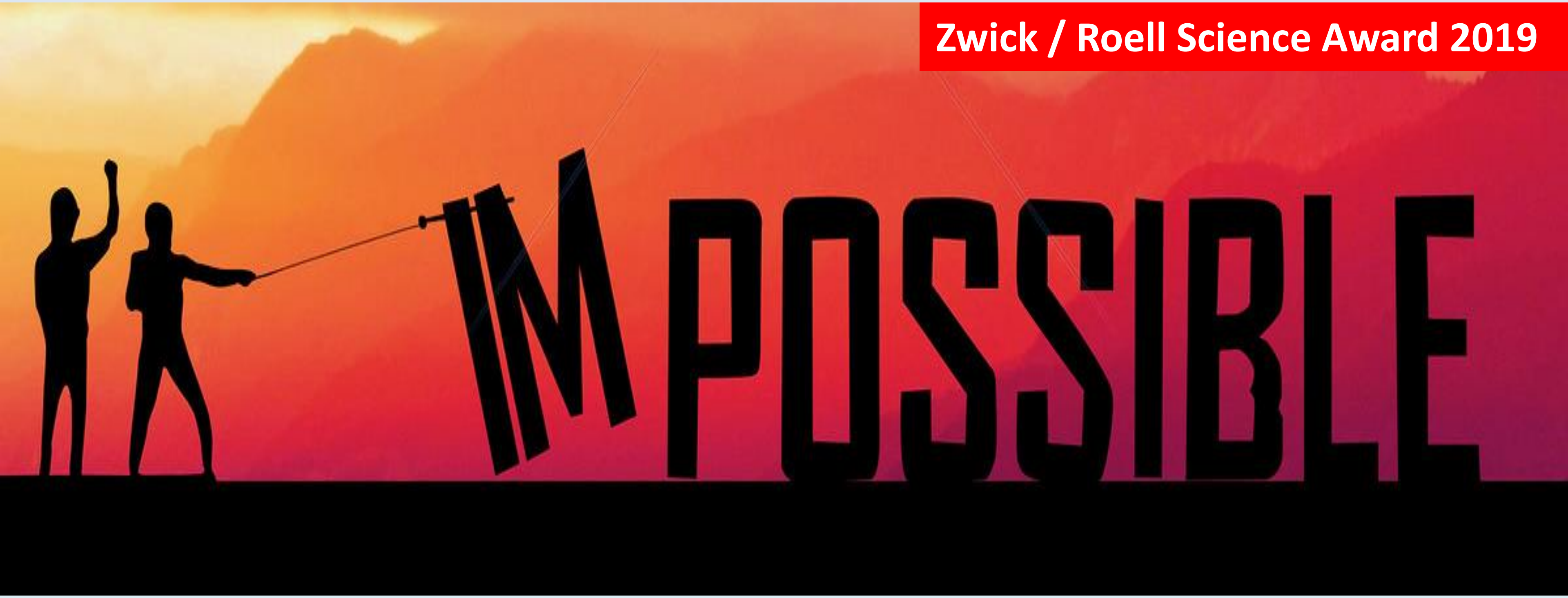
Integration of microwave and mechanical stress measurements:

NEW POSSIBILITIES FOR EXPERIMENTALISTS AND MANUFACTURERS

Zwick / Roell Science Award 2019



Yujie Zhao, Yunfei Wang, Huan Wang, Xuefei Zheng, Faxiang Qin, Dmitriy Makhnovskiy and Huaxin Peng

