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The Coolest Ideas Under the Sun
SAN DIEGO 2023

TUMA21

Dielectric and Cavity Resonators for Accurate Characterization of Liquids in the 1-50 GHz Frequency Range

Speaker: Marzena Olszewska-Placha
QWED company (Booth #2537)
(www.qwed.eu)

Why to characterise liquids/fluids?

- Dielectric characterisation of "loose" materials
  - liquids
  - powders
- Electronic coolants
  - cooling modern electronic systems
  - targeted at low Dk and Df
- Food industry
  - Microwave heating
  - Not only 2.5 GHz – microwave heating at higher frequencies e.g. 5.8 GHz
- Raw materials producers – e.g. ceramic powders

- Characterisation with resonant methods
  - Cavity devices
  - Fabry-Perot Open Resonator

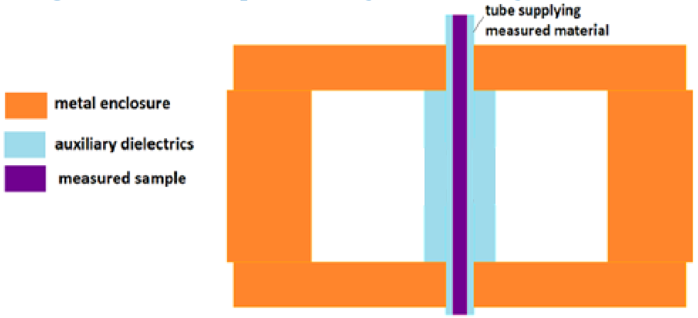
Measurements of liquids

Resonant methods are proven to be **the most accurate** among microwave material characterisation method

Low frequency dielectric resonator cavities

Dielectric resonator cavity at 2.5 GHz

Higher frequency cavity resonators



24-GHz Cavity resonator
(with fused silica tube, rubber tube and syringe)

Fabry-Perot Open Resonator

Single solution for 15-50GHz

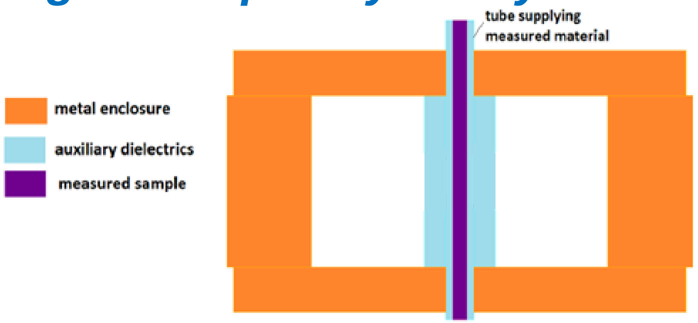
Measurements of liquids

Resonant methods covering 1 – 50 GHz frequency range

Low frequency dielectric resonator cavities

Dielectric resonator cavity at 2.5 GHz

Higher frequency cavity resonators



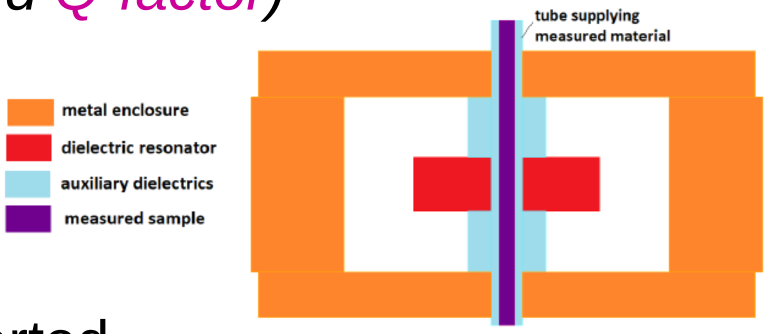
24-GHz Cavity resonator
(with fused silica tube, rubber tube and syringe)

Fabry-Perot Open Resonator

Single solution for 15-50GHz

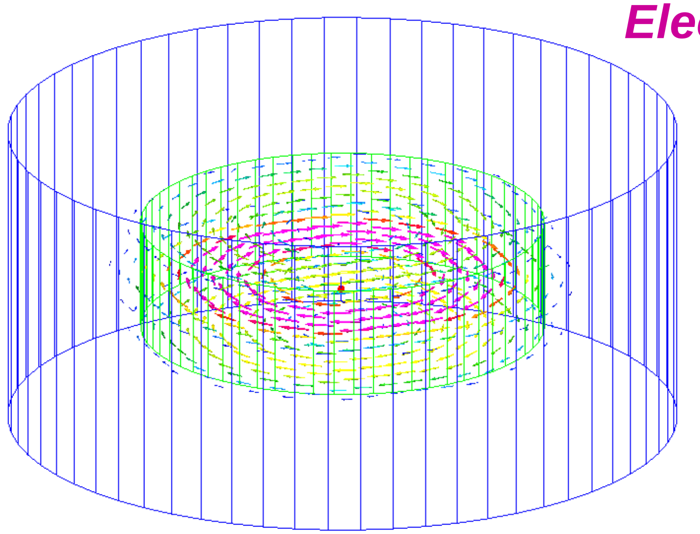
Measurement methods

- $TE_{01\delta}$ resonance mode *(described with resonant frequency and Q-factor)*
- Electric field mostly confined within the dielectric pill
- Circumferential electric field
  → no issues with galvanic connection of the lid
- Zero electric field at ρ=0
  → no risk of supressing resonance if lossy sample is inserted

