Th1E-2

A Novel Q-Choked Resonator for Microwave Material Measurements Alleviating Sample Thickness Limitations of Existing Techniques

Malgorzata Celuch, Marzena Olszewska-Placha, Lukasz Nowicki, Wojciech Gwarek

QWED, Poland

Outline

- Motivation
- Split-Cylinder Resonator
- Q-Choke concept
- Q-SCR Model
- Q-SCR vs SCR – Simulation results
- Experimental validation
- Measurement results

Motivation

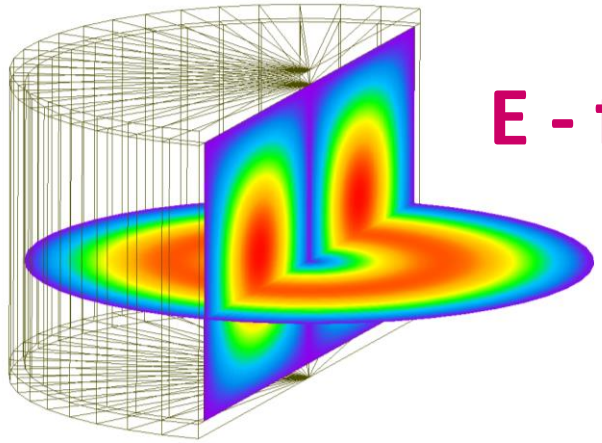
- Sample thickness limitation of common existing solutions (Split-Post Dielectric Resonator, Split-Cylinder Resonator, etc.)
  - with increasing frequency
  - with increasing dielectric constant

- Increasing demands for measurements of thick samples
  - Automotive industry – e.g. plastic plaques for bumpers
  - High power and space applications – e.g. vacuum windows
  - Etc.

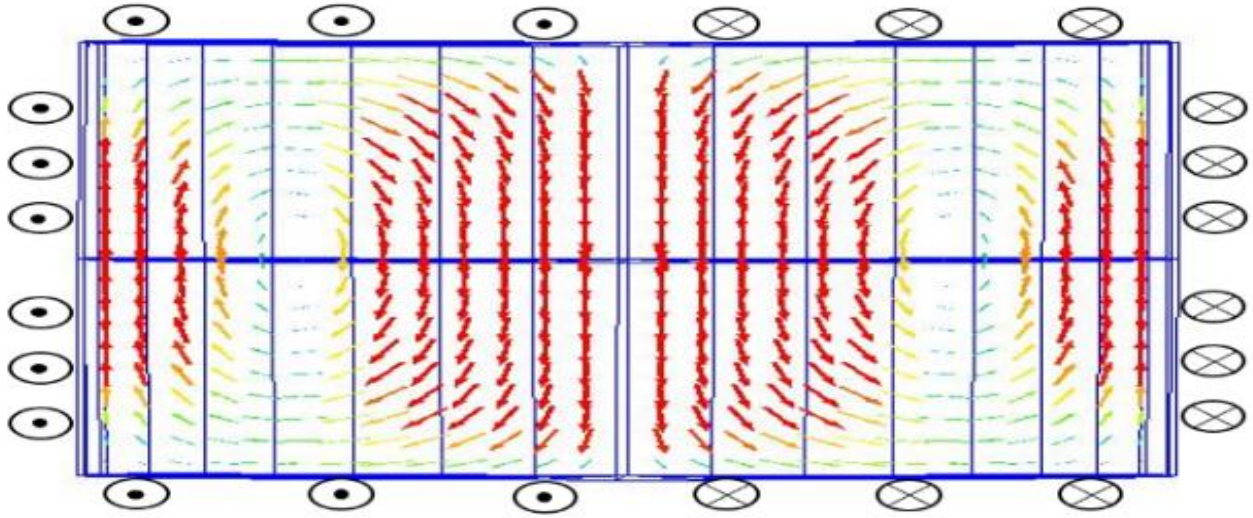
- Enhancements in SCR method mitigating known limitations