浙江大學
ZHEJIANG UNIVERSITY

功能复合材料与结构研究所
Institute for Composites Science Innovation

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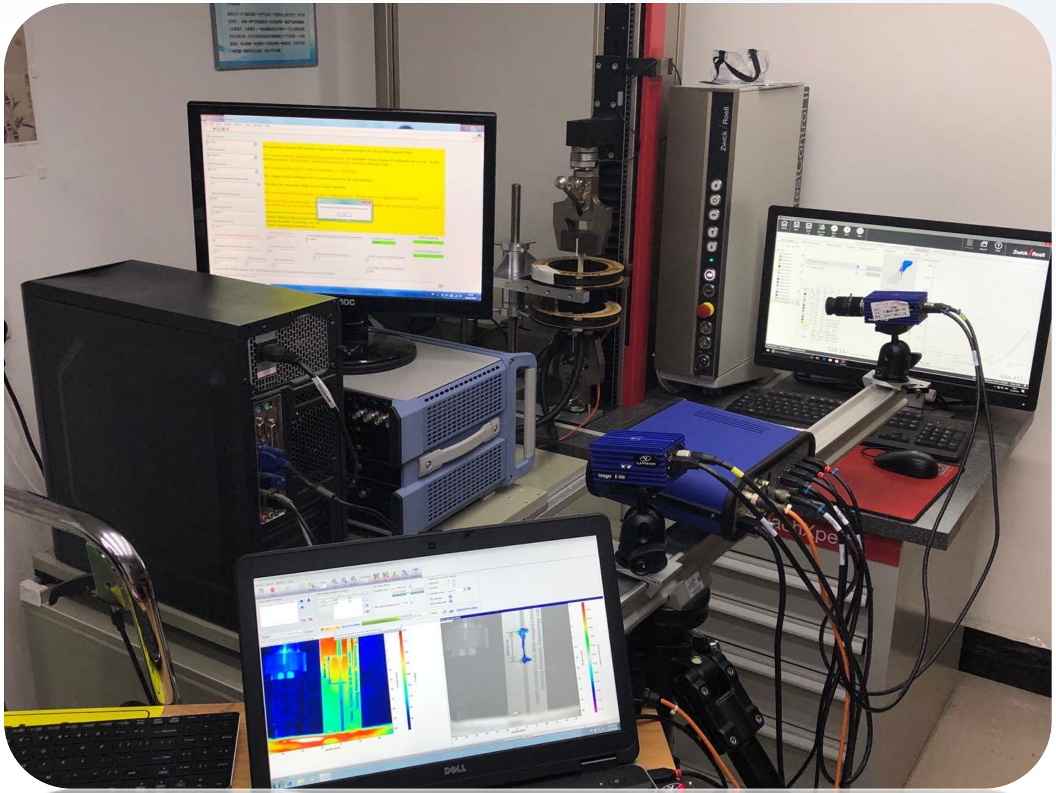
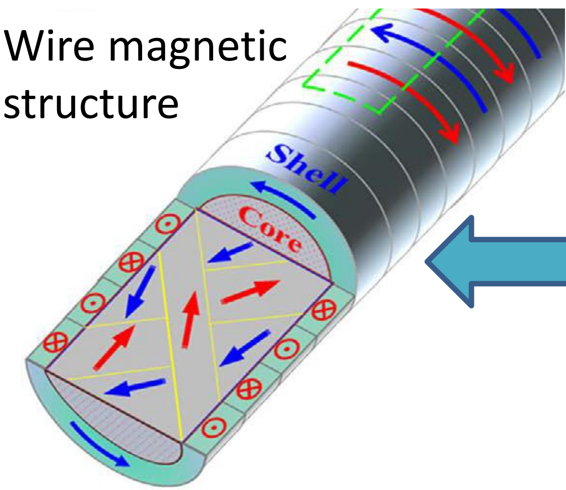


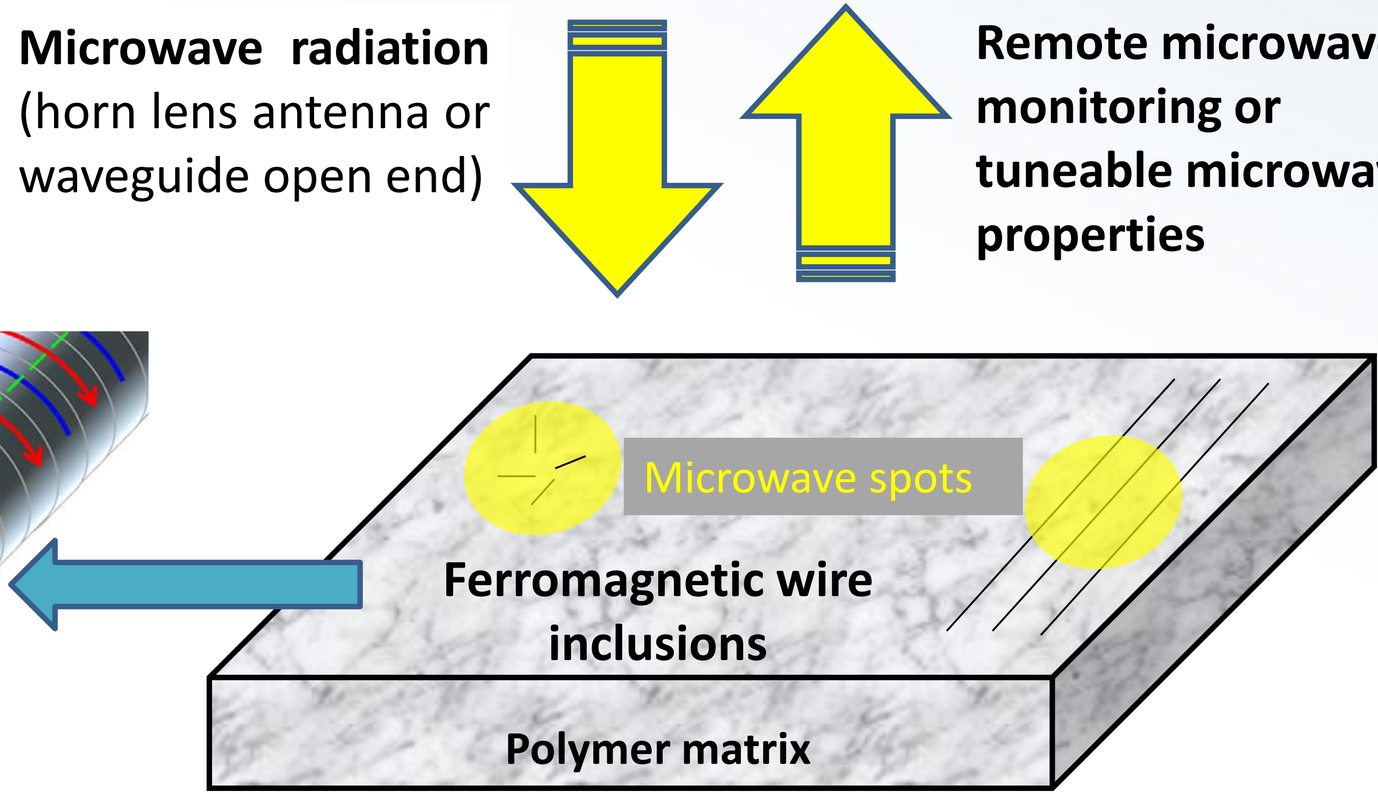
• What — composites with wire inclusions