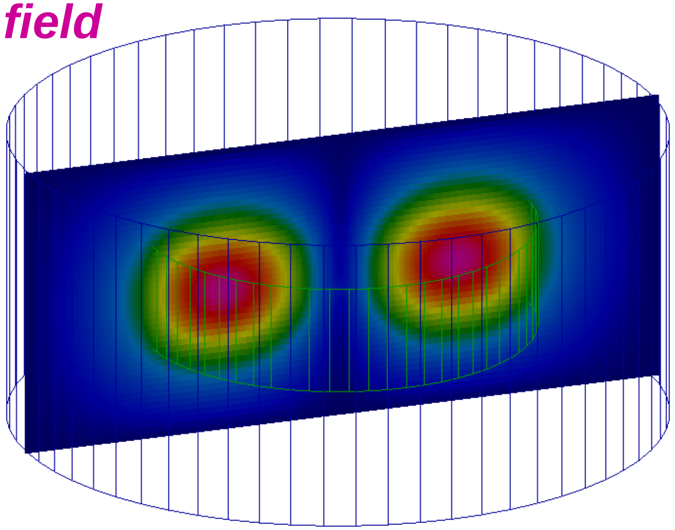


Resonance mode within dielectric resonator cavity *

Electric field

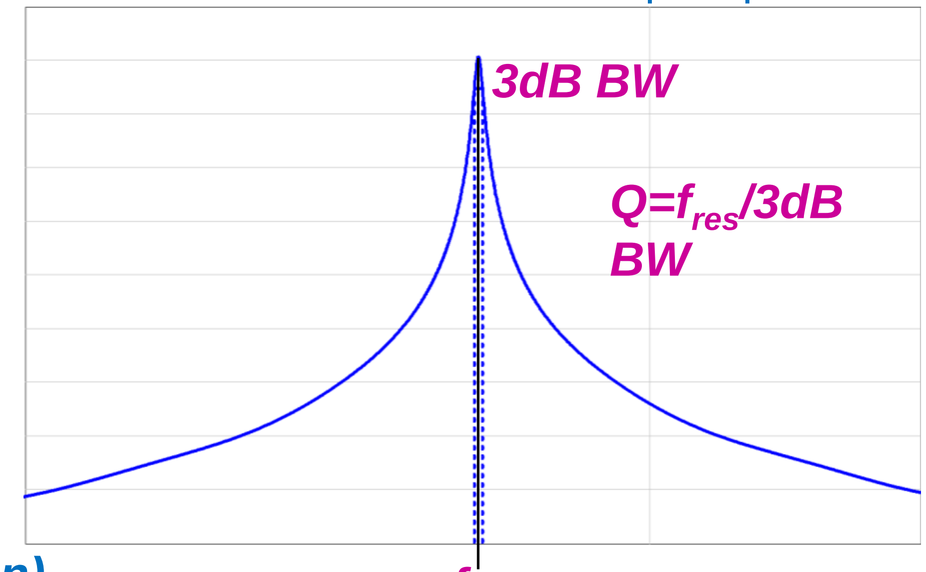


Vector view



Amplitude view (cross section)

Transmission curve |S21|



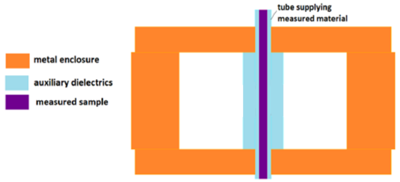
**** Obtained with QuickWave 3D software***

Measurement methods (2)

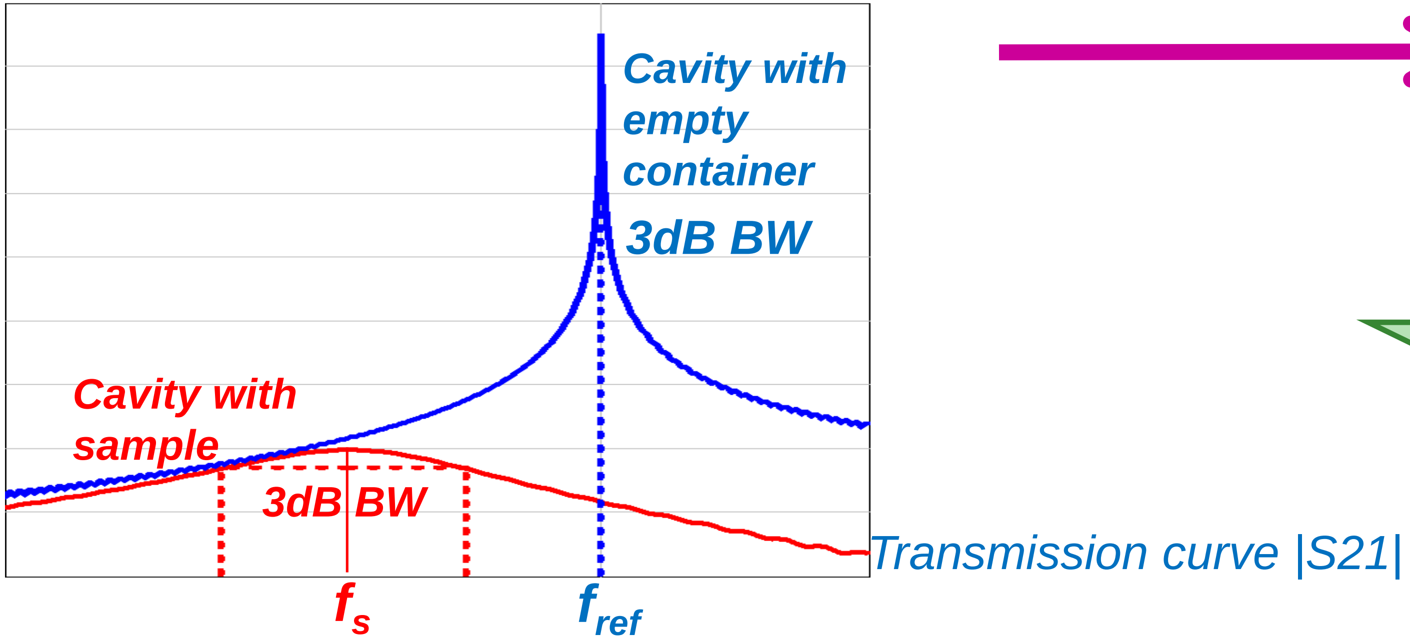
- Two/three stage measurement

- Reference measurement – cavity with empty container (f_{ref} and Q_{ref})
  → the inner diameter of the container needs to be precisely calibrated

- Measurement of sample-loaded cavity (f_s and Q_s)



- Scalar measurement of transmission curve (|S21|) is typically sufficient



→ Δf, ΔQ

Precise EM model of the resonator

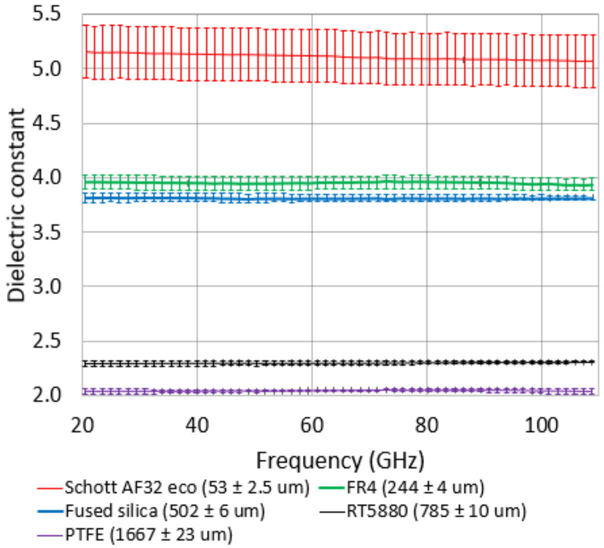
(embedded in the dedicated software)

