TUMA3

Application of Microwave Imaging Techniques for the Characterization of Ion-Implanted Battery Materials

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Outline:

1. Motivation & Background
2. Non-destructive and contactless surface scanning technique:
   - 10 GHz inverted Single-Post Dielectric Resonator (iSiPDR)
3. Process of characterizing thin-film-solid-state battery materials
   - Deposition of carbon coatings on quartz substrates
   - Samples treated by Low Energy Ion Implantation (LEII)
4. Potential implications for future advancements in battery technology - Conclusions

Motivation behind I4Bags Project

Growing demand for energy management efficiency:

→ interest in Thin Film Solid State Batteries,

→ need to increase their gravimetric capacity battery capacity in weight terms Wh/kg and stability,

→ Low-Energy Ion Implantation(LEII) as a promising tool for modifying TFSSB materials

In this work we consider:

MATERIA NOVA → PNED

- Fabrication of carbon coatings of different thickness (on quartz wafers),
- Their implantation with N ions at various fluences,

- characterisation of process effects on material parameters.

Further Work will involve I4Bags Partners:

Łukasiewicz Instytut Mikroelektroniki i Fotoniki

ionics surface technologies

Background: continuing collaborations

Nano Bat

MMAMA

I4Bags

innovative processing and characterisation for microelectronics and battery applications

QWED

Multiphysics Computational Modelling

Focus on Materials Characterisation

MATERIA NOVA

Customised Product Development

Engineering and Industrialisation

Non-destructive and contactless surface scanning technique

2D iSiPDR Scanner

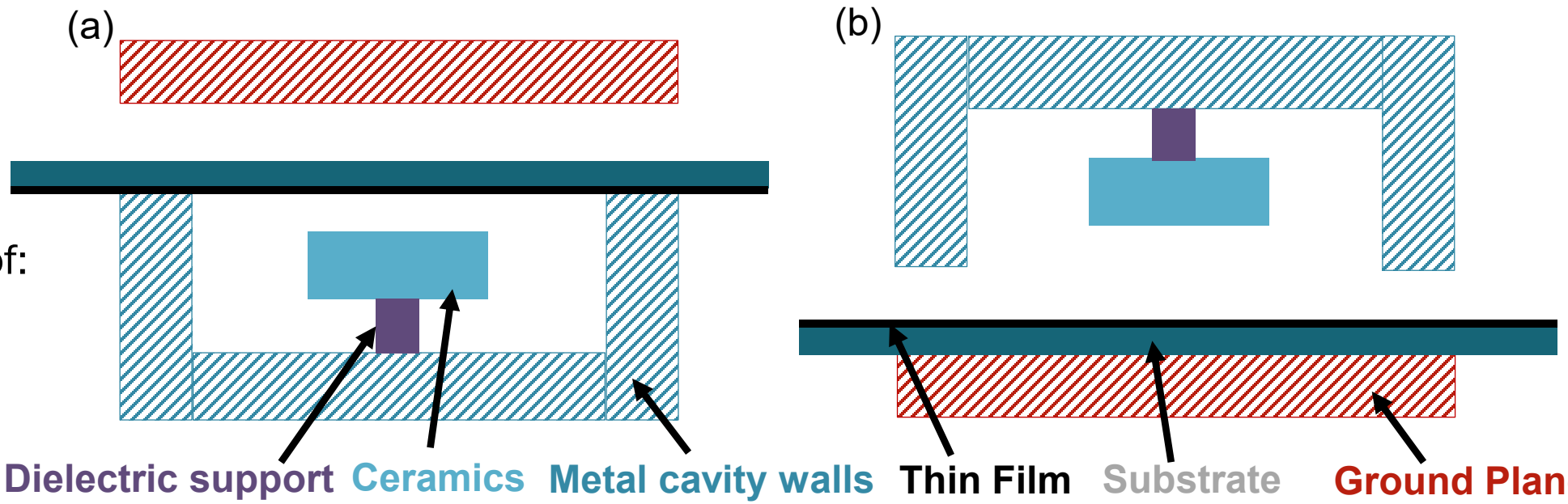
Two-Dimensional inverted Single-Post Dielectric Resonator Scanner:

- Operates at **10 GHz**.
- Working slot: Allows insertion of samples up to **1 mm thickness.**
- Metal plate with a sample placed upon is moved over a grid of points with a **spatial resolution** varying in practice in the range of **0.5 – 5 mm**, depending on the SUT lateral size and requested accuracy of the surface imaging.
- Spans over a **100 x 100 mm** surface, covering typical sizes of available material wafers.
- Standa 2D motorized translation stage with an incorporated metal reference plate as a sample holder.