Microwave radiation (horn lens antenna or waveguide open end)

Remote microwave monitoring or tuneable microwave properties

Wire magnetic structure





External stimuli: magnetic field, mechanical stress, and temperature

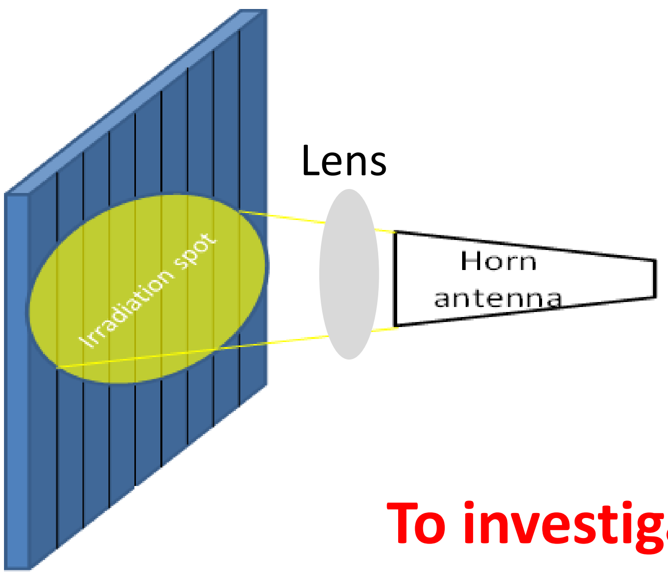
• Why—non-destructive evaluation technique

Antenna equation:

$$\frac{d^2}{dz^2}(G*j)+k^2(G*j)=\frac{i\omega\varepsilon}{4\pi}\bar{e}_z(z)-\frac{i\omega\varepsilon\zeta_{zz}}{2\pi ac}(G_\phi*j)$$

Current density induced by microwave radiation

Surface impedance



Surface impedance: material parameter which includes both conductive and magnetic properties of the wire inclusion, **changing with external stimuli.**

To investigate how microwave responses to external stress stimuli

• Why—non-destructive evaluation technique

Modelling vs Measuring

Modelling

? ?

- Complicated magnetic domain structure
- Existing models are not sufficiently accurate for microwave scattering properties of composite structures