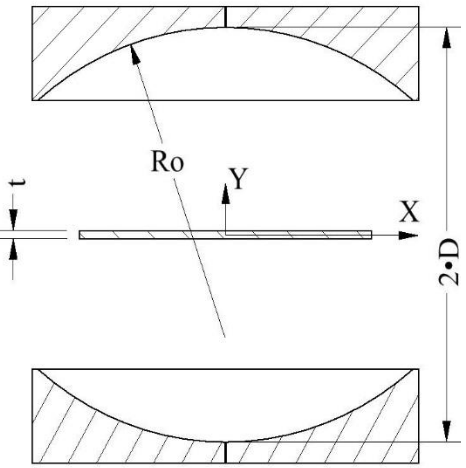
ε_r, $\tan\delta$

Measurement methods (3)

Fabry-Perot Open resonator

*Used for sheet dielectrics **up to 130 GHz***



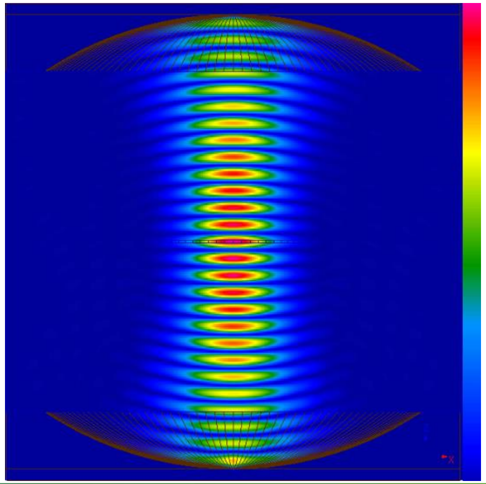


Gaussian mirror no. 1

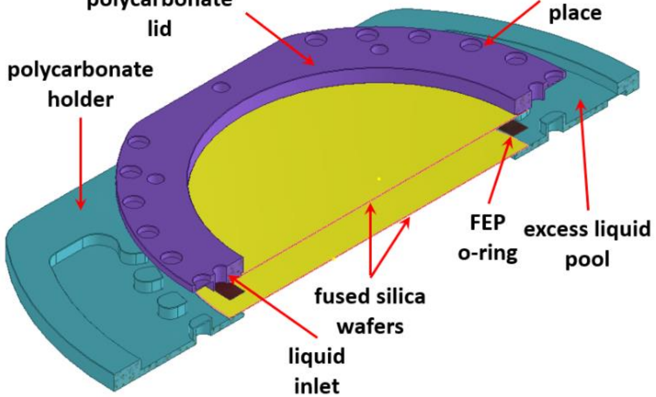
sample

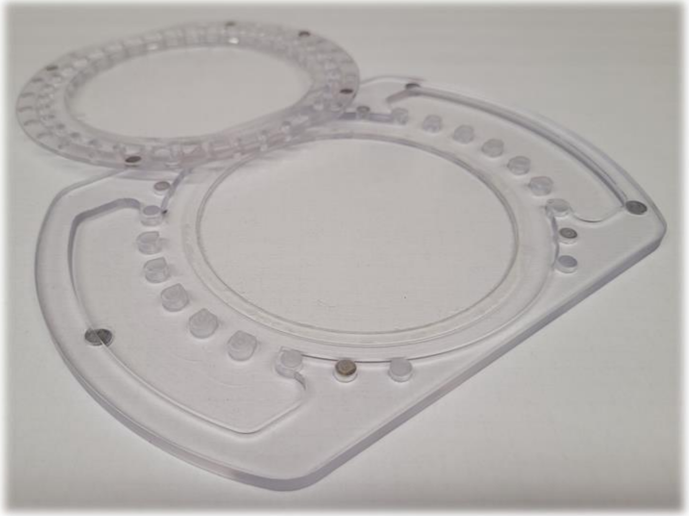
Gaussian mirror no. 2

*Gaussian **TEM00q** modes*



New solution for liquids





Measurement methods (4)

