MIKON-2022

GHz characterisation of dielectric properties of ultra-low temperature co-fired ceramic materials for 5G systems application

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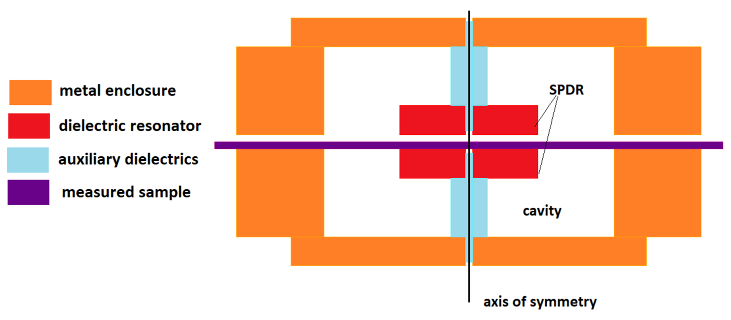
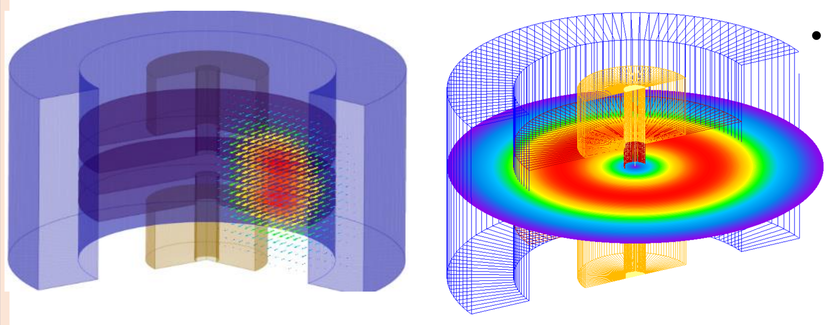
***Abstract*—This work is dedicated to non-destructive characterization of dielectric properties of novel ultra-low temperature co-fired ceramic materials. With regards to their targeted application to emerging 5G communication systems, high accuracy measurements of complex permittivity are of crucial importance for materials manufacturers and further, 5G components designers. For high system efficiency, the discussed materials are aimed at low dielectric constant, in the range of 4-6.5 and low loss tangent, being within the range of 0.0005-0.005. Complex permittivity extraction is performed with the aid of split-post dielectric resonator method, which has been known for its robustness and high accuracy.**

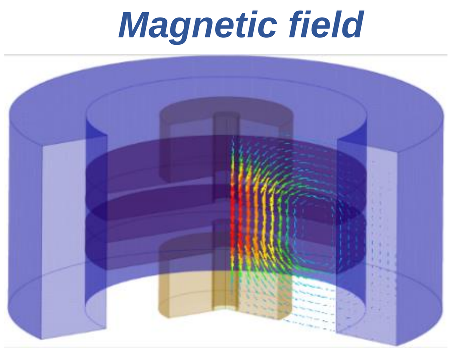
Material characterisation method – *Split-Post Dielectric Resonator*



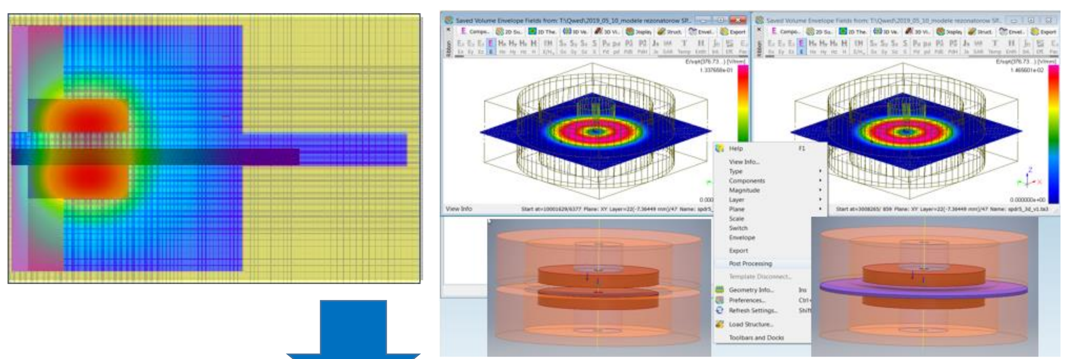
Electric field



Magnetic field



- resonant mode with EM fields mostly confined in and between those ceramic posts
  - → minimial losses in metal enclosure
- E-field tangential to SUT
  - → air slots between SUT and posts have negligible effect
- H-field is only vertical at the side wall of the enclosure → circumferential currents
  - → no radiation through slot
  - → easy SUT insertion through slot, no dismantling
- Field patterns remain practically unchanged



