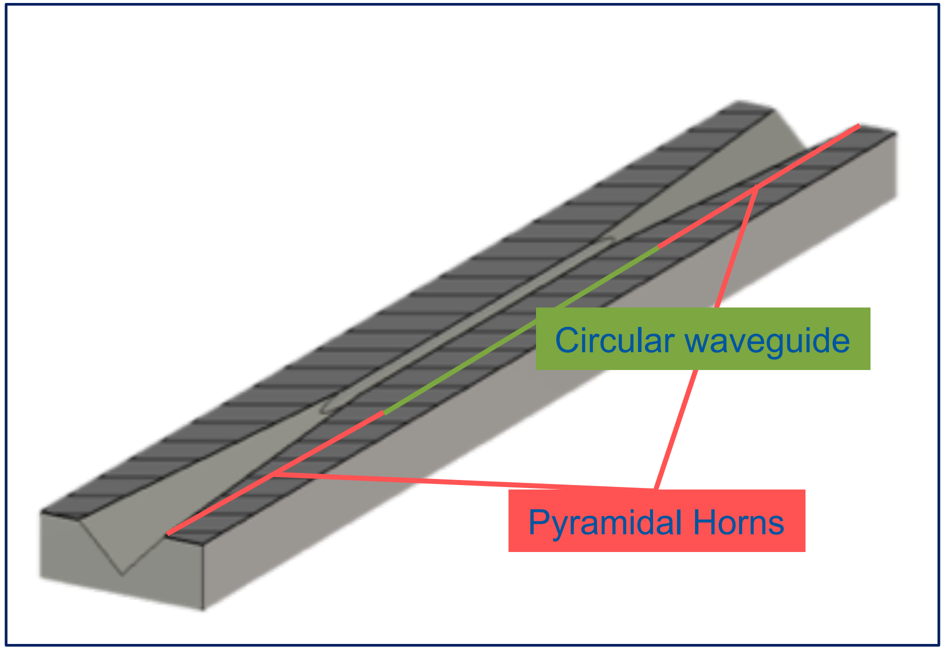
Electromagnetic characterization of coating materials.