Split-Cylinder Resonator

- Simple geometrical configuration
- A slot for inserting a sample is made without causing radiation of the measurement mode
- Multimode structure
  - measurement disrupted by higher order modes
  - for higher sample thickness
  - for higher dielectric constant



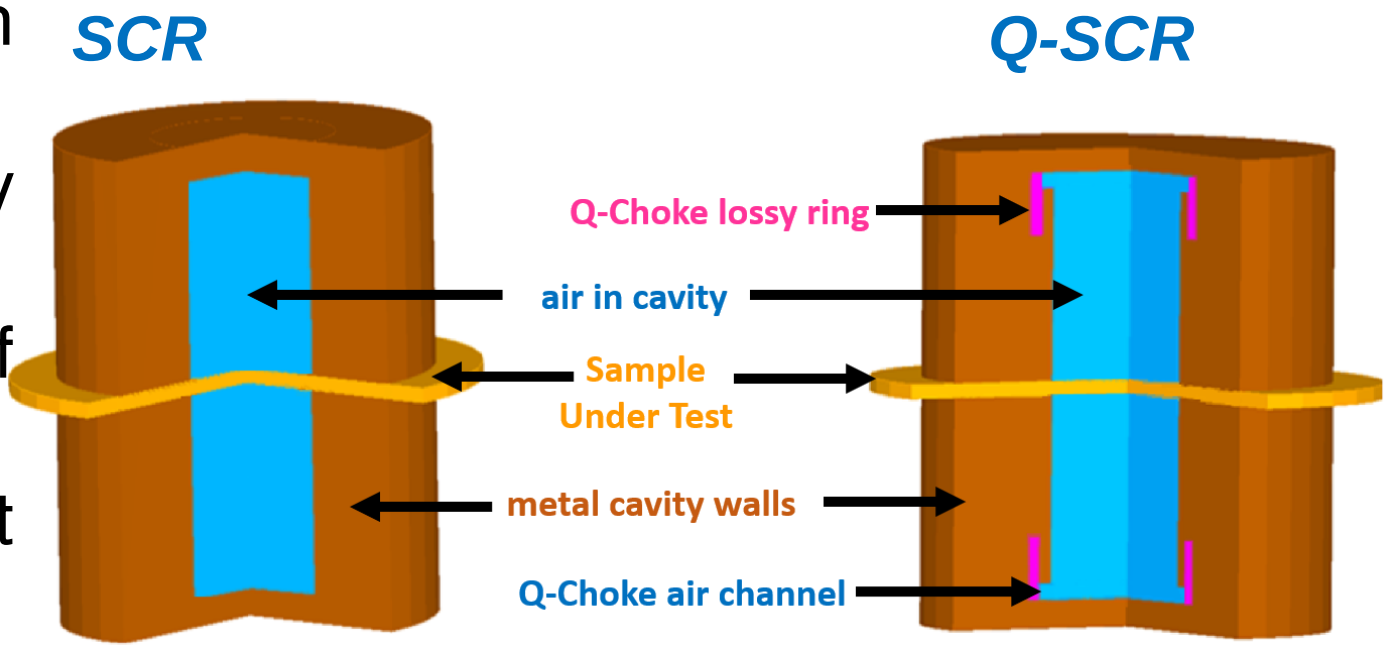
E - field



Vertical cross-section of the cavity with magnetic field lines and currents in the cavity walls, for the TE011 mode