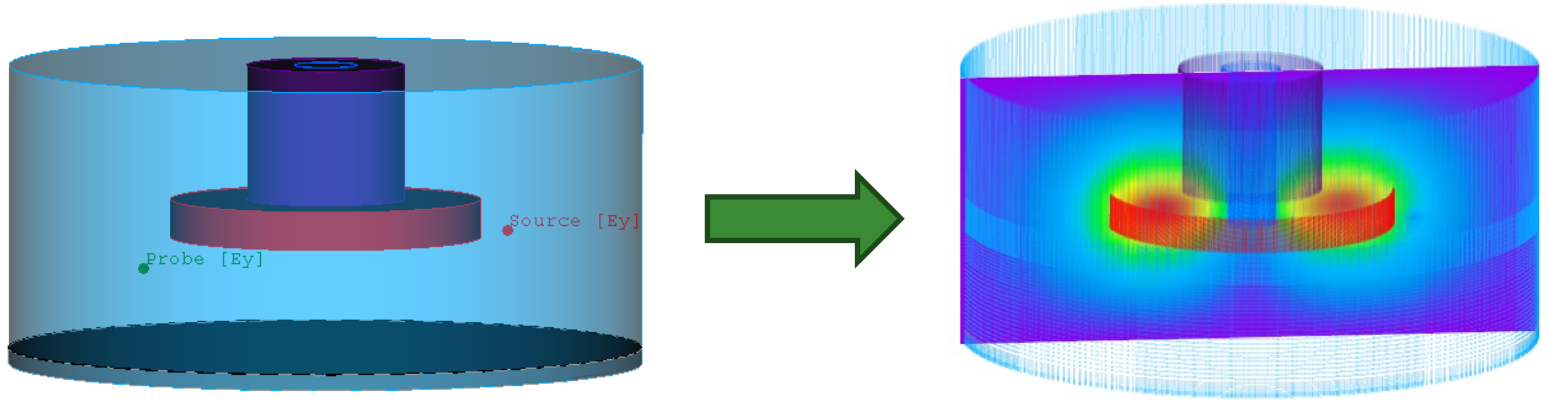
Non-destructive and contactless surface scanning technique