Dielectric resonator

Specification

Fluid diameter: **< 16 mm**

$TE_{01\delta}$: ***f = 2.45 GHz (Q = 29,400)***

$TE_{02\delta}$: ***f = 5.16 GHz (Q = 27,200)***

Cavity resonator

Specification

Fluid diameter: **< 3 mm**

TE_{011}: ***f = 23.8 GHz (Q = 14,200)***

Fabry-Perot open resonator with a dedicated fluid container

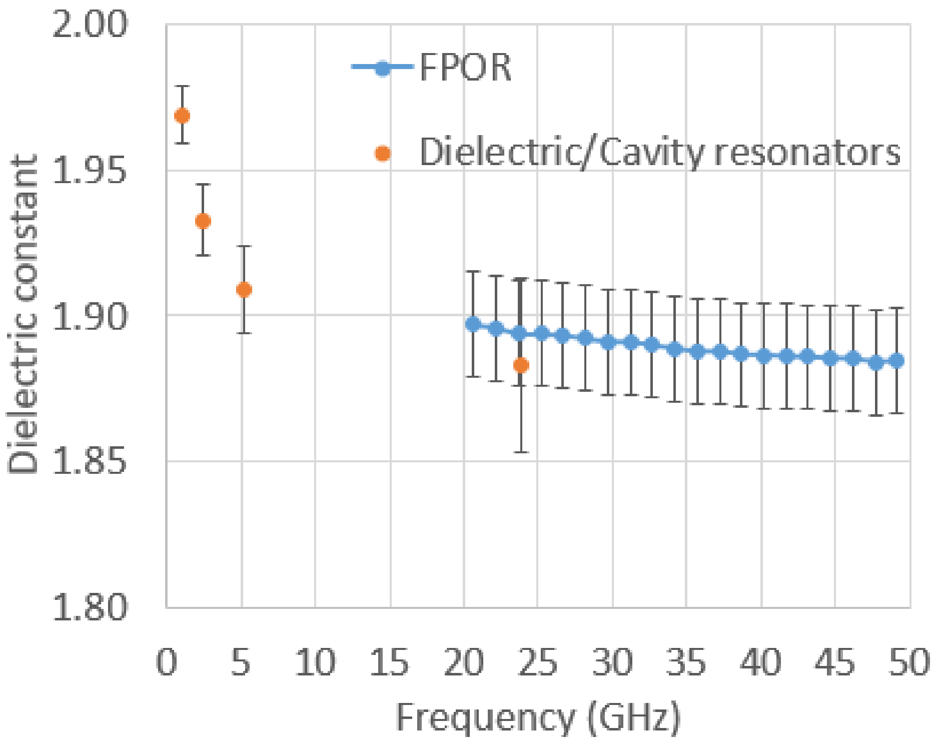
Specification

Fluid thickness: **100-400 µm**

Frequency: ***15-50 GHz***

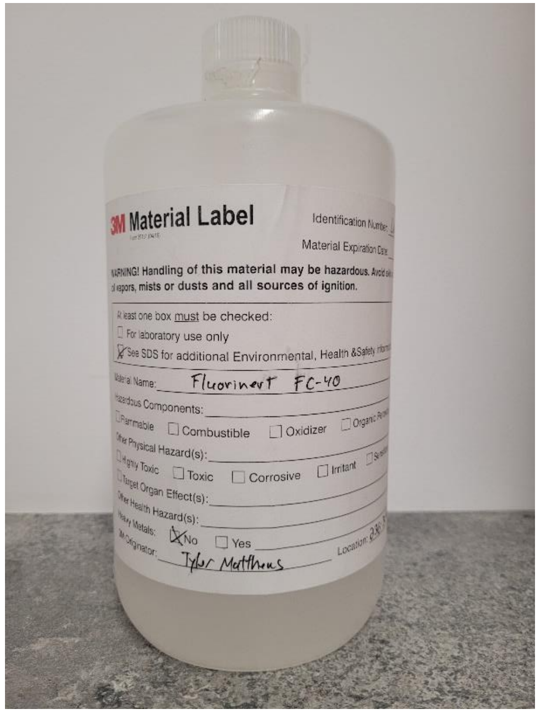
Electronic coolants

Low-loss liquids typically exhibit dispersive properties at microwaves (Debye-like relaxation)

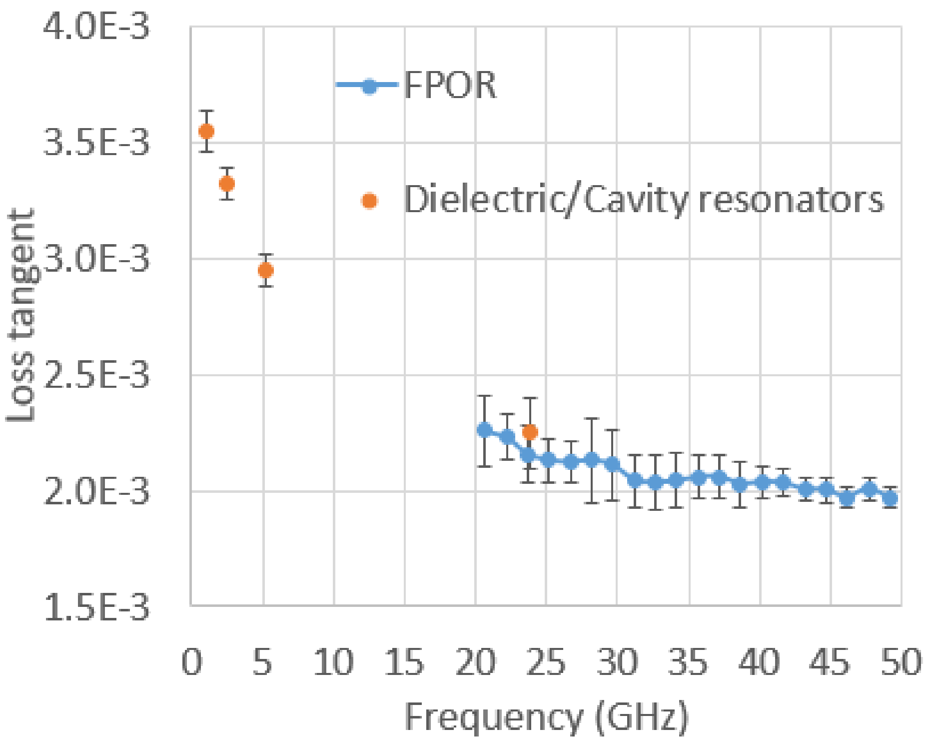


Dielectric constant

Uncertainty of Dk <1%

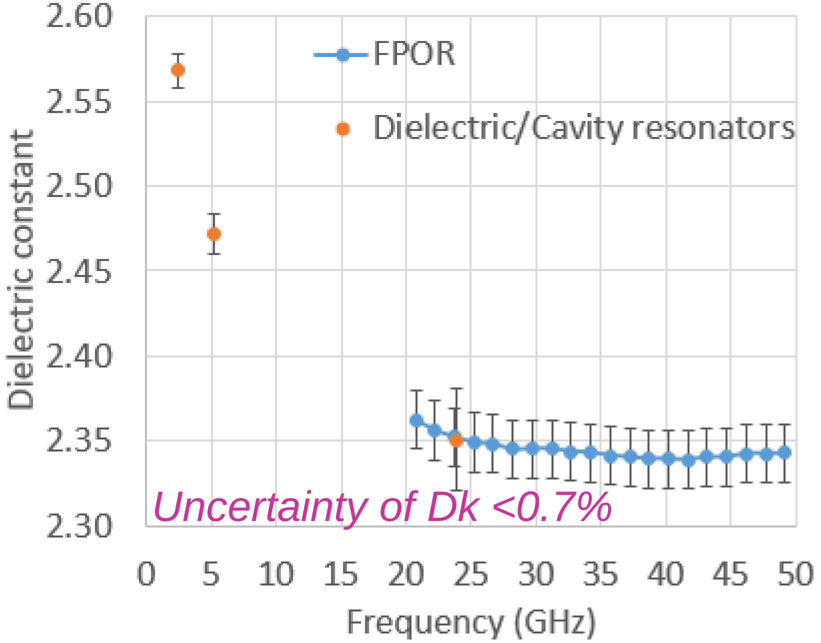


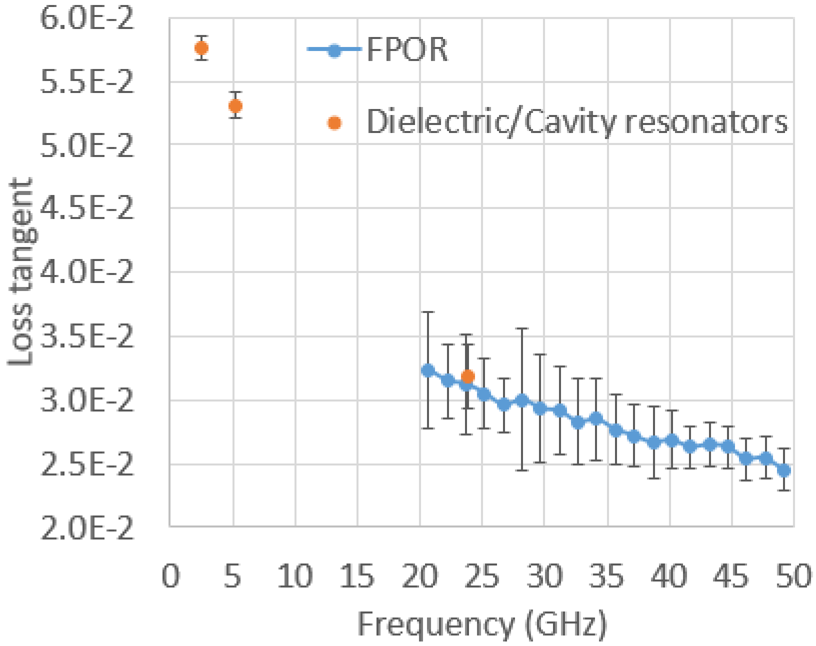
Fluorinert
(3M FC-40)