Q-Choke concept

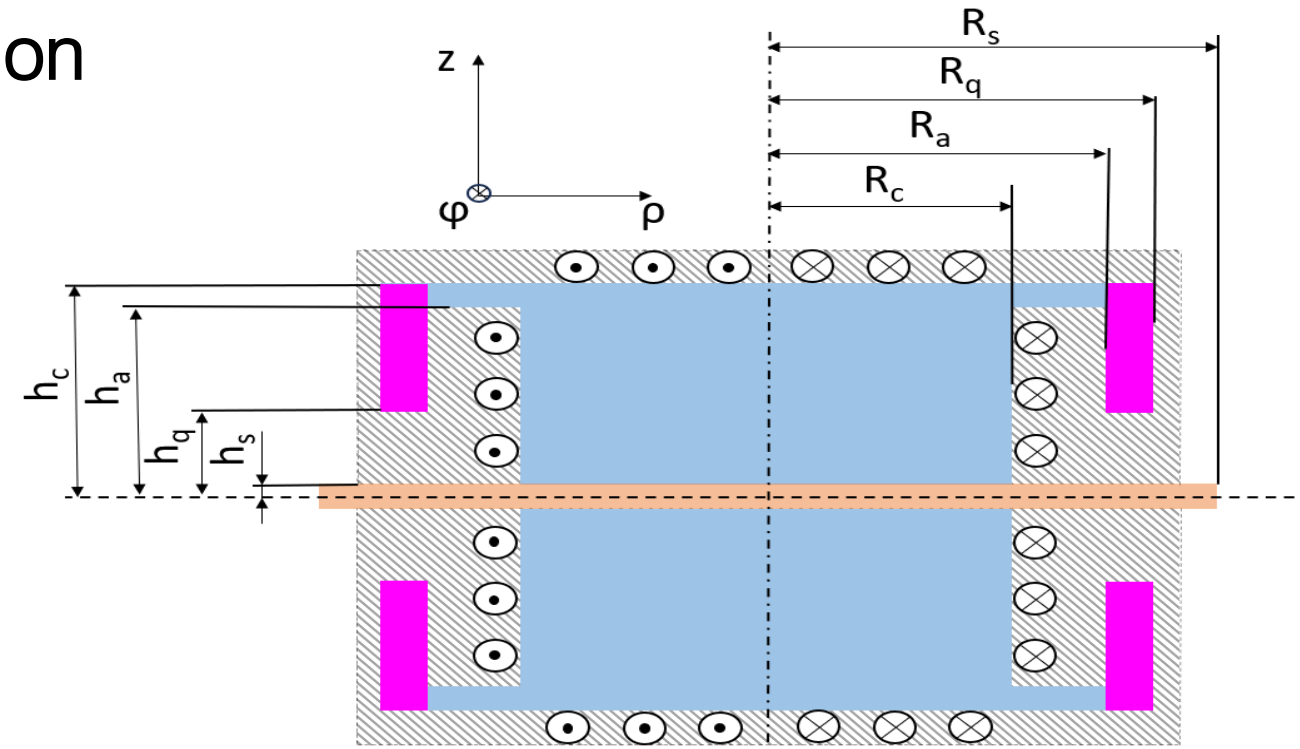
- Q-Choke
  - mitigating undesired modes in cylindrical cavity resonators
  - symmetric slots in the cavity walls,
  - close to top and bottom ends of the cavity
  - uniform disruption of current paths
- "transparent" to useful TE_{011} (TE_{0np}) modes
- selectively inhibits the propagation of unwanted modes (TE_{mnp} m>0 & TM modes



3D views (with 90 deg cut to show the interior)