Measuring

√ √

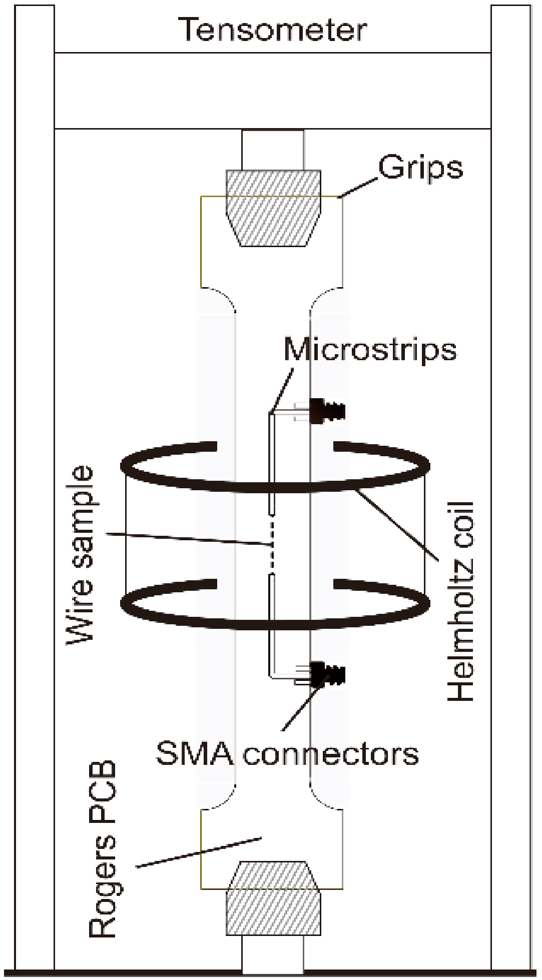
- Broad frequency range calibration and measurement technique
- Recalculation into surface impedance by

$$\zeta_{zz}(\omega, H, \sigma) = 10^{9} aZ(\omega, H, \sigma)/(2cl)$$

$$\sigma - \text{stress},\ H - \text{magnetic field}$$

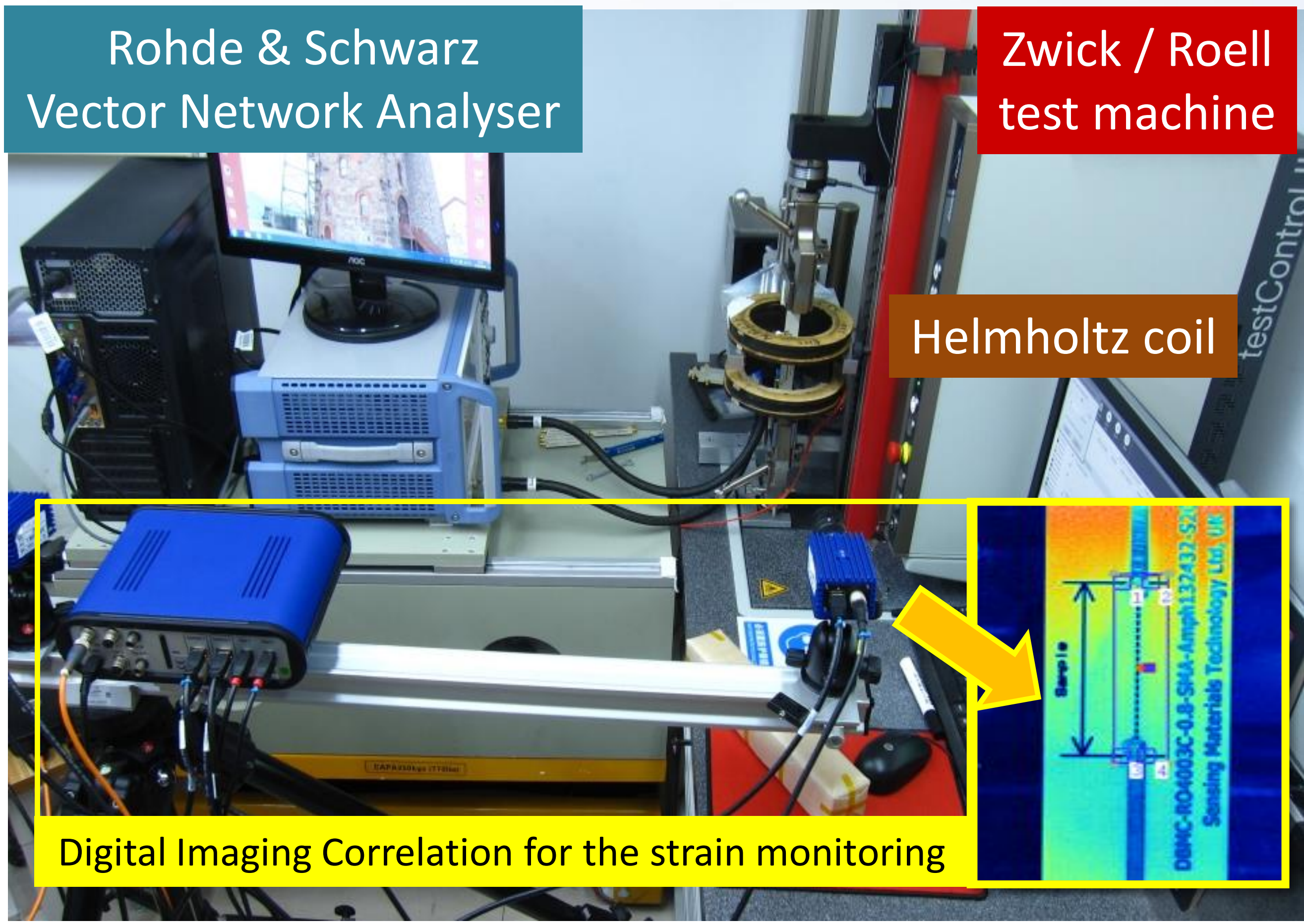
- Develop scattering theory based on the antenna equation

