Application of Dual-Mode Ruby Dielectric Resonator for Characterization of Copper Foils in High-Frequency Circuits

Lukasz Nowicki, e-mail: lukasznowicki@qwed.eu
Tomasz Nalecz, e-mail: tomasznalecz@qwed.eu
Malgorzata Celuch, e-mail: mceluch@qwed.eu
Thomas Devahif, e-mail: thomas.devahif@circuitfoil.com
Janusz Rudnicki, e-mail: jrudnicki@qwed.eu

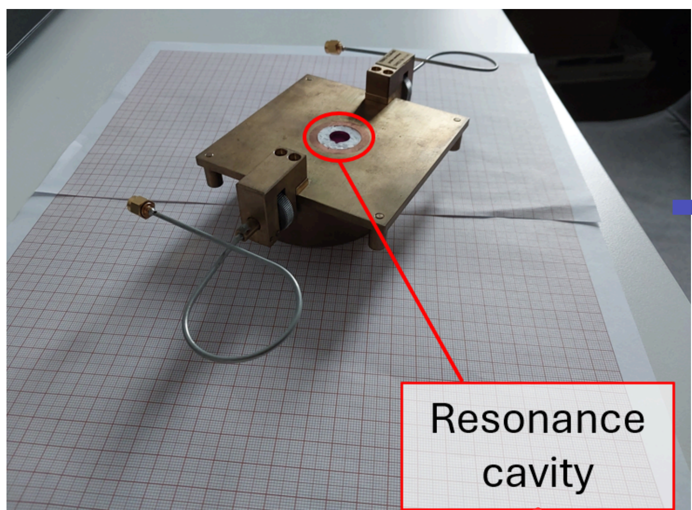
Head Office/Postal Address
QWED Sp. z o.o.
ul. Krzywickiego 12/1
02-078 Warsaw, POLAND

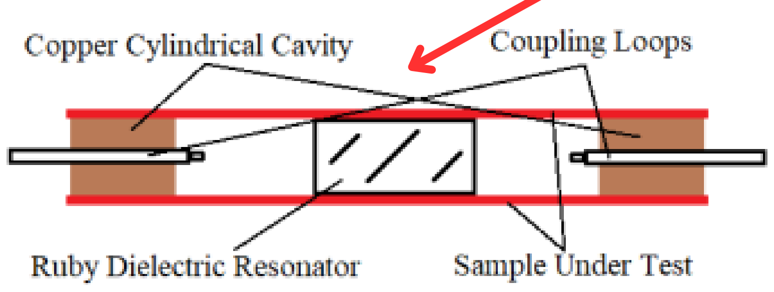
Head Office/Postal Address
6 Salzbaach,
9559 Wiltz,
Grand Duchy of Luxembourg

Abstract: Achieving high electrical performance in mmWave PCBs often compromises copper foil reliability. This study introduces a novel measurement approach using Ruby Dielectric Resonators (RuDR) operating at 13 GHz and 21 GHz to assess copper foil conductivity without substrate interference. By focusing on direct loss measurements, these resonators provide accurate data on the effects of surface roughness on foil performance, crucial for 5G applications. The RuDR resonator, used in this study, highlights a decreasing exponential relationship between conductivity and surface roughness, confirming the significance of surface texture. The findings guide the development of high-performance materials for next generation mmWave technologies.