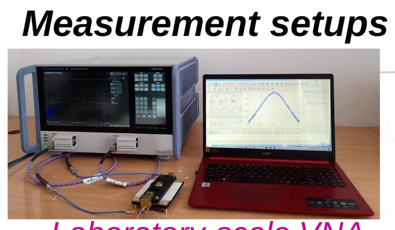
Sample in strong E-field nearly constant between the two posts

For laminar dielectrics and high-resistivity semiconductors

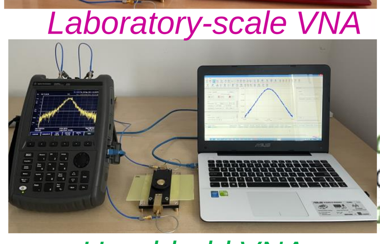
SUT of $\varepsilon_s = \varepsilon_s' - j\,\varepsilon_s''$ is inserted into DR:

resonant frequency *changes* from f_e to f_s and Q-factor *changes* from Q_e to Q_s

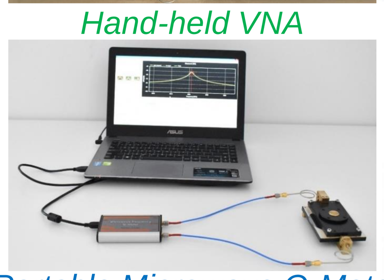
Measurement setups



Laboratory-scale VNA

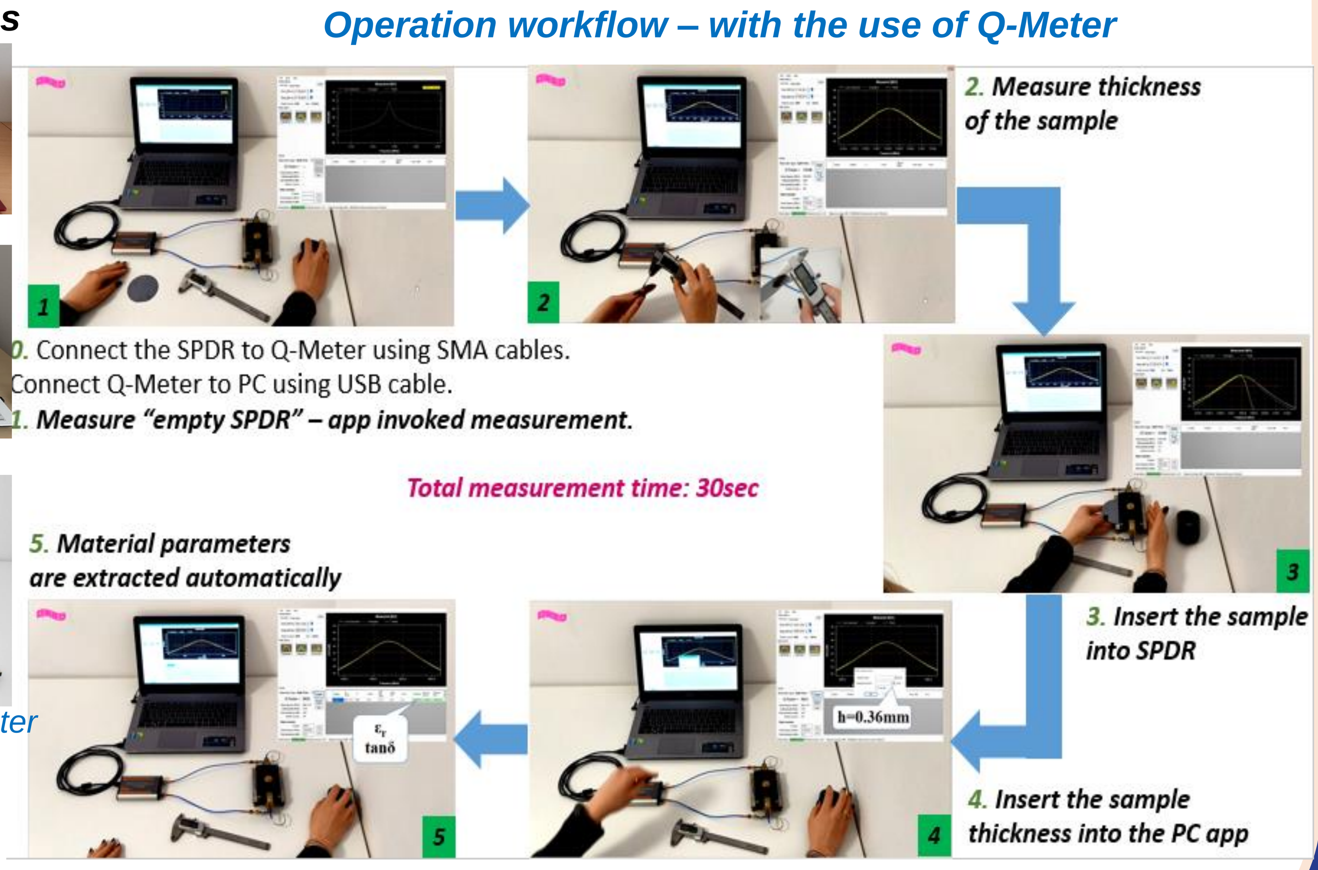


Hand-held VNA



Portable Microwave Q-Meter

Operation workflow – with the use of Q-Meter



Materials

Motivation

- Low temperature co-fired ceramics (LTCC) and novel ultra-low temperature co-fired ceramic (ULTCC) materials
- Application to demanding 5G and 6G systems
- Gaining continuously growing interest due to:
  - Lowered sintering temperature (compared to HTCC),
  - keeping compatibility with already existing fabrication methods.
- LTCC and ULTCC materials are foreseen to deliver enhanced