Sub-THz transmission methodology

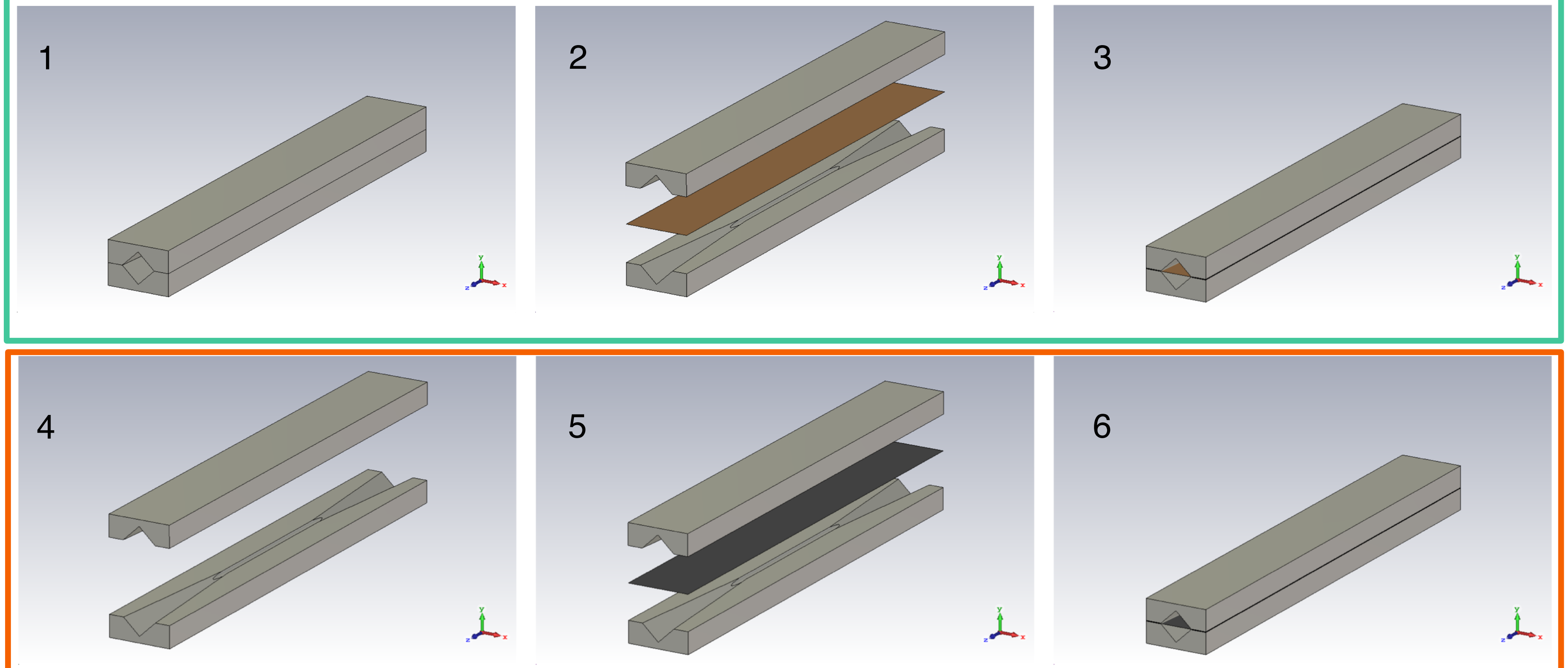


The DUT

Dimension in mm	
Material	Iron
Waveguide	Circular
Length	42
Radius	0.9
Horns	Pyramidal
Length	39
External side	6
Total Length	120



The Device Under Test



Copper foil as reference

Coated foil to measure

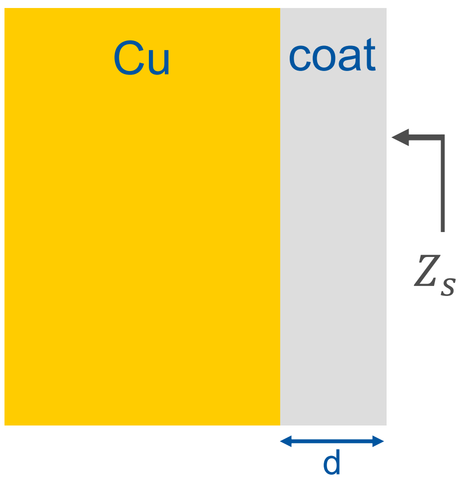
Methodology advantages: 1)Homogeneous deposition, 2)System reusability, 3)Large area coating

Analytical evaluations

In-house retrieval method

Waveguide of length l_g ($TE_{1,1}$ mode) + pyramidal transitions of length l_t ($TE_{1,0}$ $TE_{0,1}$ modes)

$$A_{DUT} = \alpha l_g + 2\int_0^{l_t} \alpha(z)\, dz = \frac{1}{2} Re(Z_s) \frac{\int_l \left|\boldsymbol{n}\times\boldsymbol{H}_{1,1}\right|^2 dl}{Z_{1,1}\left|I_{1,1}\right|^2} l_g + \int_0^{l_t} Re(Z_s) \frac{\int_l \left|\boldsymbol{n}\times(\boldsymbol{H}_{1,0}+\boldsymbol{H}_{0,1})\right|^2 dl}{Z_{1,0}\left|I_{1,0}\right|^2 + Z_{0,1}\left|I_{0,1}\right|^2} dz$$

