2D imaging technique for quantitative and qualitative characterisation of high-resistivity GaN semiconductor wafers for light and power electronics

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Overview

- Motivation
- 2D scanner for materials testing
- Materials under test
- 2D imaging results
- Summary

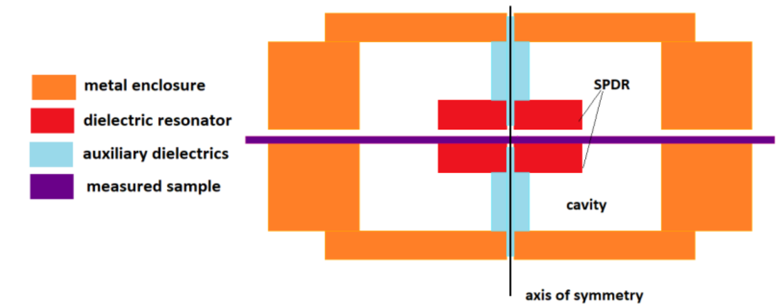
Motivation

- ❑ High homogeneity of GaN templates required for light and power electronics
- ❑ Heteroepitaxial growth on foreign substrates → the risk of lattice mismatch
  - ❑ lower structural and electrical quality of the device
- ❑ Single-point measurement.
- ❑ Surface imaging for detection of variability of properties across the wafer
  - ❑ for increasing packaging efficiency
  - ❑ for assuring high quality, repeatability, and reproducibility of operation parameters of final devices

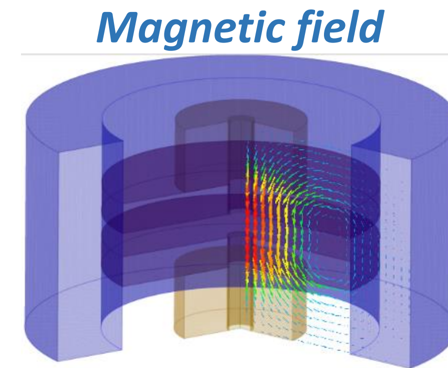
- ❑ Automatic 2D SPDR scanner applied for evaluation of homogeneity of GaN templates for power electronics.
- ❑ Joint qualitative and quantitative measures of semiconductor characterisation.

2D SPDR scanner for materials testing (1)

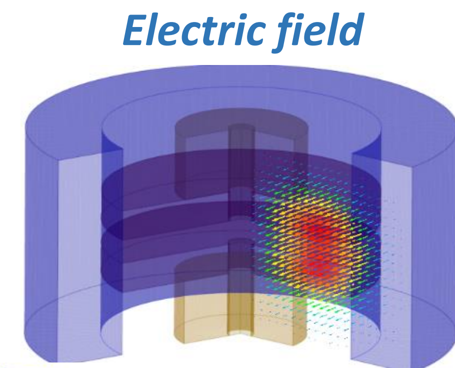
- Based on Split-Post Dielectric Resonator (SPDR) [1]
- Resonant mode with EM fields mostly confined in and between those ceramic posts
- H-field is only vertical at the side wall of the enclosure
- E-field tangential to SUT
- easy SUT insertion through slot
- Non-destructive measurement
- Field patterns remain practically unchanged
- Resonant frequencies and Q-factors change, upon SUT insertion