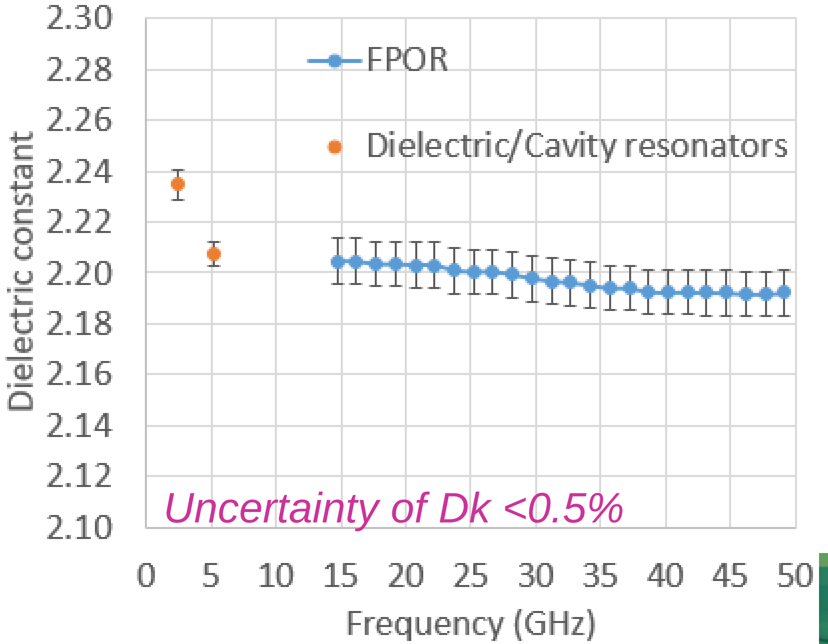
Loss tangent

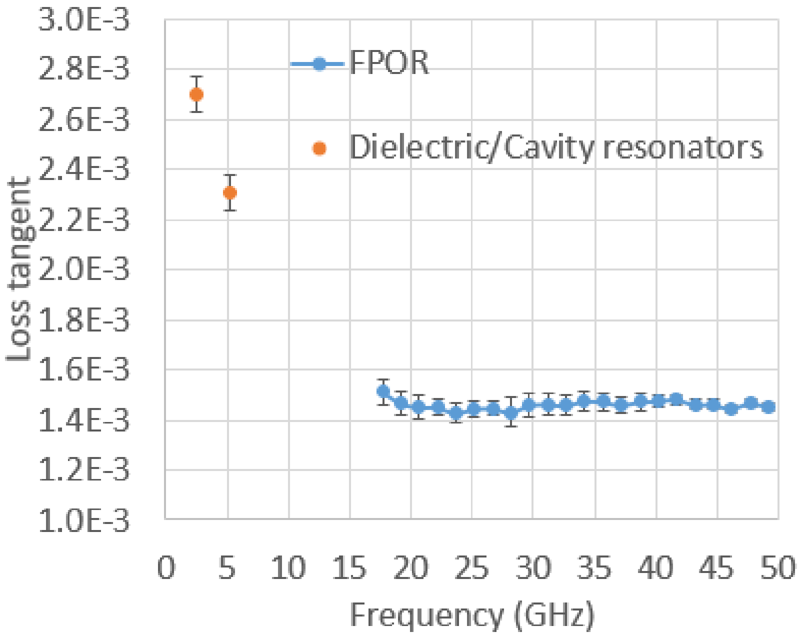
Oils





Canola oil





Engine oil

Temperature dependence (1)

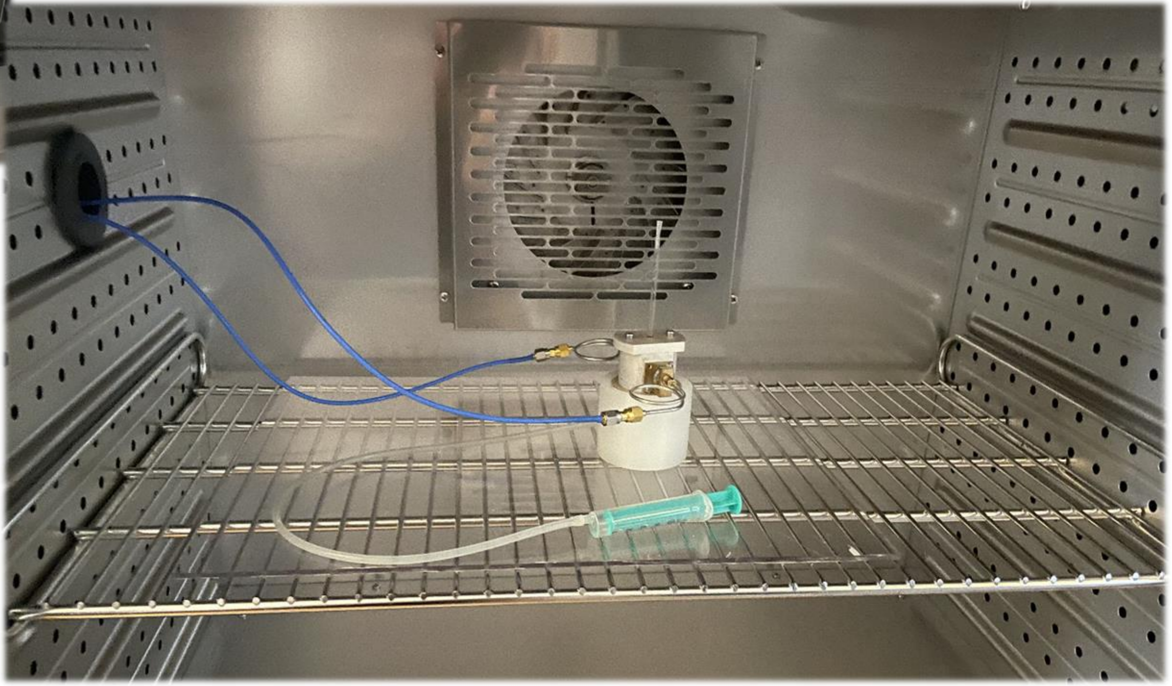
Dielectric characterisation versus temperature