Dual-Mode Ruby Dielectric Resonator - Measurement

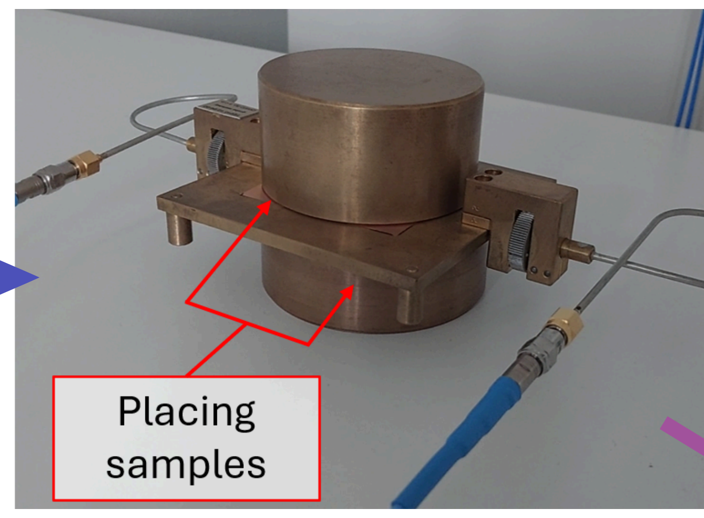
Ruby Dielectric Resonator RuDR

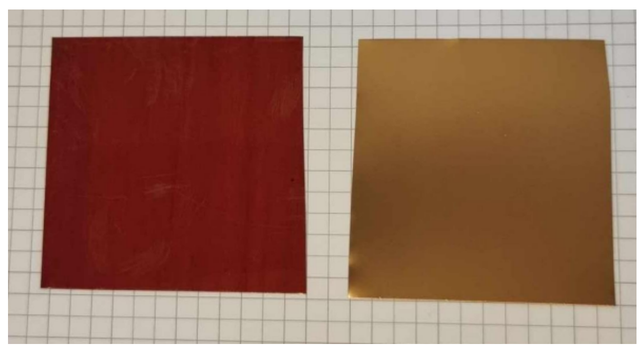




Cross-section of the resonance cavity

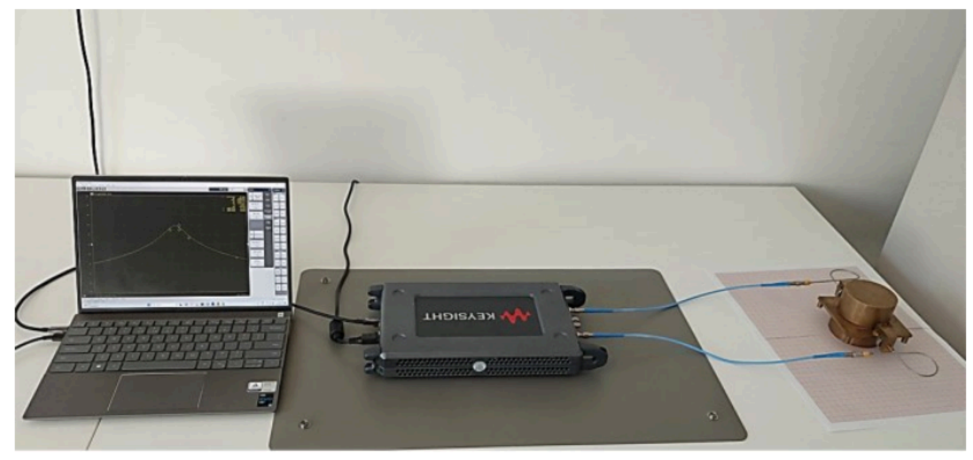