• How—measurement system



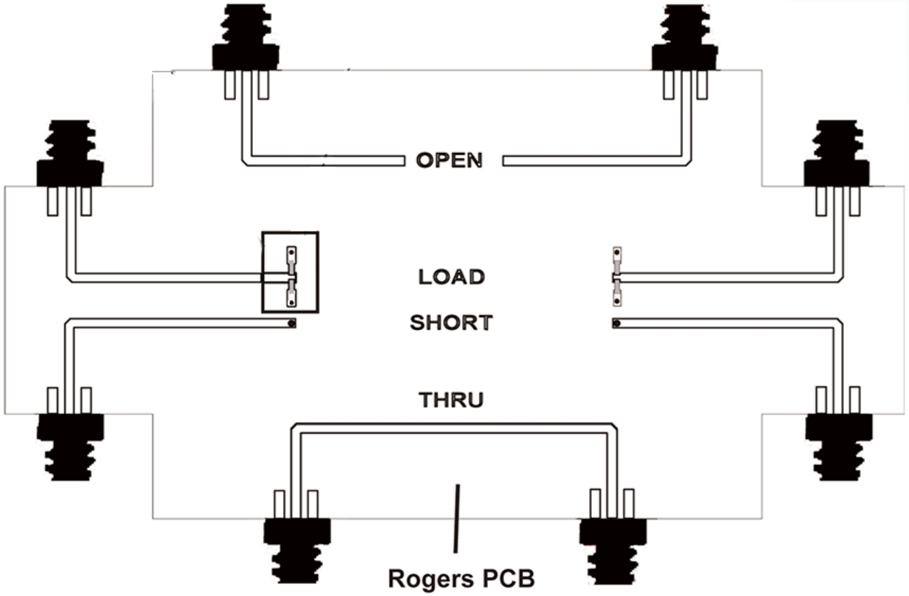
Dog-bone sample cell

Broadband impedance measurements
in the presence of tensile stress

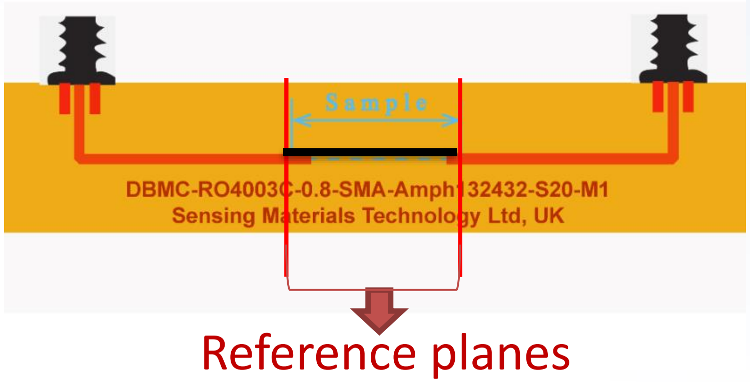


• How— RF calibration technique

1. SOLT calibration technique



SOLT calibration kit



SOLT calibration can extend the reference plane to the front of microwire, eliminating phase and amplitude distortions caused by the cables and microstrips.

• How— RF calibration technique

2. Phase compensation

$$S_{21M}(\omega, H) = A(\omega, H)\exp(i(\gamma(\omega, H) - \omega\Delta t))$$

Phase distortion caused by the delay time Δt due to the wire waveguide properties

$$S_{21\text{refined}}(\omega, H, \sigma) = \frac{S_{21\text{measured}}(\omega, H, \sigma)}{\exp(-i\omega\Delta t)} \text{ – free of any distortions}$$