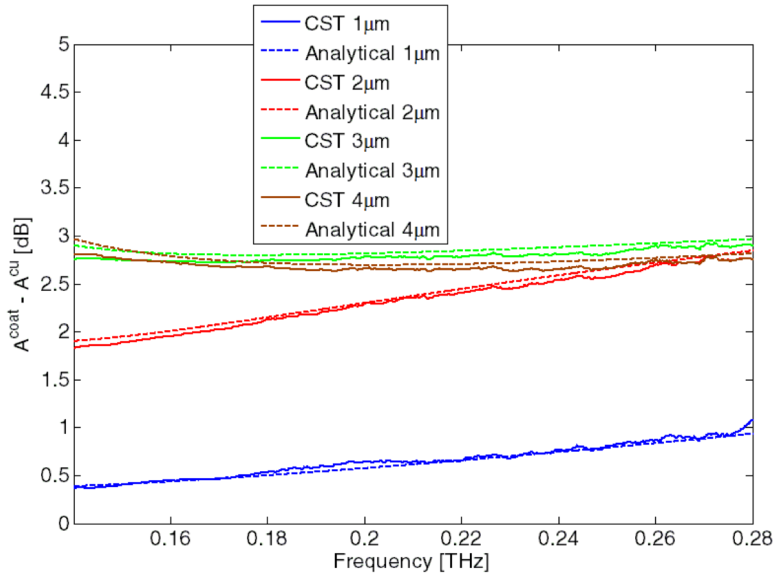


Reliable analytical tool

$$Z_s = Z_{coat} \frac{Z_{Cu} + jZ_{coat}\tan(k_{coat} d)}{Z_{coat} + jZ_{Cu}\tan(k_{coat} d)}$$

Surface impedance

Z and k are functions of material conductivity

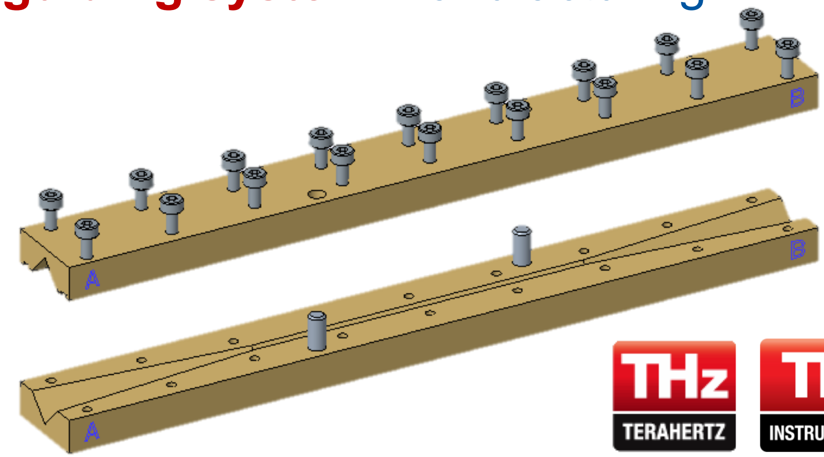


For calculations
Copper conductivity: $\sigma_{cu} = 6\cdot10^7$ S/m
NEG conductivity: $\sigma_{NEG} = 3.5\cdot10^5$ S/m