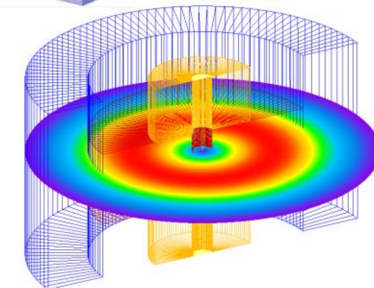


Magnetic field



Electric field



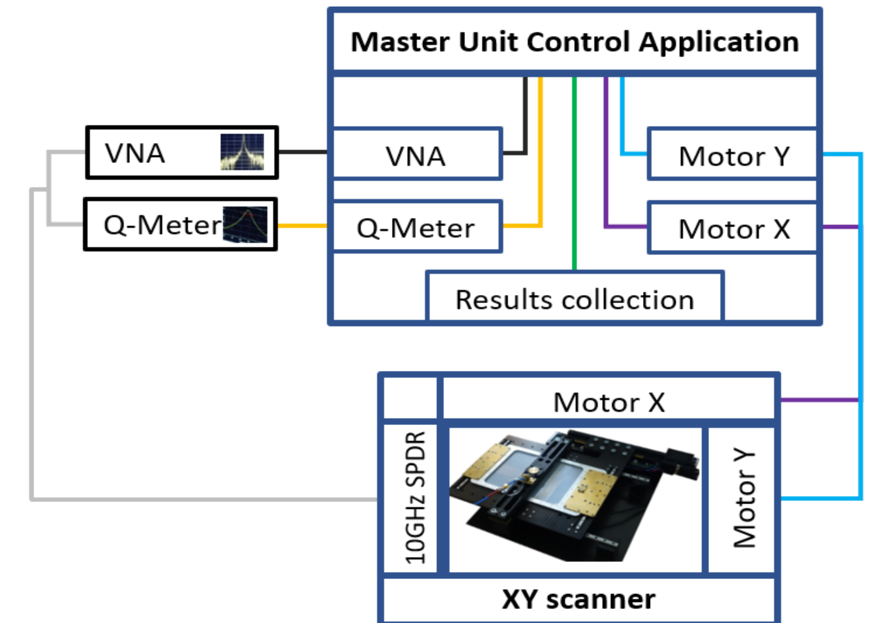


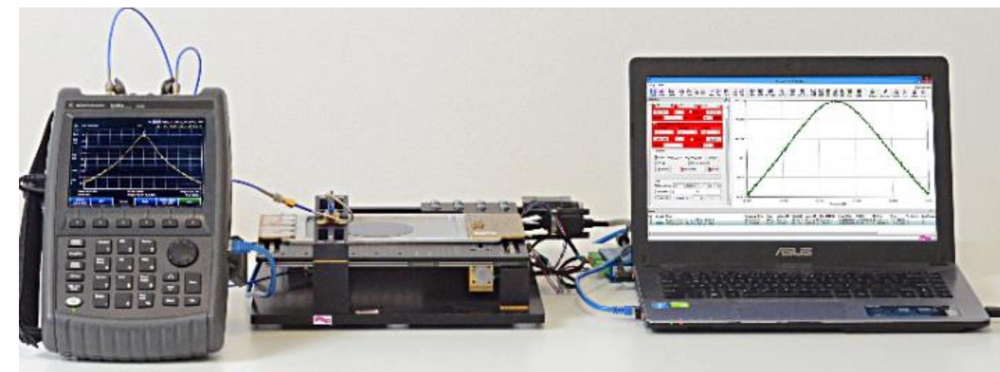
[1] J. Krupka, A. P. Gregory, O. C. Rochard, R. N. Clarke, B. Riddle, and J. Baker-Jarvis, "Uncertainty of complex permittivity measurements by split-post dielectric resonator technique", J. Eur. Ceramic Soc., vol. 21, pp. 2673-2676, 2001.

2D SPDR scanner for materials testing (2)

- 2D SPDR scanner operating at 10GHz – compromise between sample thickness and raw lateral resolution
- XY-motorized table (Standa and Nanotec motors)
- Movement resolution as low as 5 μm
- SUT placed on a Teflon foil (stable and intact)
- Positioning and measurement controlled and invoked with dedicated *Master Unit Control Application* (PC app)
- Microwave measurement (resonance frequency and Q-factor) performed over a grid of points across SUT surface
- Extracted parameters' values aggregated into 2D maps of Dk, Df, and resistivity