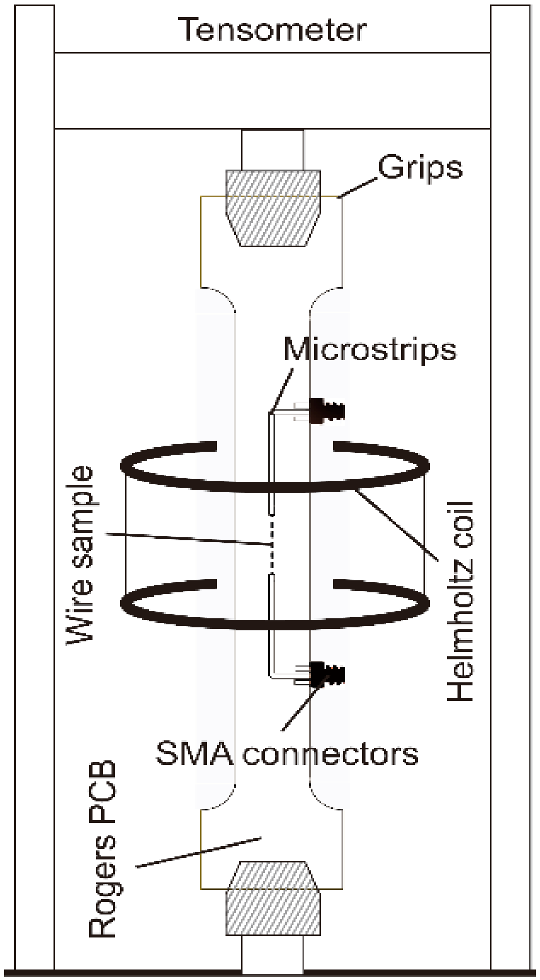
$$Z(\omega, H, \sigma) = \frac{100 \times (1 - S_{21\text{refined}}(\omega, H, \sigma))}{S_{21\text{refined}}(\omega, H, \sigma)} \text{ – impedance free of any distortions}$$

$$\zeta_{zz}(\omega, H, \sigma) \Rightarrow \frac{d^2}{dz^2}(G * j) + k^2(G * j) = \frac{i\omega\varepsilon}{4\pi}\bar{e}_z - \frac{i\omega\varepsilon\zeta_{zz}}{2\pi ac}(G_\phi * j)$$

microwave-stress correlation !!!

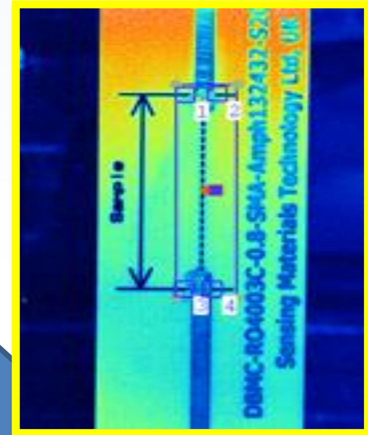
• How—automatic measurement system

Stress control



Dog-bone sample cell

“Strain” paused. Impedance measurements for different bias fields



Impedance measurement and strain monitoring

Grasp strain via DIC

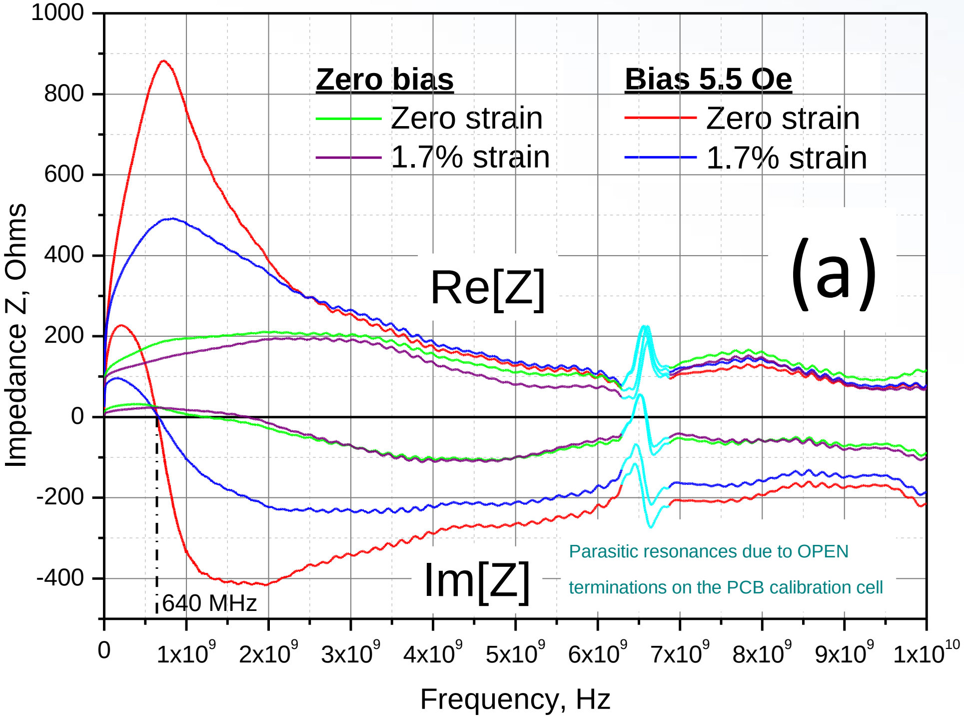
Field loop

VNA measures S21-parameter over discrete frequency points ranging from 100kHz to 15GHz