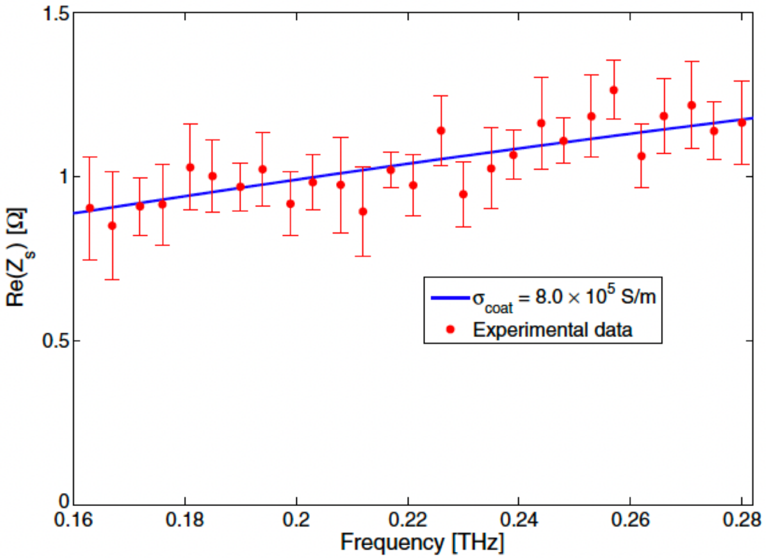
Measurement results on NEG

System specifications:
- Spectral Range: > 5 THz
- Dynamic Range > 90 dB
- Scanning Range ~ 850 ps
- Spectral Resolution < 1.5 GHz

Accurate **guiding system** manufacturing



NEG thickness 3.96 micron



- The methodology allows us to directly evaluate the $Re(Z_s)$ that we can use in beam dynamics calculations
- From surface impedance Z_s to resistive wall impedance Z_{wall}