Introduction to iSiPDR

Schematic diagram of:
(a) **SiPDR**
(b) **iSiPDR**



Simulation of iSiPDR model made in QuickWave™

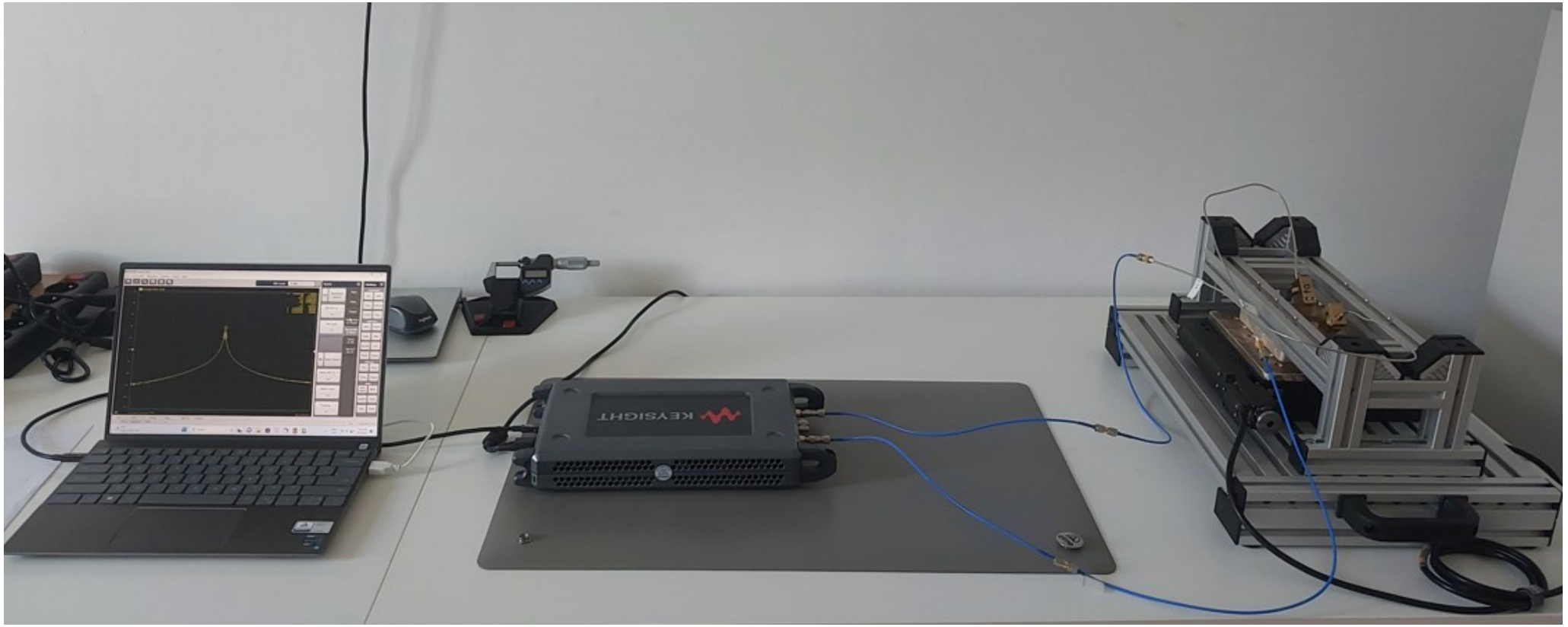


Electric field

TE01 mode

Non-destructive and contactless surface scanning technique

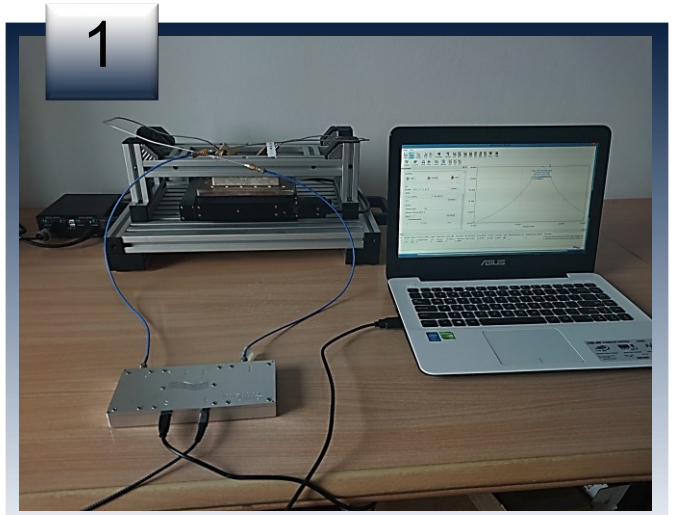
Measurement Setup

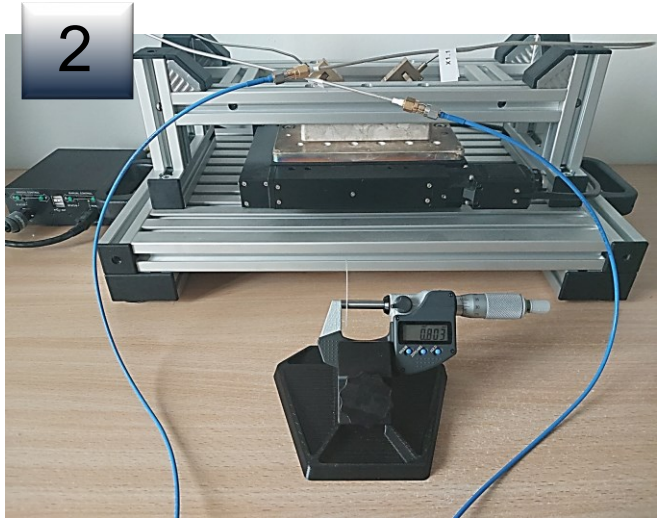


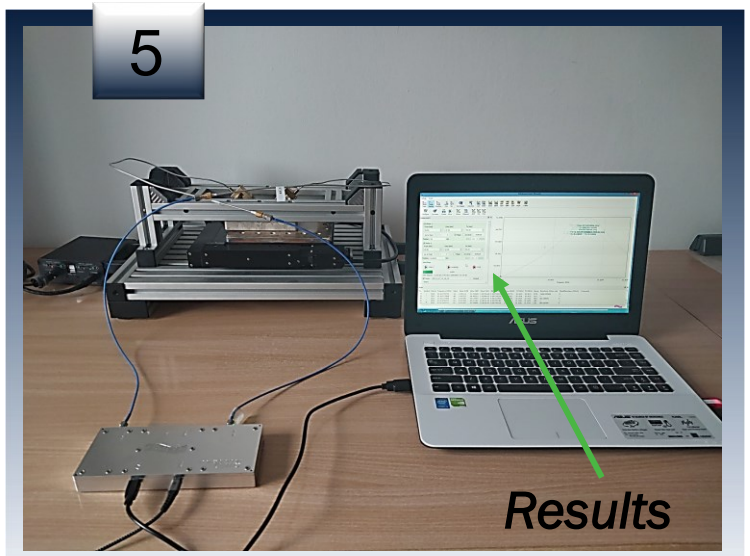
A measuring station consisting of 10 GHz iSiPDR scanner, vector network analyzer (or dedicated Q-meter) and laptop with dedicated software.

Non-destructive and contactless surface scanning technique

Measurement procedure