Q-SCR Model

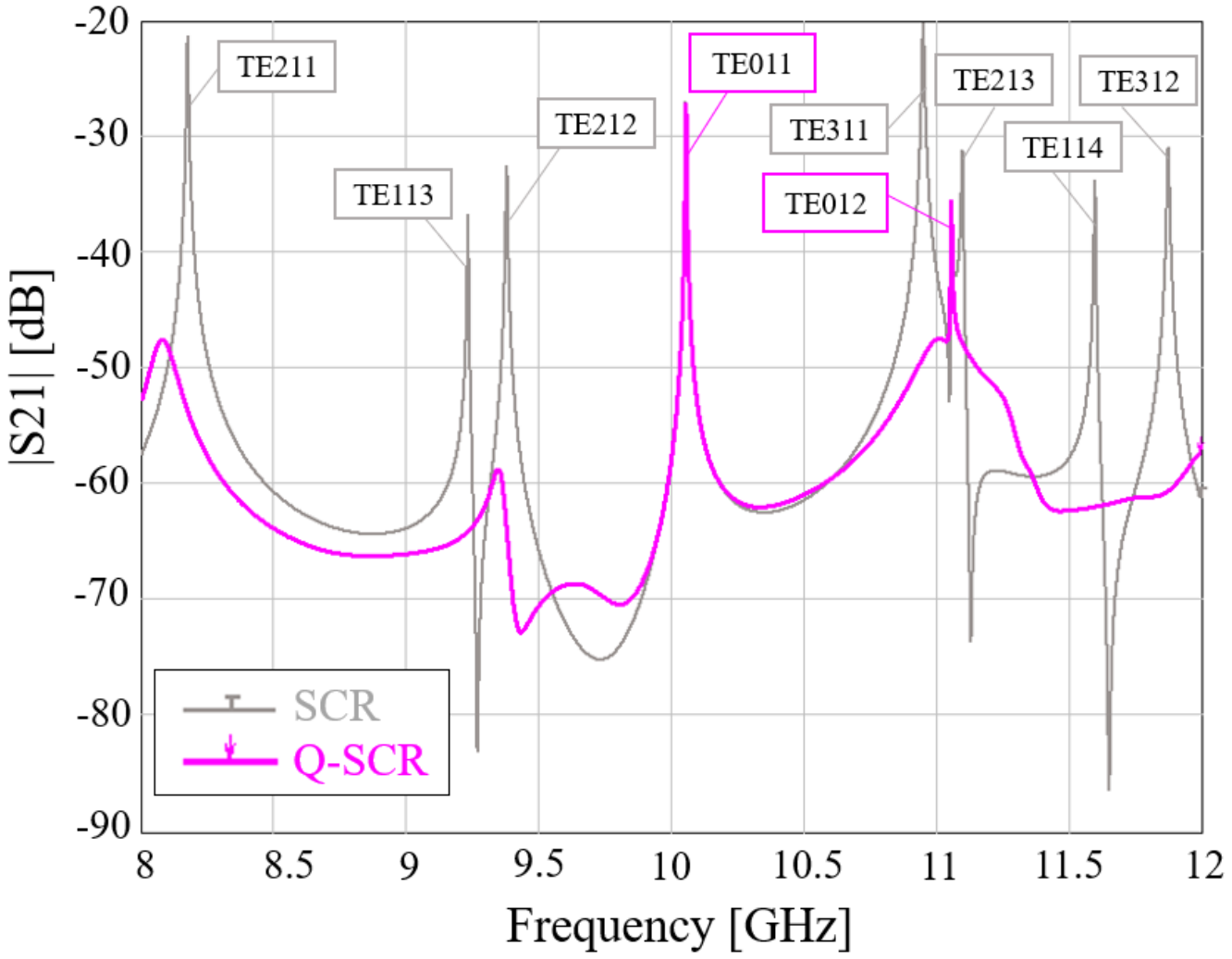
- 10 GHz Q-SCR is under investigation
  - Rc=18.85mm,
  - hc=28.2mm,
  - Ra=25mm,
  - ha=26.2mm,
  - Rq=28mm,
  - hq=10mm.
- Copper-made cavity
- Lossy rings for choke pockets - PLA Conductive 750g Capifil via 3D printing.



Vertical cross-section of Q-SCR (classical SCR if $h_a=h_c$).

Q-SCR – Simulation results

- Simulated transmission spectrum
- Classical SCR and new Q-SCR,
- Visible suppression of undesired modes by the Q-Choke.