Placement of samples

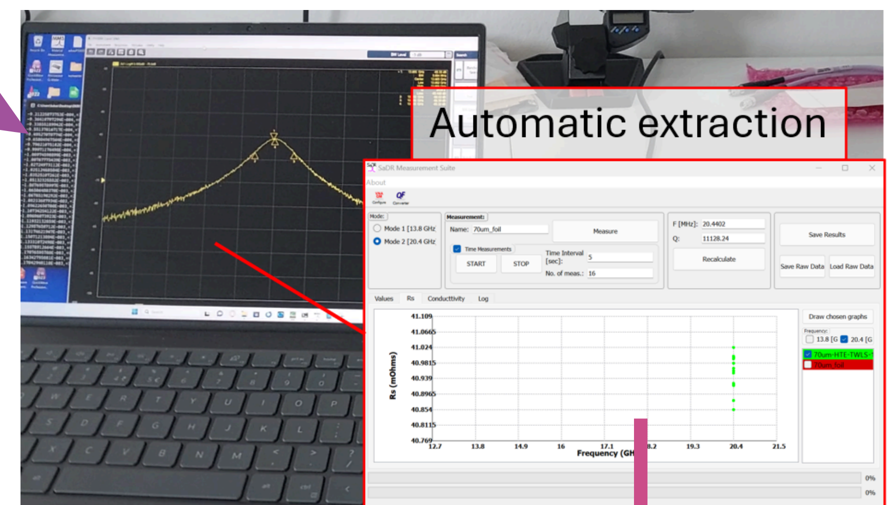




Example of two sides of the same sample

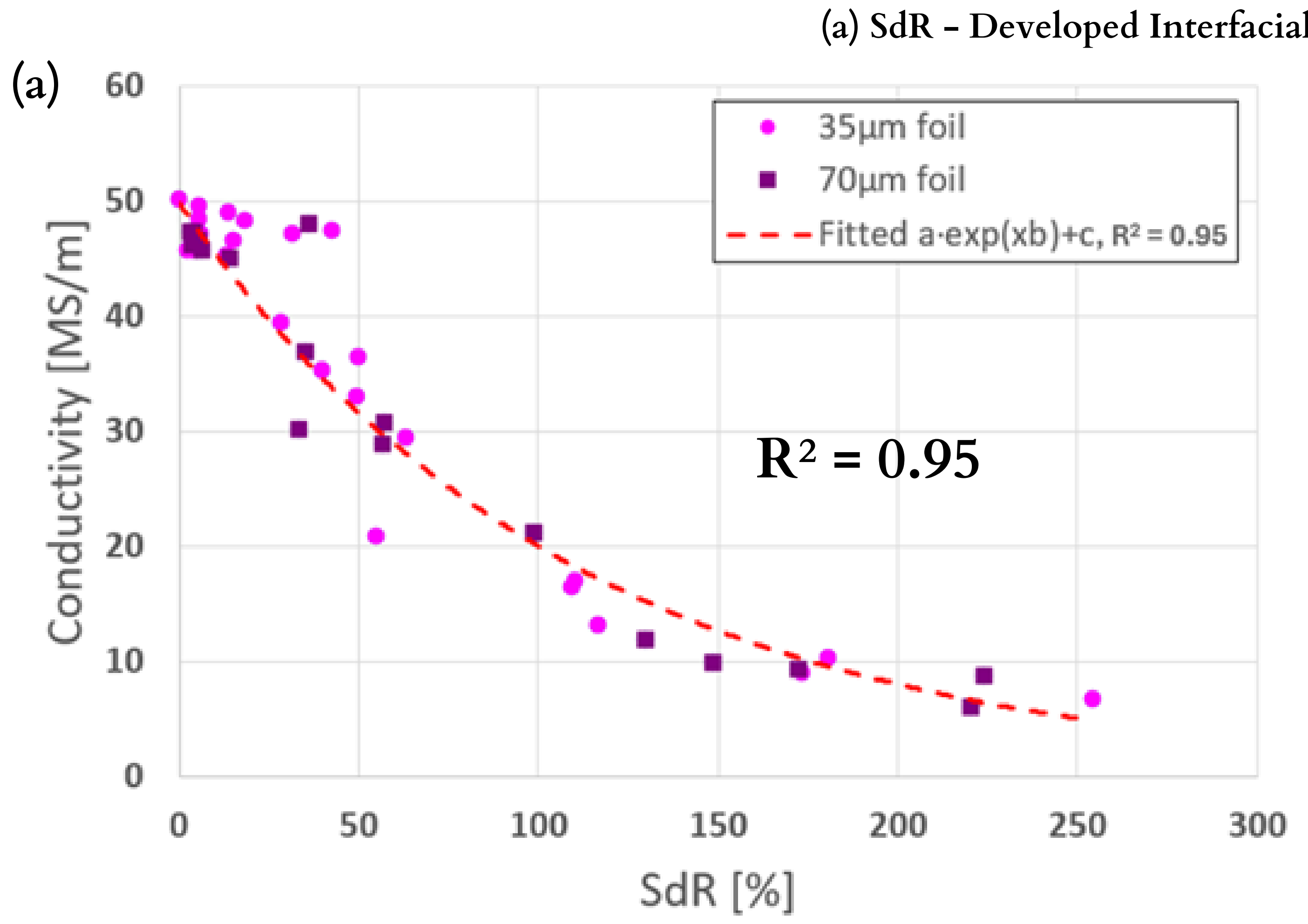
Dual mode RuDR measurement setup which also includes VNA and laptop with dedicated software.