0. Connect the iSiPDR to Q-Meter using SMA cables

Connect Q-Meter and STANDA Motor to PC using USB cable.

1. Measure "empty" iSiPDR - app invoked measurement.
2. Measure thickness of the sample.
3. Insert the sample into iSiPDR.
4. Insert the sample thickness into the PC app.
5. Material parameters are extracted automatically with each step.

Process of characterizing thin-film-solid-state battery materials

Fabrication procedure

Deposition of Carbon Coating on Quartz → Nitrogen Ion Implantation

MATERIA NOVA

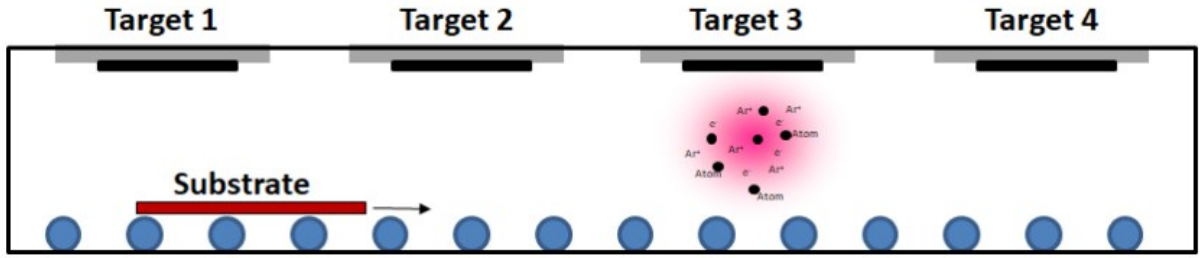
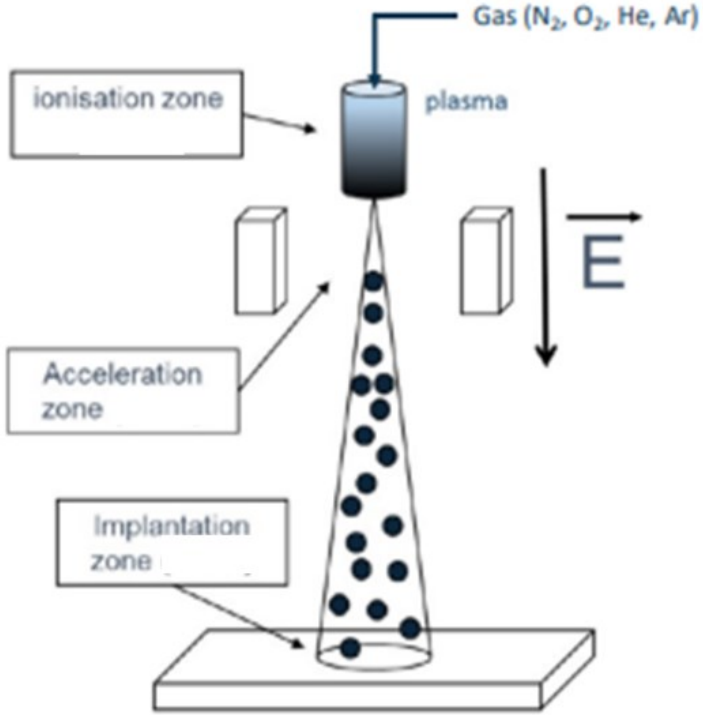