Sub-THz Waveguide Spectroscopy of Coating Materials for Particle Accelerators

by Andrea Passarelli [1,2], Can Koral [2], Maria Rosaria Masullo [2], Wilhelmus Vollenberg [3], Lucia Lain Amador [3] and Antonello Andreone [1,2,*]

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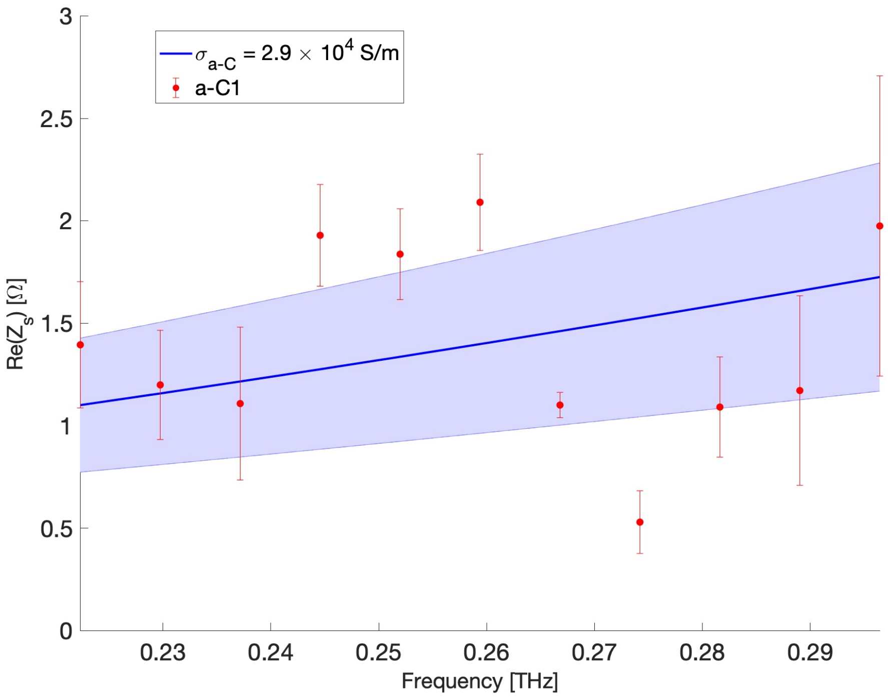
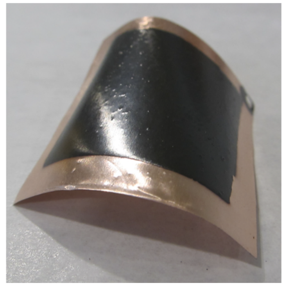
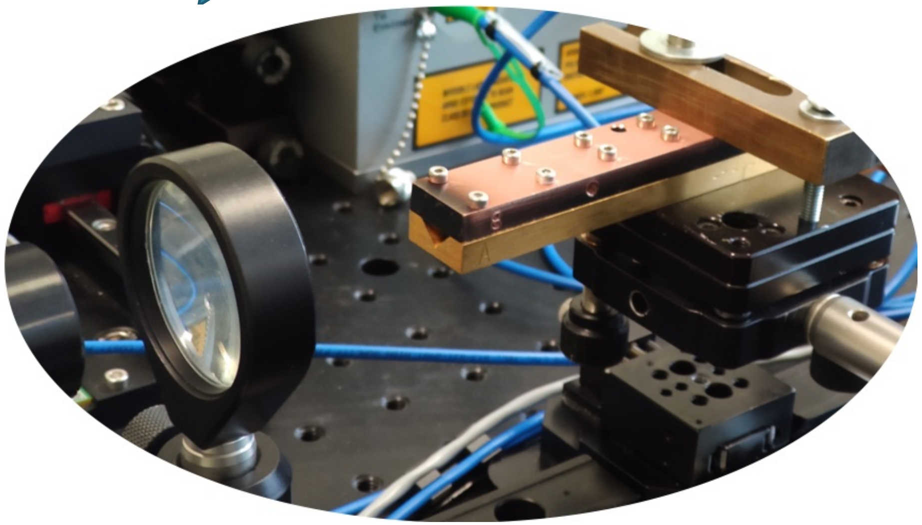
Measurement results on a-C