Experimental validation

- Prototype of 10 GHz Q-SCR
- Keysight Streamline P5008B VNA
- Laptop with Dedicated Application

Measurement setup

- Single crystal material chosen as a test material – sapphire
- Five 2-inch ca. 400um-thick samples have been considered
- Sample thickness: 400 um – 2 mm

Measurement results (1)

Dielectric constant

Nb. of discs	H_s [mm]	ε_r	$\varepsilon_{r,av}$	$\varepsilon_{r,ref}$*	$\delta\varepsilon_r$ [%] wrt $\varepsilon_{r,av}$	$\delta\varepsilon_r$ [%] wrt $\varepsilon_{r,ref}$
1	0.404	9.407	9.403	9.3954	*0.043*	*0.123*
2	0.812	9.398			*-0.053*	*0.028*
3	1.219	9.415			*0.128*	*0.211*
4	1.625	9.401			*-0.021*	*0.060*
5	2.030	9.395			*-0.085*	*-0.004*

**J. Krupka, K. Derzakowski, A. Abramowicz, M. E. Tobar, and R. Geyer, "Use of whispering-gallery modes for complex permittivity determinations of ultra-low-loss dielectric materials", IEEE Trans. Microw. Theory Tech., vol 47, no. 6, pp. 752-759, June 1999.*

Measurement results (2)

Dielectric loss

Nb. of discs	H_s [mm]	$\tan\delta_s$	$\tan\delta_{ref}$ *	$\delta\tan\delta_s$ wrt $\tan\delta_{ref}$
1	0.404	$1.37\cdot10^{-5}$	$1.21\cdot10^{-5}$	$0.16\cdot10^{-5}$
2	0.812	$1.89\cdot10^{-5}$		$0.68\cdot10^{-5}$
3	1.219	$1.83\cdot10^{-5}$		$0.62\cdot10^{-5}$
4	1.625	$1.93\cdot10^{-5}$		$0.72\cdot10^{-5}$
5	2.030	$1.9\cdot10^{-5}$		$0.69\cdot10^{-5}$

** Single sapphire wafer measured with commercial SPDR 10GHz fixture*

Other results

	Q-SCR 10GHz		SPDR 10GHz	
	*Dielectric constant**	*Loss tangent*	*Dielectric constant**	*Loss tangent*
COP 189um	2.345 ± 0.014	$2.84 \cdot 10^{-4} \pm 2 \cdot 10^{-5}$	2.342 ± 0.018	$2.98 \cdot 10^{-4} \pm 2 \cdot 10^{-5}$
Fused silica 800um	3.808 ± 0.008	$8.99 \cdot 10^{-5} \pm 2 \cdot 10^{-5}$	3.804 ± 0.007	$9.25 \cdot 10^{-5} \pm 2 \cdot 10^{-5}$
Quartz 2mm	4.447 ± 0.004	$1.80 \cdot 10^{-5} \pm 2 \cdot 10^{-5}$	N/A	
Alumina 500um	9.123 ± 0.020	$5.37 \cdot 10^{-3} \pm 2\%$	9.121 ± 0.030	$5.40 \cdot 10^{-3} \pm 2\%$

** Uncertainty bounds due to thickness variation*

Conclusions

- Innovative Q-Choked Resonators (Q SCRs) for Microwave Measurements:
  - thick material samples with arbitrary permittivity
  - verified through computational modeling
  - 10 GHz Q SCR prototype designed and manufactured.
- Validation and Performance:
  - stacks of sapphire samples up to 2 mm thick were measured
  - exceeding declared thickness limitations of commercially available SCRs by over a factor of 8.
  - measured Dk and Df in excellent agreement with reference data and own SPDR measurements.
- Future Prospects:
  - a series of Q SCRs for mmWave frequencies
  - using higher order modes
  - application to real life materials: automotive bumper plaques, semiconductor wafers, glass panes, vacuum windows, etc.

Acknowledgment

This work was supported by the Polish National Centre for Research and Development

under M-ERA.NET program: ULTCC6G_EPac and I4BAGS projects

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

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

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

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

and under EUREKA-Eurostars 5G_Foil project under contracts DWM/InnovativeSMEs/176/2023

Thank you for your attention!