Photo and drawing of magnetron sputtering system



Simplified diagram of the ion implantation process

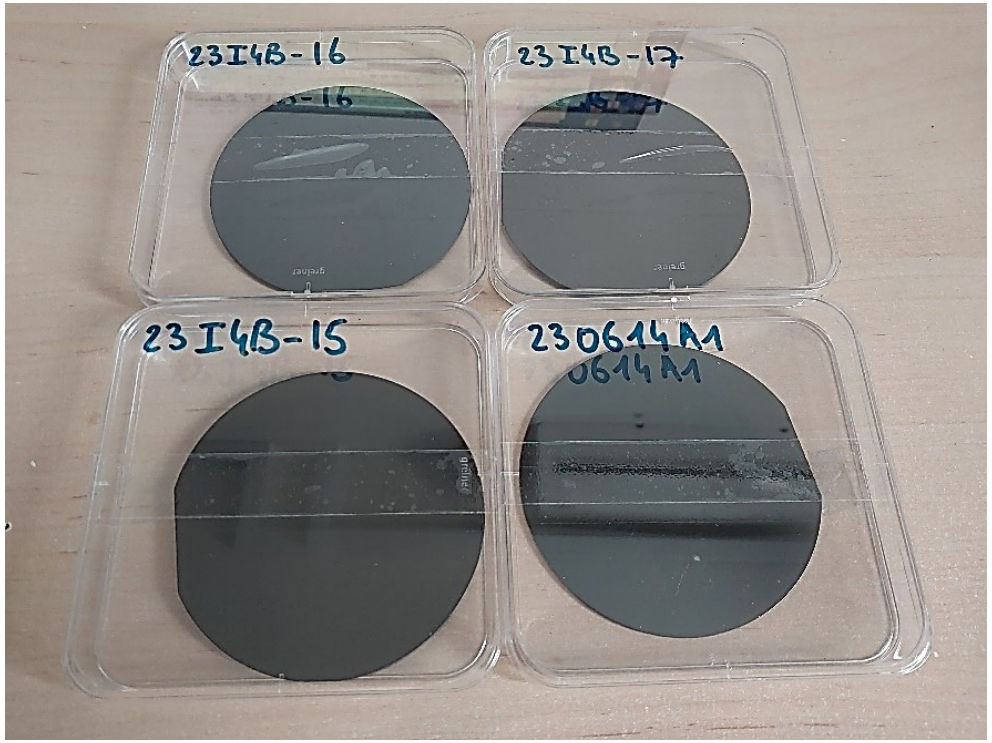
Process of characterizing thin-film-solid-state battery materials

Samples under Test

Deposition of Carbon Coating on Quartz

Carbon coatings of various thicknesses deposited on quartz substrate

Nitrogen Ion Implantation



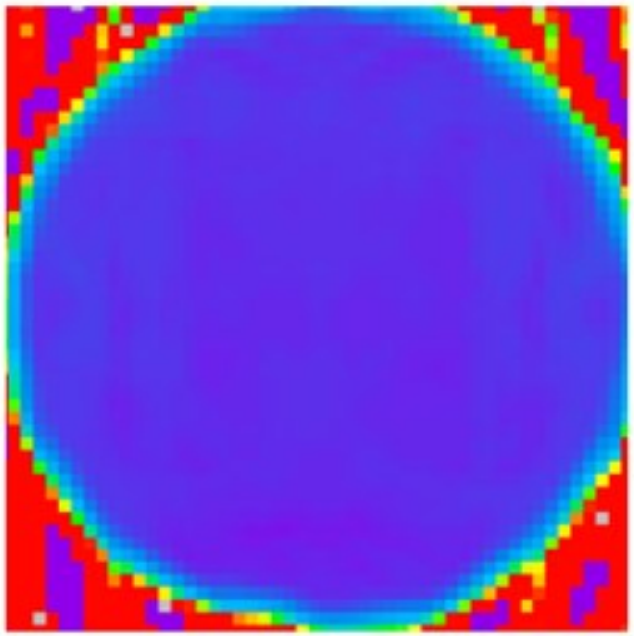
Ion-implanted samples (23I4B-15/16/17) and a reference sample (230614A1) with a carbon coating thickness of 200 nm.