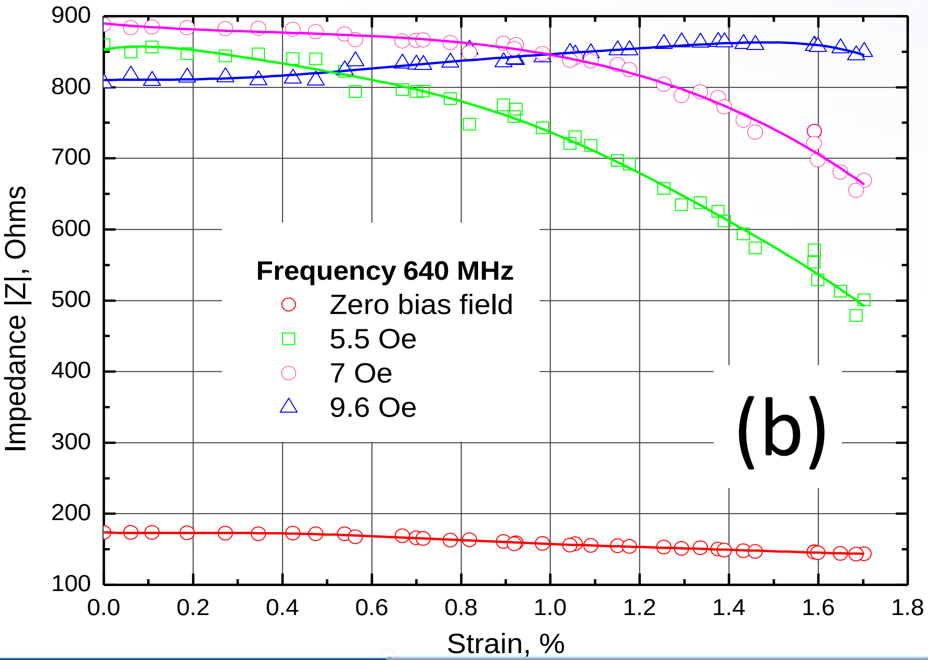
Z is calculated from S21-parameter by LabVIEW program

Bias fields are applied by coil

Broadband magneto- and stress-impedance measurements



For 640 MHz (ferromagnetic resonance) and bias field 5.5 Oe, microwire impedance shows the largest strain sensitivity (≈ 40 %).