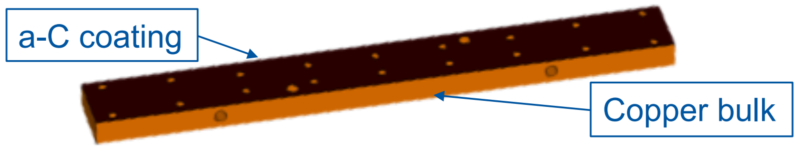


3 μm of **Amorphous carbon** on copper bulk

Mechanical stress a-C coating on Cu slab



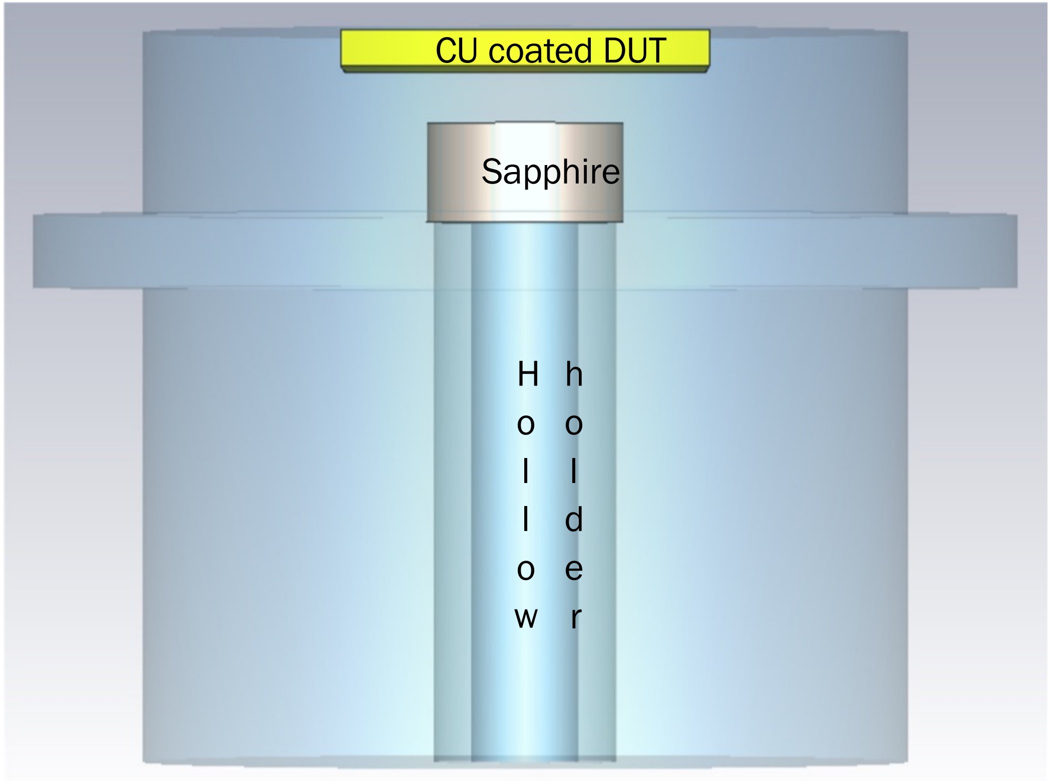


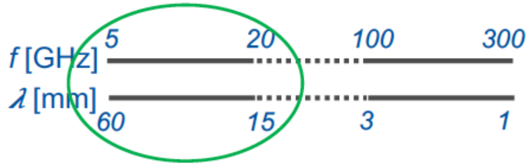


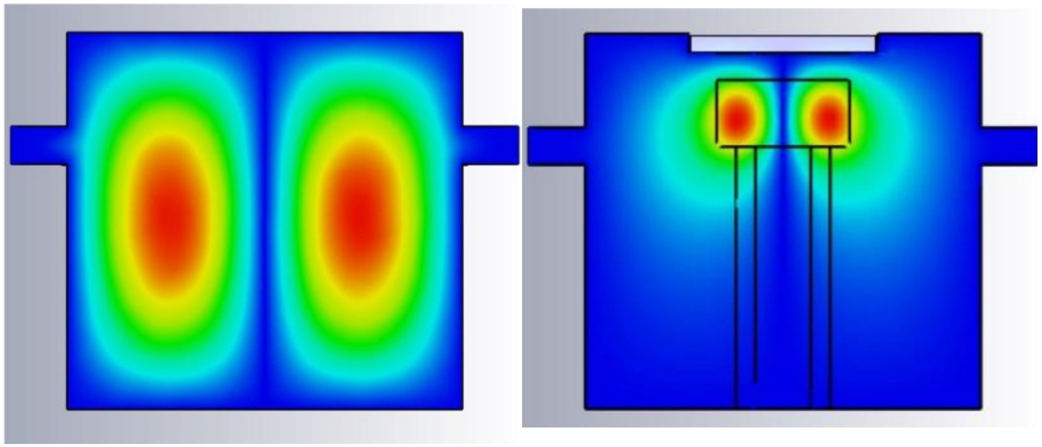
Dielectric resonant cavity

Resonant structure methodology

Dielectric resonator: Resonant structure methodology improves the sensitivity for the electromagnetic characterization of very thin laser surface treated structures and conductivity close to copper one