Schematic of the measurement setup



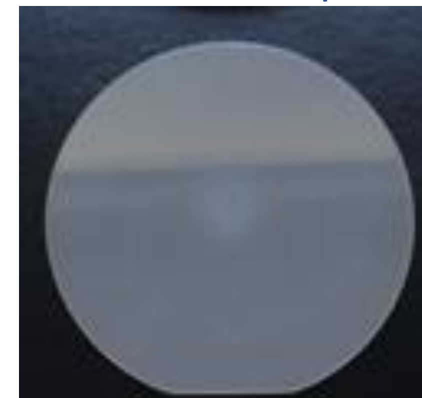


Materials under test

- Two test samples: sapphire substrate and HR-GaN
- Epitaxial structure of HR-GaN:
  - 750 nm AlN layer
  - 1.5 µm GaN layer on the top
- HR-GaN growth:
  - 2” SSP (0001)-oriented Al_2O_3 substrate
  - low-pressure metal-organic vapour phase epitaxy reactor (LP MOVPE)
  - three types of precursors: trimethylaluminium (TMAl), trimethylgallium (TMGa), and ammonia (NH_3)
  - carrier gas: hydrogen (H_2)
  - epitaxial growth temperature: ca. 1000 °C
  - epitaxial growth pressure: 200 mbar
  - in situ control of thickness and quality of layers (emissivity corrected pyrometry)

Sapphire substrate

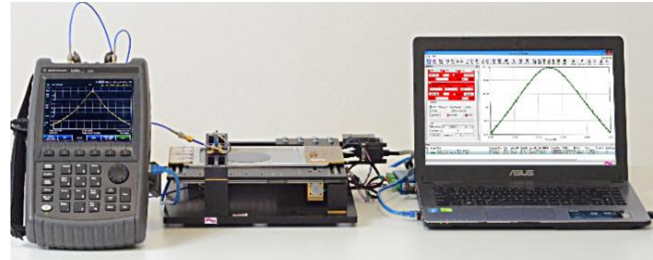
HR-GaN sample



2D imaging results

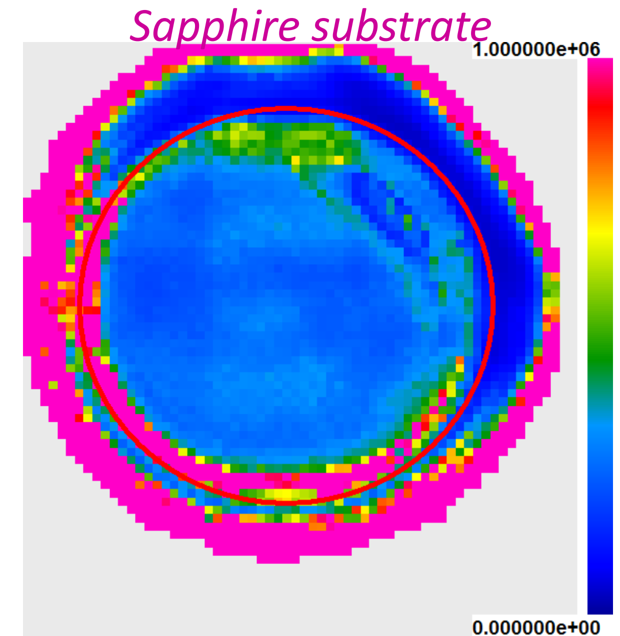
- Scanning area: 70 mm x 70 mm
- Uniform scanning step: 1 mm
- 5112 measurement points
- Resistivity maps
- Sapphire: 2.5-3 $\cdot 10^5$ Ωcm
- HR-GaN template:
  - edge ring inherent to so-called edge effect
  - ca. $2 \cdot 10^4$ Ωcm in the centre (dark blue),
  - ca. $5 \cdot 10^4$ Ωcm along the inner ring (light blue)
  - up to 1.2 – 3 $\cdot 10^5$ Ωcm across outer SUT's area (blue-green).
- Quantitative and qualitative measures

2D imaging measurement setup

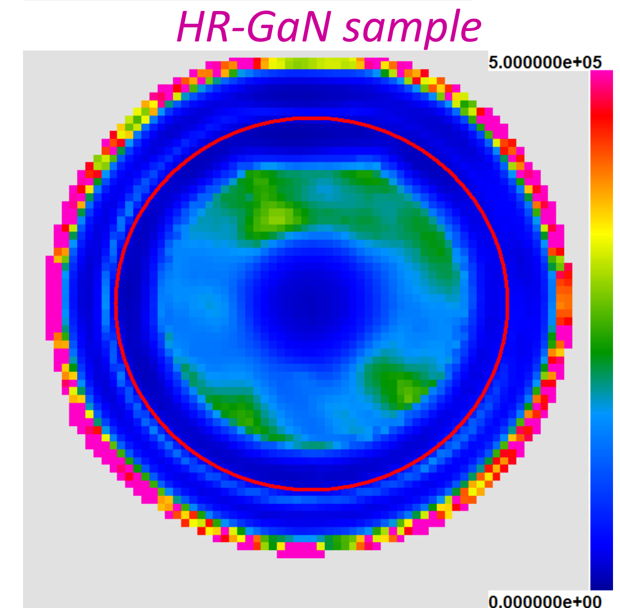


2D maps of resistivity [Ω cm]