PC with control app

VNA

Climatic chamber with cavity resonator @24GHz

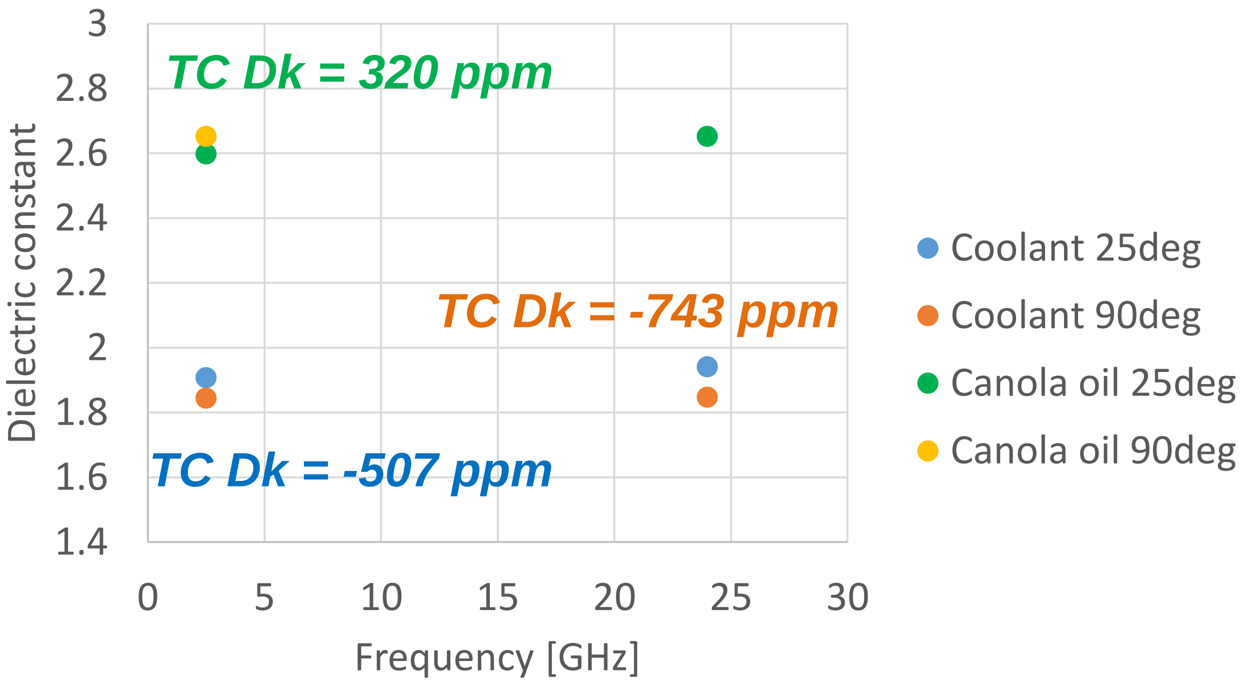
Cavity resonators and dielectric resonator cavities

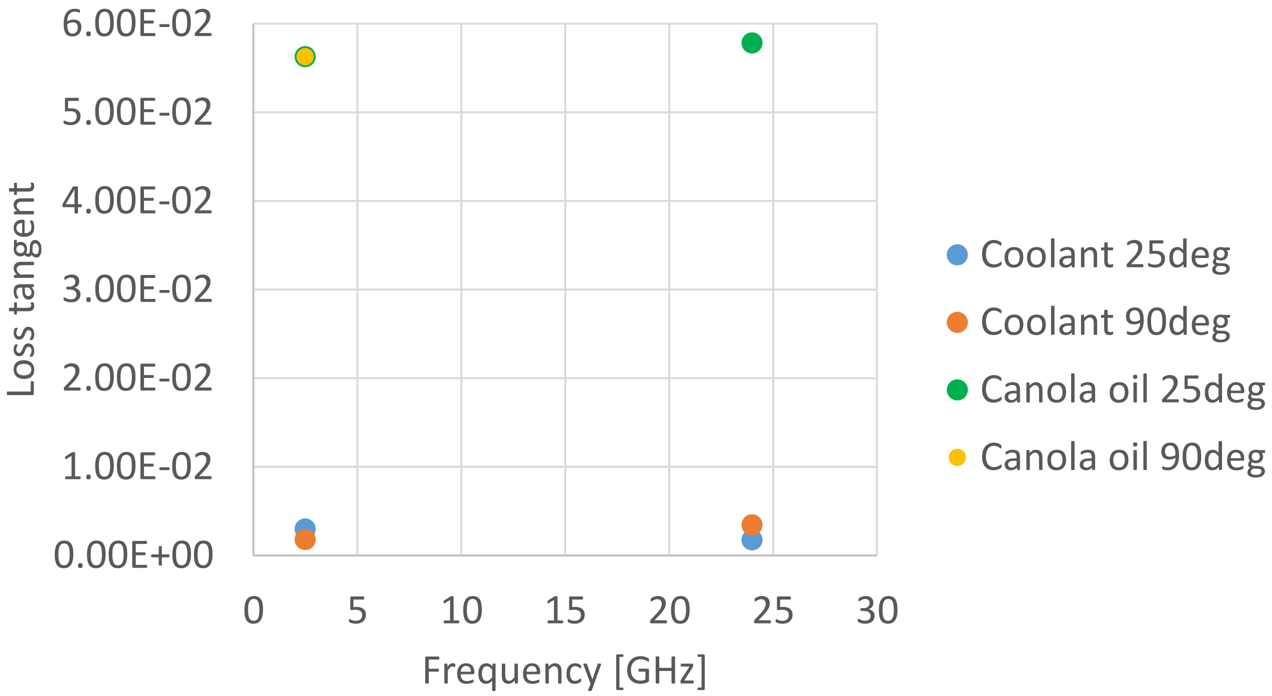


Temperature dependence (2)