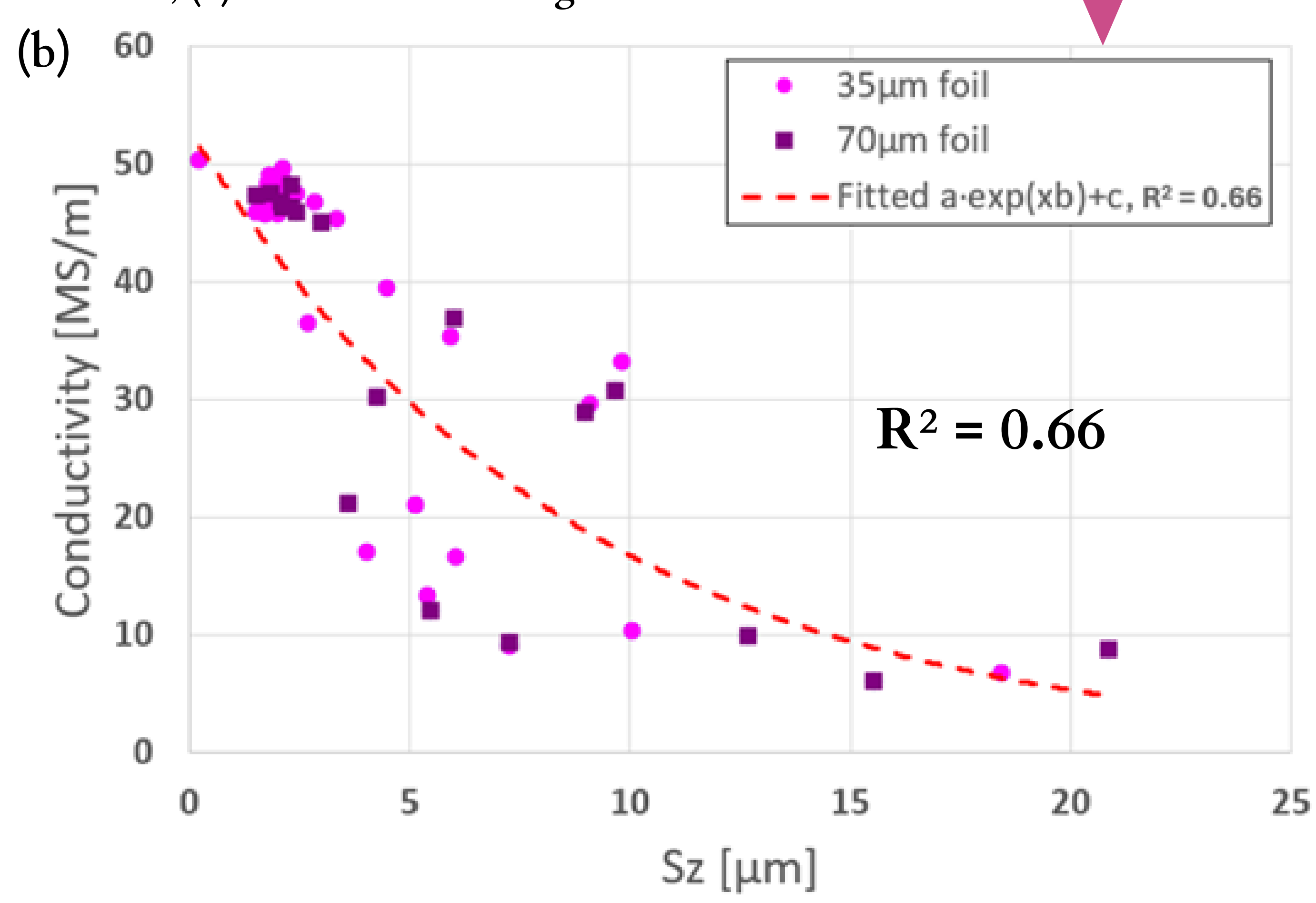




24 types of foils
-> 72 samples

Correlation between effective conductivity σ (measured at 21 GHz in the RuDR test-fixture and surface roughness parameters: (a) SdR - Developed Interfacial Area Ratio, (b) Sz - Maximum Height





Research Overview

Study Overview:

- 72 samples: 24 foil types
- 3 sheets per type, cut to **60 x 60 mm.**
- Foils measured for conductivity σ using a RuDR at 21 GHz.

Industrial Copper Foils:

- Manufactured by Circuit Foil Luxembourg.
- Two thicknesses: **35** *µm* and **70** *µm*.
- Characterized by roughness parameters *Sz, Sa, Sdr* using laser interferometry.

Measurement Process:

- Two identical samples from each foil sheet.
- Samples mounted in a cylindrical ruby resonator and tested with a VNA.
- Conductivity values derived from Q-factor and resonance frequency via full-wave modeling.
- 16 repeated measurements, every 5 seconds (averaged values shown in the graphs).

Key Findings:

- Exponential relationship: Conductivity σ decreases as surface roughness *Rs* increases.
- Thickness does not affect conductivity.
- Factors like grain size may also influence conductivity (investigated in the 5GFoil project).

Conclusions

The RuDR method effectively characterizes copper foils for microwave and mmWave PCBs, offering precise conductivity σ and surface resistance *Rs* measurements without substrate interference. Operating at 13.8 GHz and 20.4 GHz, it highlights an exponential correlation between conductivity and surface roughness, with *SdR* being the most representative parameter **(R^2 = 0.97 at 13 GHz and R^2 = 0.95 at 20.4 GHz).** While surface roughness strongly influences conductivity, additional factors like grain size also play a role. The method is scalable and practical, supporting advancements in 5G and mmWave PCB materials. Further research will explore additional manufacturing parameters influencing conductivity.

ACKNOWLEDGEMENT

This work is performed within the EUREKA-Eurostars project 5G_Foil and co-funded by the Polish National Centre for Research and Development under contract InnovativeSMEs/4/100/5G_Foil/2023 and by the Ministry of Economy, Luxembourg, under contract 2023-A127-X187.

National Centre for Research and Development
THE GOVERNMENT OF THE GRAND-DUCHY OF LUXEMBOURG
Ministry of Finance