Process of characterizing thin-film-solid-state battery materials

Extraction of 2D Maps of Surface Resistance

Uniformity of carbon coatings

a) C 407 nm/Quartz – 230315A



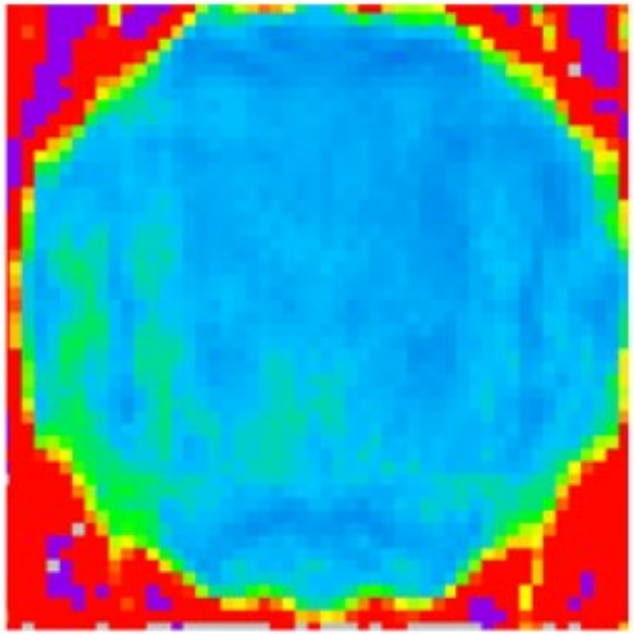
Sheet Resistance varies from **4983.06** to **7159.57** Ω/sq

Average Sheet Resistance **6126.82** Ω/sq.

Conductivity varies from **343.28** to **493.1** S/m.

Average Conductivity **401.12** S/m.

b) C 271 nm/Quartz – 230314A2



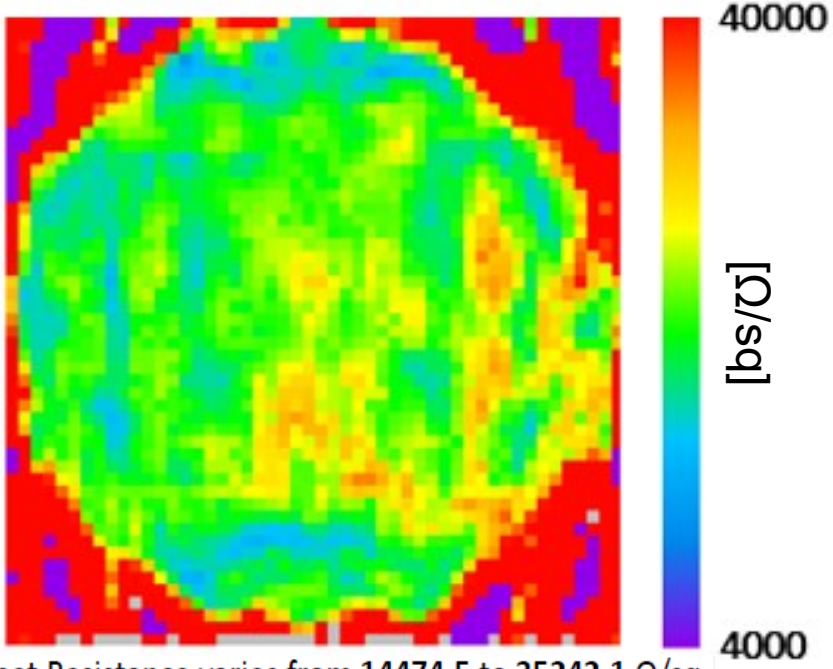
Sheet Resistance varies from **9884.95** to **20300.6** Ω/sq.