Dielectric characterisation versus temperature

coolant liquid and canola oil



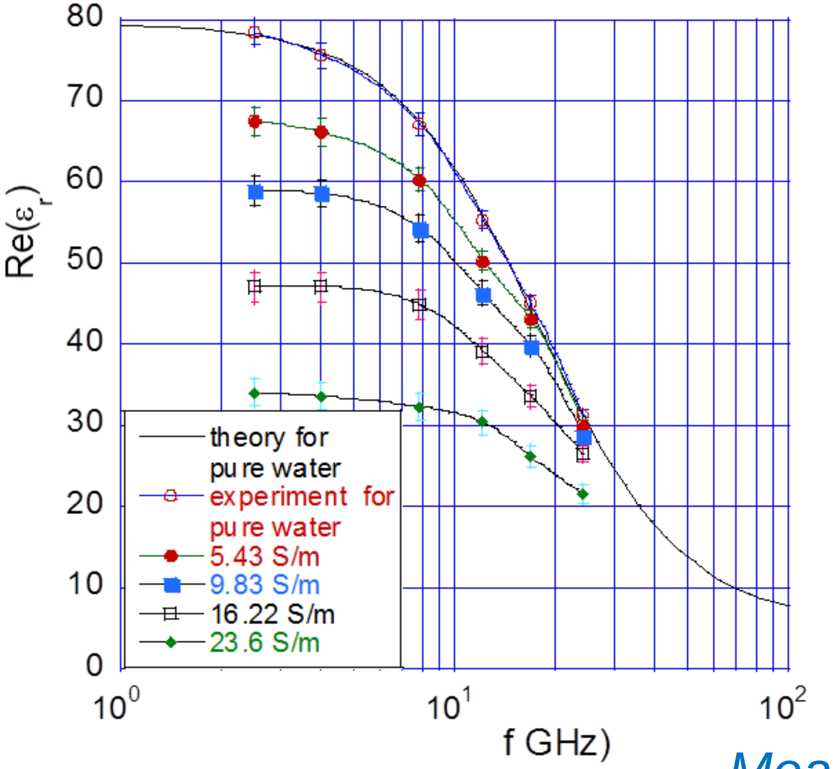


Uncertainty of Dk due to variation of diameter of quartz tube

@2.5 GHz – 0.1% *@24GHz – 0.7%*

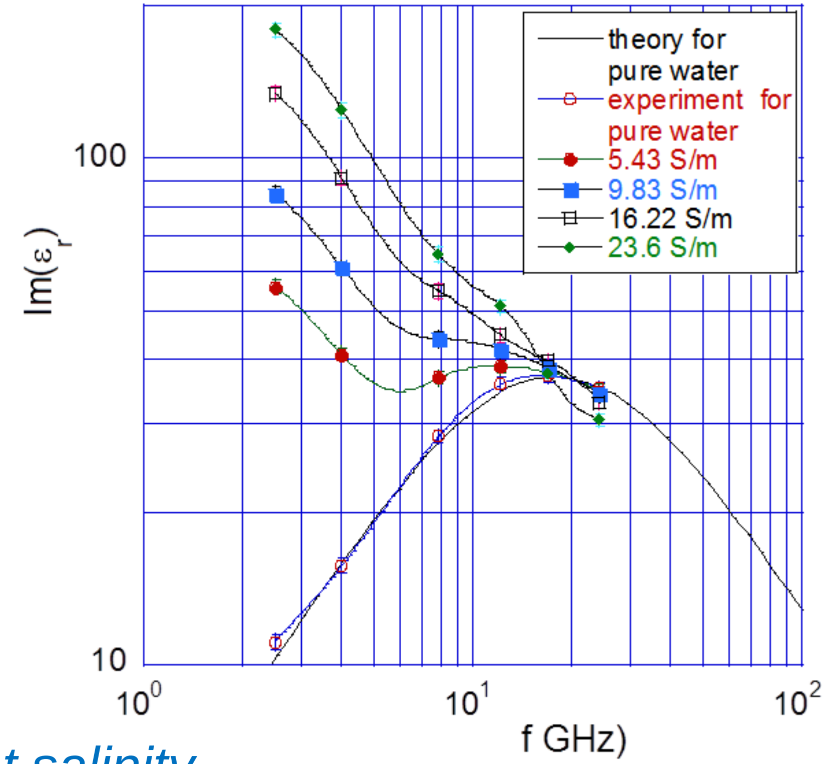
Water

TE_{0mn} cylindrical modes provide superior accuracy in the characterisation of lossy liquids, like saline water.



$$\varepsilon(\omega) = \varepsilon_\infty + \frac{[\varepsilon_s - \varepsilon_\infty]}{(1 + j\omega\tau)} - j\frac{\sigma}{\omega\varepsilon_0}$$

ε_s	low-frequency limit
ε_∞	high-frequency limit
τ	relaxation time
σ	ionic conductivity



Measurements of saline water for different salinity, at 2.5 GHz, 4 GHz, 7.86 GHz, 12.2 GHz, 16.9 GHz, 24.3 GHz

* J. Krupka, Measurements of the complex permittivity of highly concentrated aqueous NaCl solutions and ferrofluid employing microwave cylindrical cavities, Meas. Sci. Technol. 26 (2015).

Quartz Sand

Intrinsic properties of mixture components can be evaluated

(e.g. using Maxwell-Garnett model)

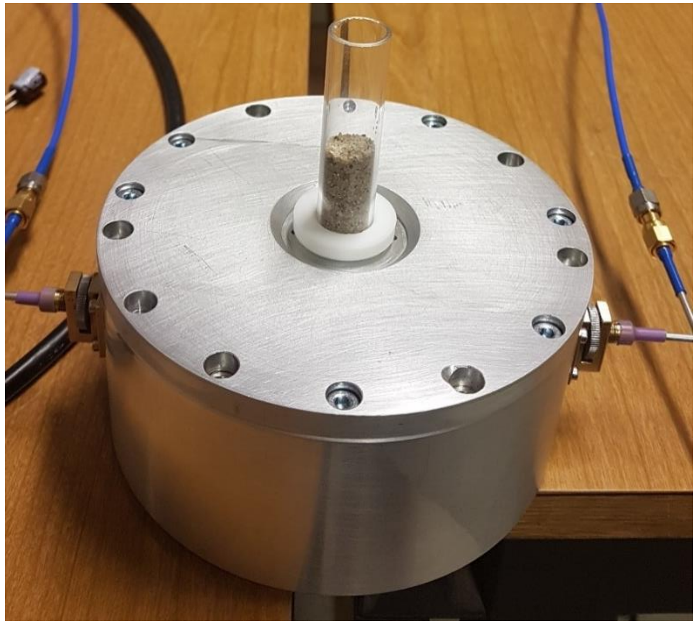
Effective parameters

Dk = 2.851 @ 1 GHz

Dk = 2.758 @ 2.5 GHz

Df = 3.367×10^{-3} @ 1 GHz

Df = 2.539×10^{-3} @ 2.5 GHz



Dielectric resonator (1.04 GHz)