Sapphire substrate



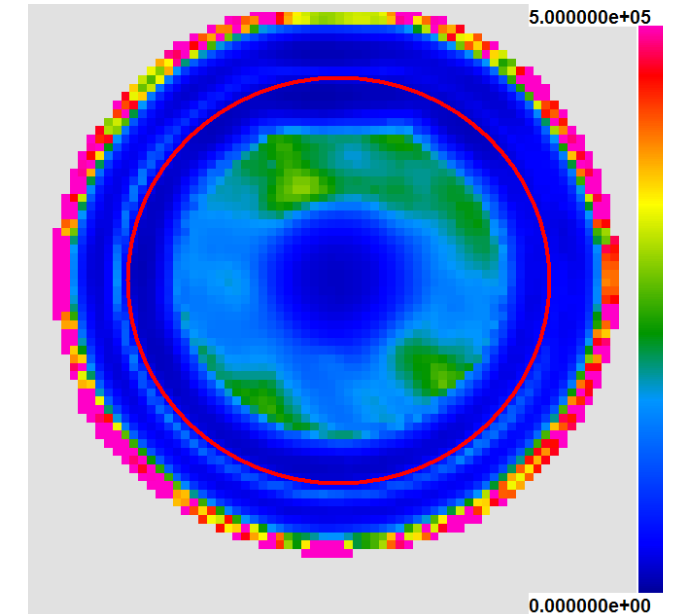
HR-GaN sample



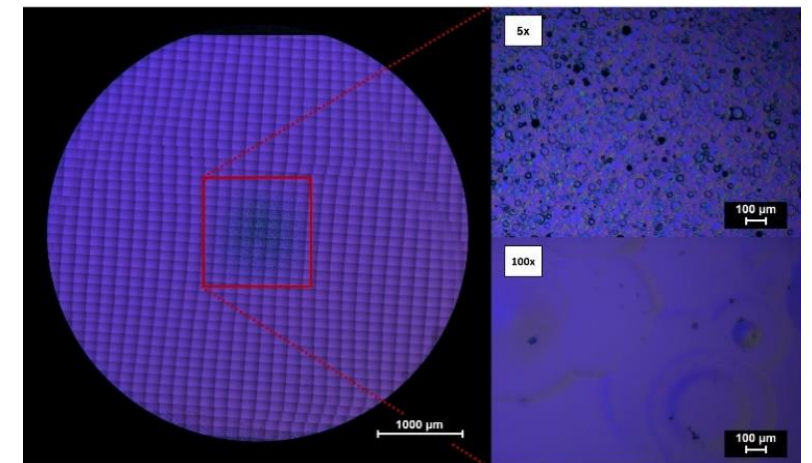
2D imaging results

- 2D resistivity map compared with optical microscope image
- A map obtained with 5x magnification
- Single images with 5x and 100x magnifications
- Volmer-Weber (island) growth mode of GaN on sapphire substrate
- Inhomogeneity of morphology in the central area
  - due to non-uniformity of the growth
- Morphology image from optical microscopy,
  - only the central part unuseful for the implementation of devices.
- 2D resistivity scanning gives a deeper insight into SUT’s quality

2D resistivity map [Ω



Optical microscope image



Summary

- Dielectric resonator technique for surface mapping of electrical parameters has been discussed.
- 2D imaging measurement setup consists of 10GHz 2D SPDR scanner connected to VNA (or Q-Meter device).
- Measurement procedure is fully automated and controlled with a computer application.
- First time application to homogeneity evaluation and quality control of HR-GaN templates for light and power electronics has been presented.
- Qualitative agreement with optical images has been reported.
- Quantitative measures delivered by 2D maps from 2D SPDR scanner open new perspectives for large surface material testing.

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Thank you for attention!

Questions?

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