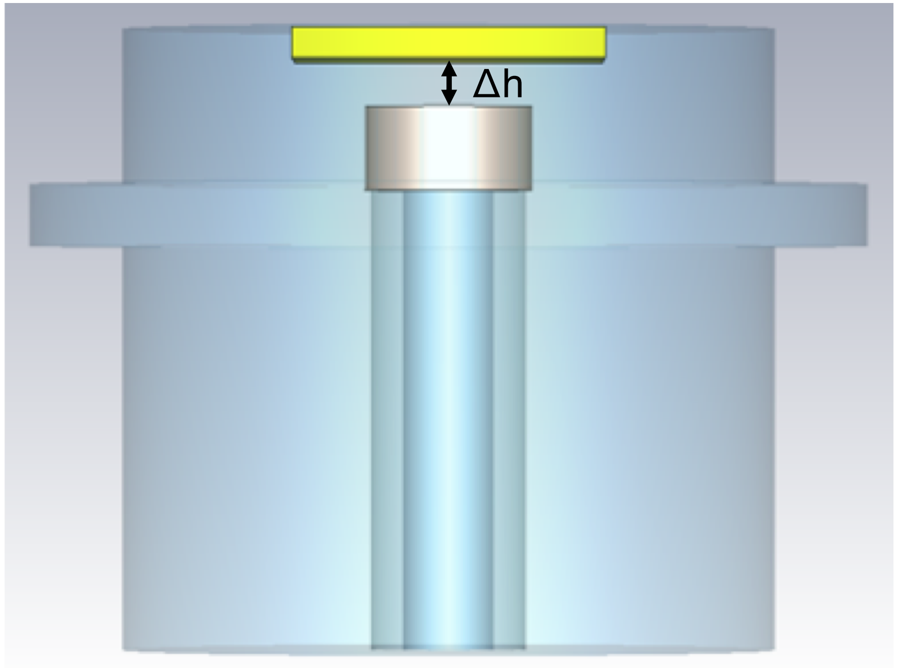




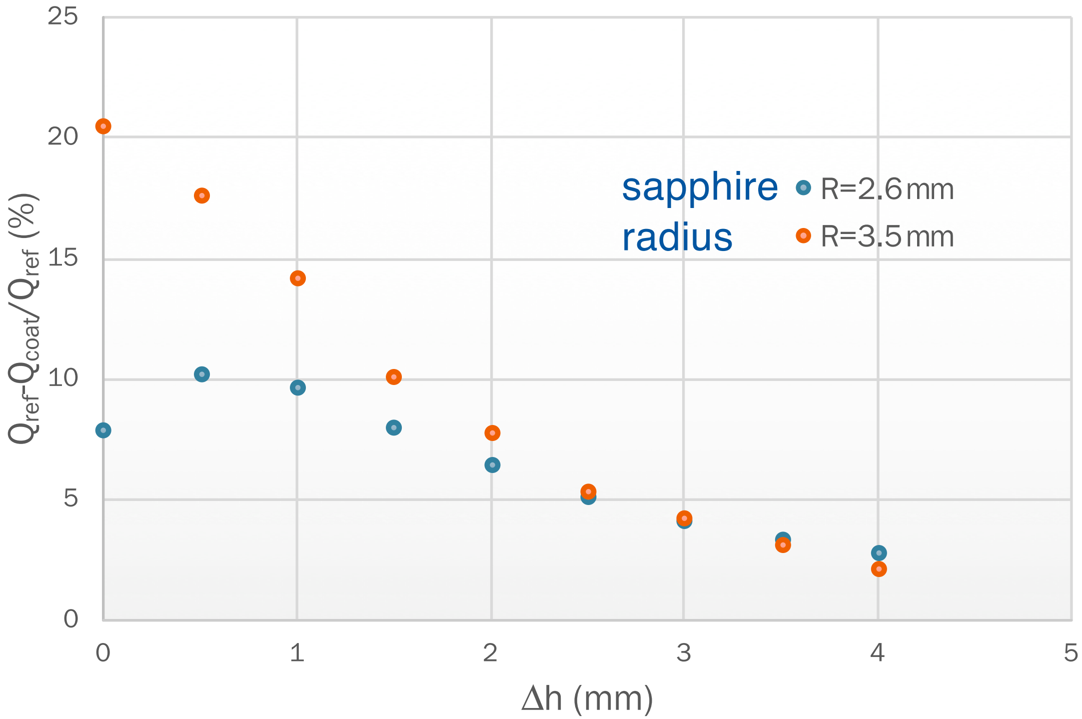


E field distribution
TE_{011} mode

Resonant structure methodology-simulations

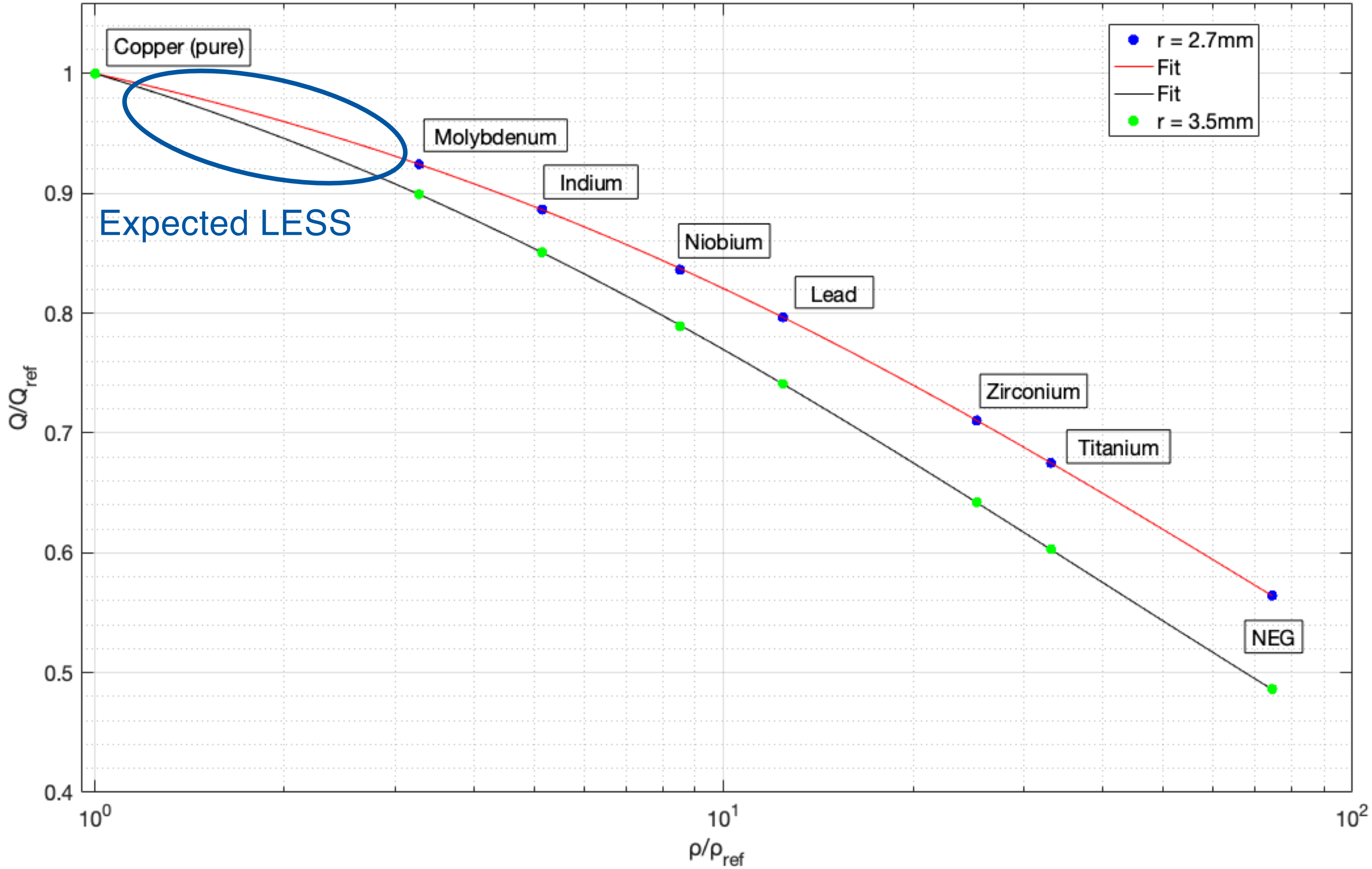


Copper vs. molybdenum coated DUT



The maximum Q-factor percentage difference is obtained with a minimum distance between the DUT and the sapphire

Resonant structure methodology- simulations



The sapphire with larger radius (3.5 mm) will be used, because of its higher sensitivity in EM characterization of coating materials (LESS)

Conclusion

Electromagnetic characterization of coating materials

- Sub-THz waveguide attenuation
  - Reliable analytical model for the conductivity retrieval. Good agreement with CST solver.
  - Successful measurement campaign: reliable and handy method to evaluate the electromagnetic properties of samples under test.
  - Published results on NEG and novels on a-C coatings.
- Resonant structure methodology
  - Improves the sensitivity, useful for electromagnetic characterization of very thin laser surface treated structures (i.e. LESS)