Intrinsic parameters

Dk = 4.275 @ 1 GHz

Dk = 4.104 @ 2.5 GHz

Df = 4.117×10^{-3} @ 1 GHz

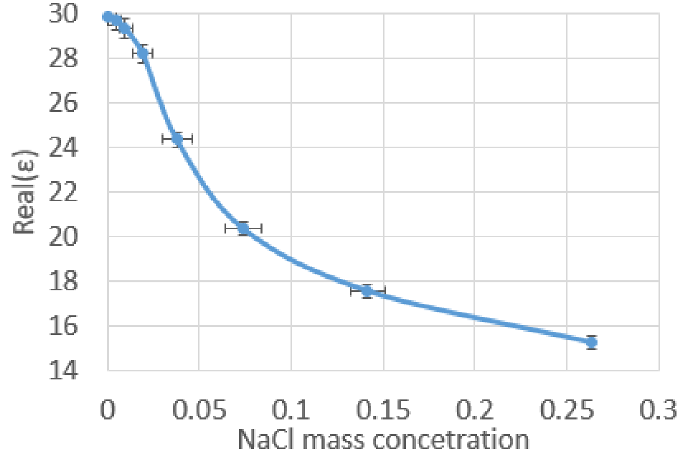
Df = 3.124×10^{-3} @ 2.5 GHz

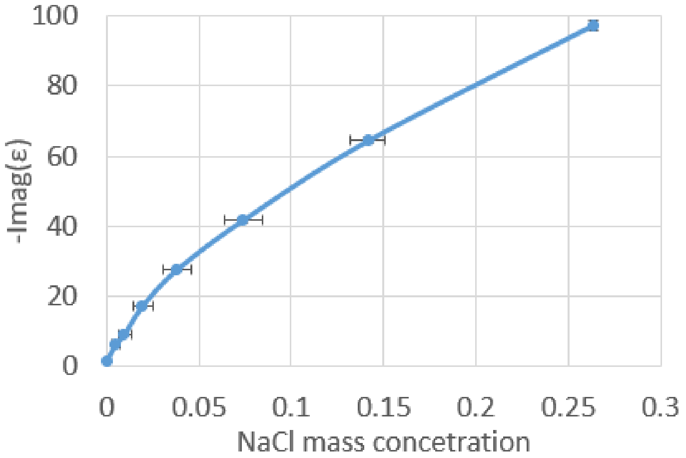
Air volume fraction: 36.4%

Sand with saline water

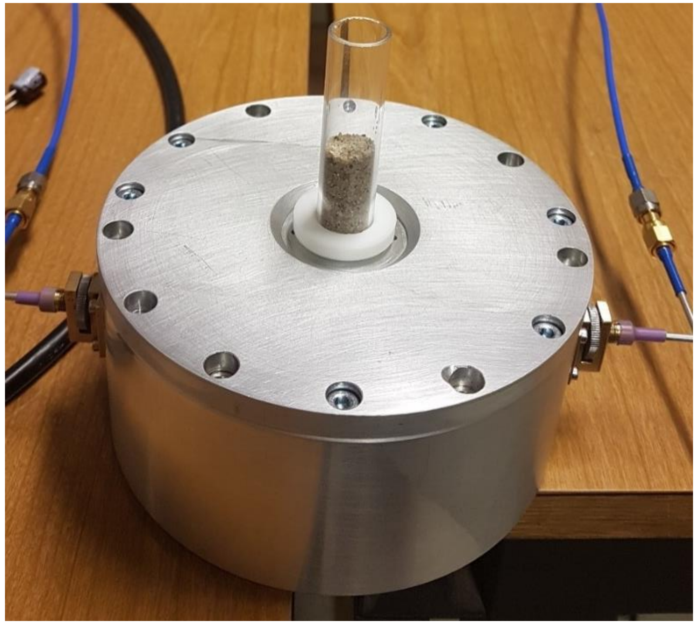
Intrinsic properties of mixture components can be evaluated

(e.g. using Maxwell-Garnett model)

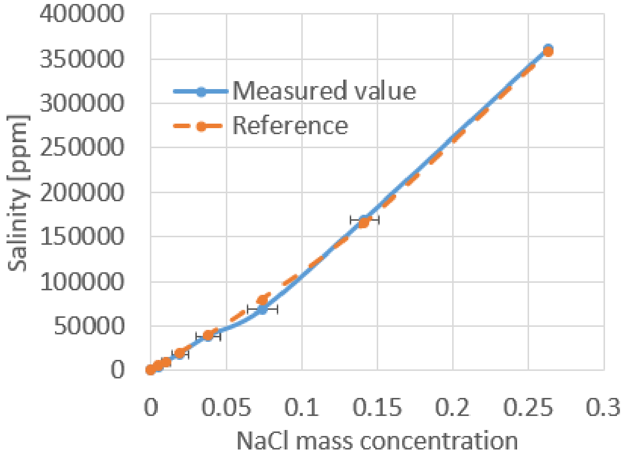


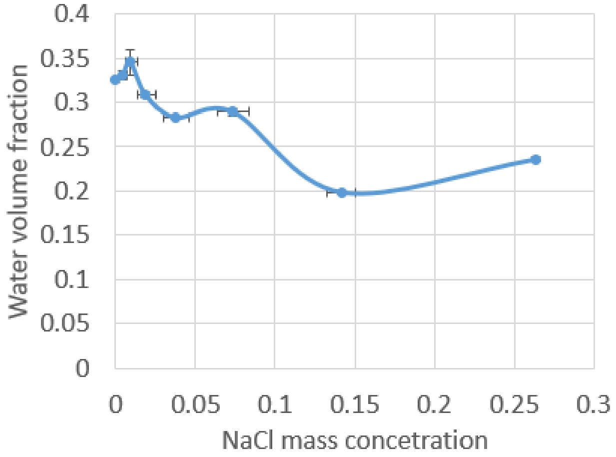


T = 22 ^{0}C



Dielectric resonator (1.04 GHz)





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Acknowledgement

The work has been conducted within ULTCC6G_EPac and I4BAGS projects under M-ERA.NET2 and M-ERA.NET3 programs.

Part of this work was funded by the Polish National Centre for Research and Development

under ***M-ERA.NET2/2020/1/2021*** *contract*

under ***M-ERA.NET3/2021/83/I4BAGS/2022*** *contract*

Ultra-Low Temperature Co-fired Ceramics for 6th Generation Electronic Packaging

Ion Implantation for Innovative Interface modifications in BAttery and Graphene-enabled Systems

With contribution from**:**

Prof. Bartlomiej Salski, Warsaw University of Technology

Piotr Czekala, Warsaw University of Technology