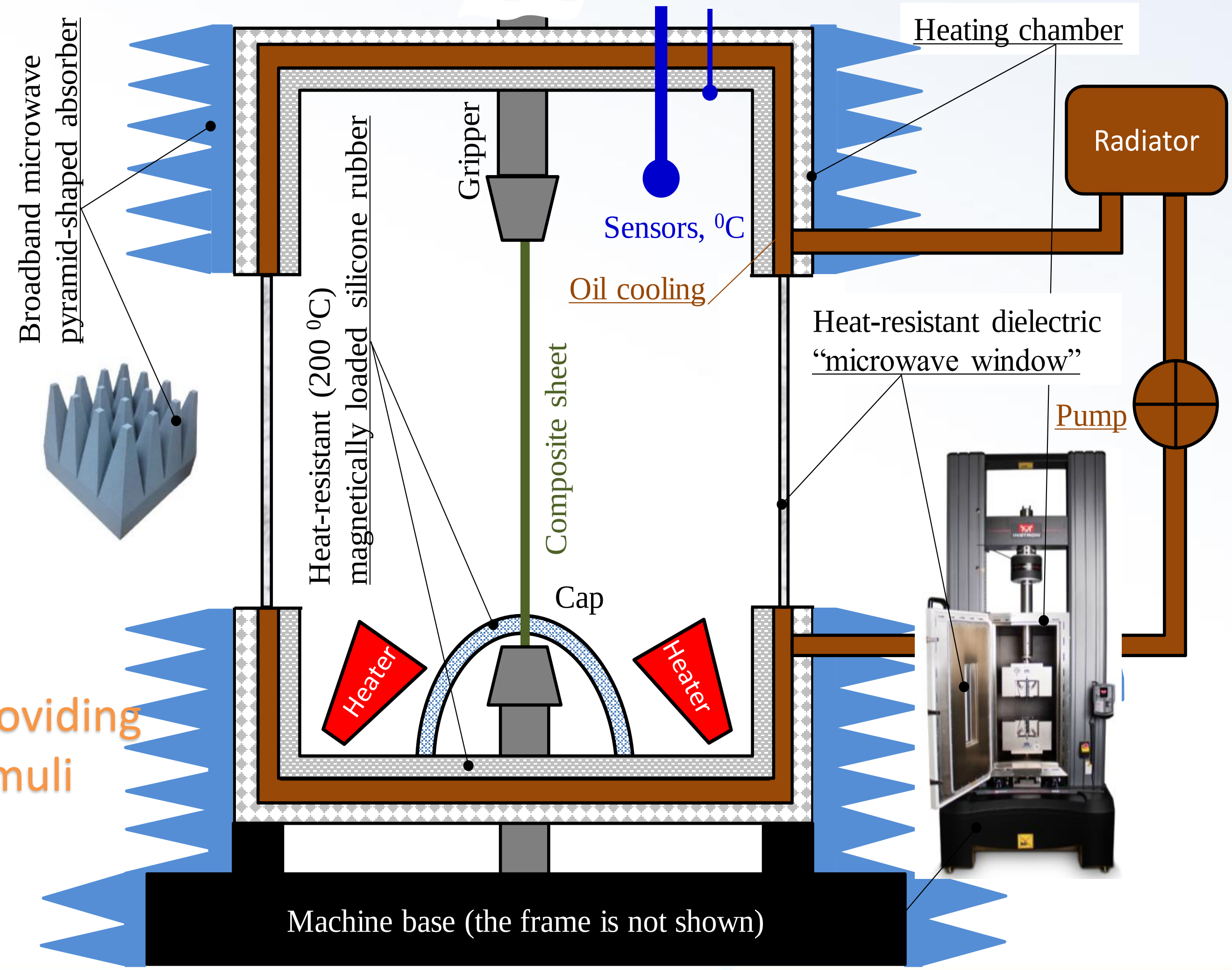


$\Delta Z \approx 450\ \Omega$ for bias field 5.5 Oe

• Beyond—Integration of microwave measurements with multi-stimuli

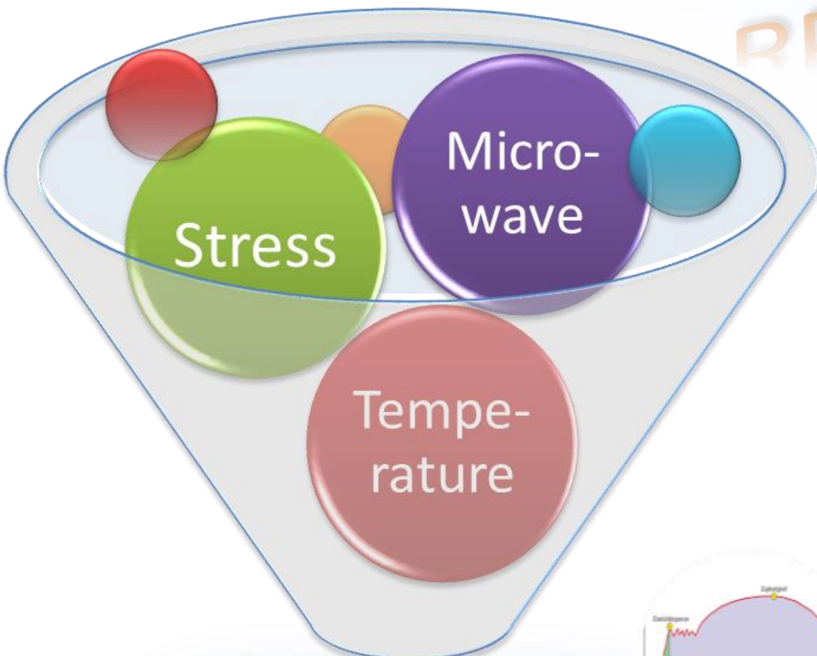
Microwave in

Microwave out



Measurement chamber providing stress and temperature stimuli

Industry and academia cooperation



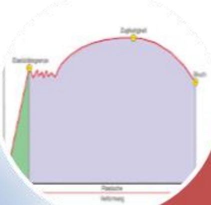
Integrated test platform

BEYOND

Zwick Roell

Commercial integrated test systems

Bespoke designs to fit experimental requirements



Basic mechanical property tests

Thank you

With best wishes from Hangzhou