  - manufacturing flexibility,
  - miniaturization,
  - packaging degree,
  - lower production cost,
  - higher sustainability,
  - environmental friendliness.
- Needed: Precise characterization with regards to complex permittivity (used in the electromagnetic design of telecommunication components).

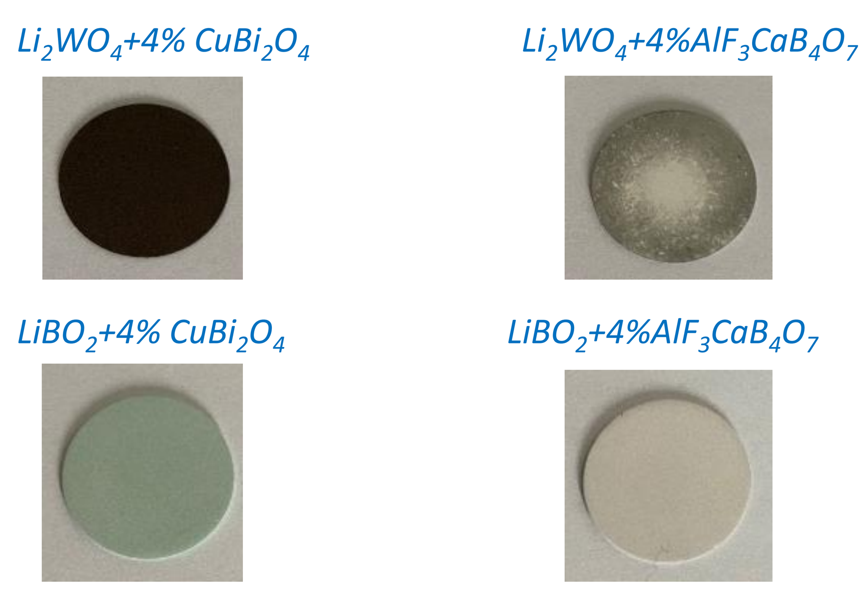
ULTCC material fabrication scheme

- Materials have been prepared according to the conventional ceramic procedure:
  - –solid state synthesis of oxide components,
  - –ball milling,
  - –uniaxial pressing of pellets.
- Sintering at 610-650° C for 1 - 2h.
- ULTCC samples are based on new ceramic materials with a low dielectric permittivity:
  - – Li_2WO_4 with 4 wt.% $CuBi_2O_4$,
  - – Li_2WO_4 with 4 wt. % $AlF_3CaB_4O_7$
  - – $LiBO_2$ with 4 wt. % $CuBi_2O_4$
  - – $LiBO_2$ with 4 wt.% AlF_3-CaB_4O_7.
- Expected to have low dielectric constant and loss tangent, making them good candidates for laminar substrates for components dedicated to 5G systems.

Test samples

φ=20 mm

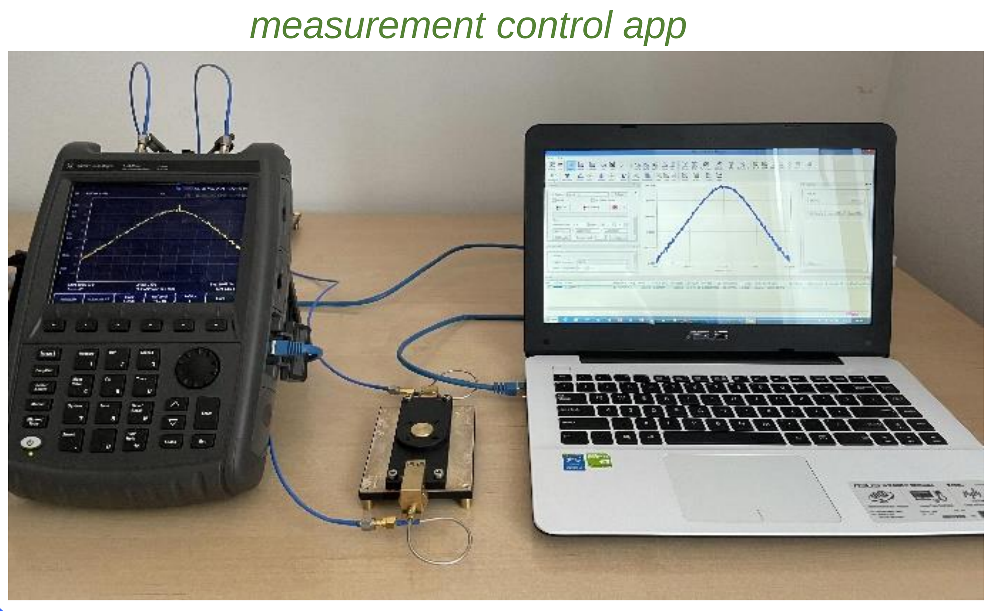
Expected by chemical composition: Dk= 4-6.5
Df= 0.0005-0.005



Results and discussion

Family of SPDR test-fixtures: 1.1GHz, 1.9GHz, 2.5GHz, 5GHz, 10GHz, 15GHz

Measurement setup: SPDR 10GHz, hand-held VNA, measurement control app



PARAMETERS OF ULTCC MATERIALS MEASURED WITH 10 GHZ SPDR

Sample name	*Thickness [mm]*	*Dielectric constant*	*Loss tangent*
Li_2WO_4 with 4 wt.% $CuBi_2O_4$	0.485 ± 0.015	5.40 ± 2.5%	0.00200 ± 3%
Li_2WO_4 with 4 wt.% $AlF_3CaB_4O_7$	0.64 ± 0.030	6.52 ± 4%	0.00233 ± 3%
$LiBO_2$ with 4 wt.% $CuBi_2O_4$	0.6 ± 0.030	5.12 ± 4%	0.00195 ± 3%
$LiBO_2$ with 4 wt.% AlF_3-CaB_4O_7	0.55 ± 0.020	4.48 ± 3%	0.00328 ± 3%

- Uncertainty of dielectric constant extraction is directly related to: uncertainty of resonant frequency measurement and determination of SUT's thickness.
- For the investigated ULTCC materials samples, a dominant factor influencing uncertainty of Dk extraction is SUTs thickness variation across the surface
- Dielectric properties of SUTs have been retrieved for an average thickness values
- Thickness variation has been used to determine a related uncertainty of Dk evaluation.

- Conducting uncertainty study for measured dielectric properties becomes crucial, specifically when samples, due to e.g. technological constraints, are needed to be mechanically postprocessed or are known to be of limited flatness.
- The extracted values of dielectric constant and loss tangent, with evaluated uncertainty bounds, show good correlation with targeted dielectric properties, implying the investigated materials are promising for laminar substrates for 5G systems designers.

Acknowledgement

This work has been conducted within ULTCC6G_EPac project under M-ERA.NET2 program, receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 685451

The work was co-funded by the Polish National Centre for Research and Development under M-ERA.NET2/2020/1/2021 contract.

M-ERA.NET

The National Centre for Research and Development