Average Sheet Resistance **14950.18** Ω/sq.

Conductivity varies from **181.79** to **373.298** S/m.

Average Conductivity **246.83** S/m.

c) C 207 nm/Quartz – 230313A1



Sheet Resistance varies from **14474.5** to **35242.1** Ω/sq.

Average Sheet Resistance **24036.05** Ω/sq.

Conductivity varies from **137.08** to **333.75** S/m.

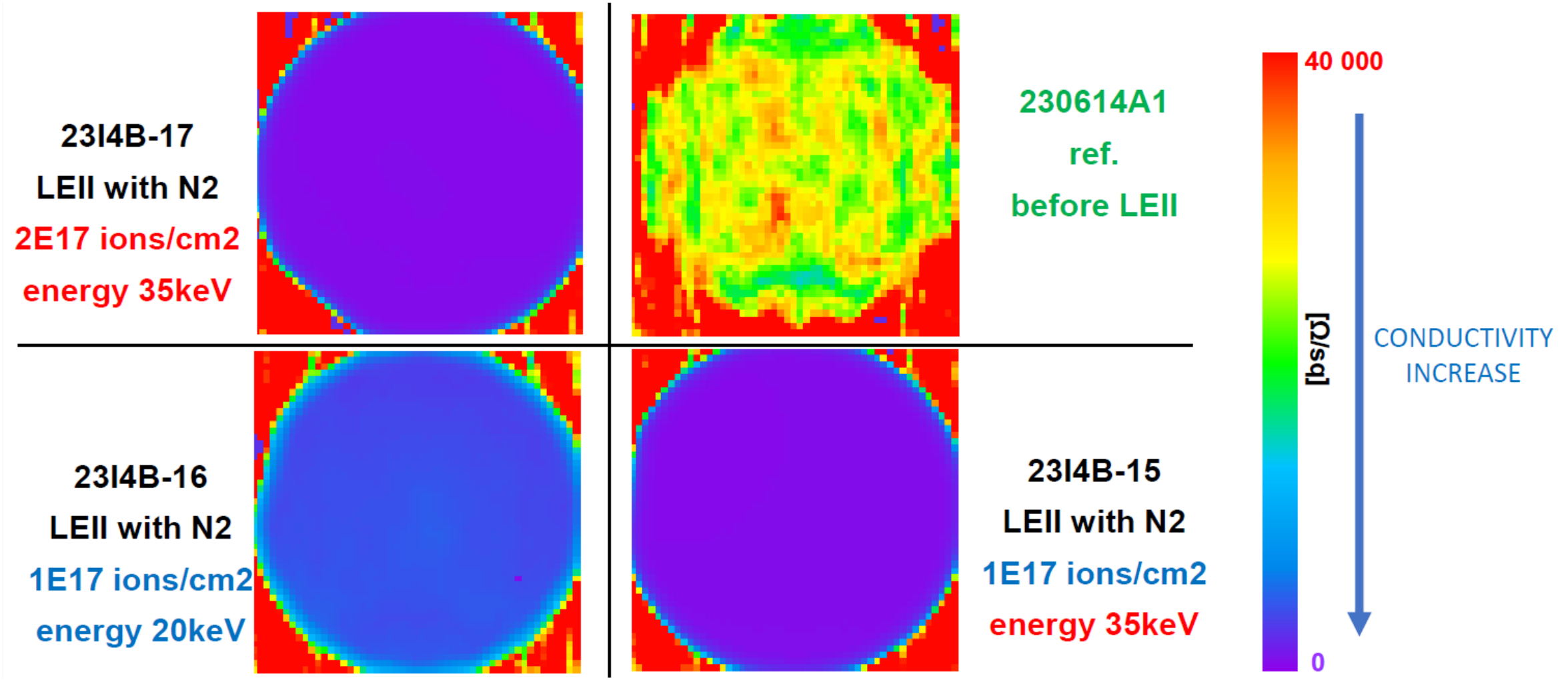
Average Conductivity **201.005** S/m.

As expected, thicker layers provide smaller sheet resistance, higher effective conductivity, and are more uniform.

Process of characterizing thin-film-solid-state battery materials

Overall Implantation Effects

Extraction of 2D Maps of Surface Resistance

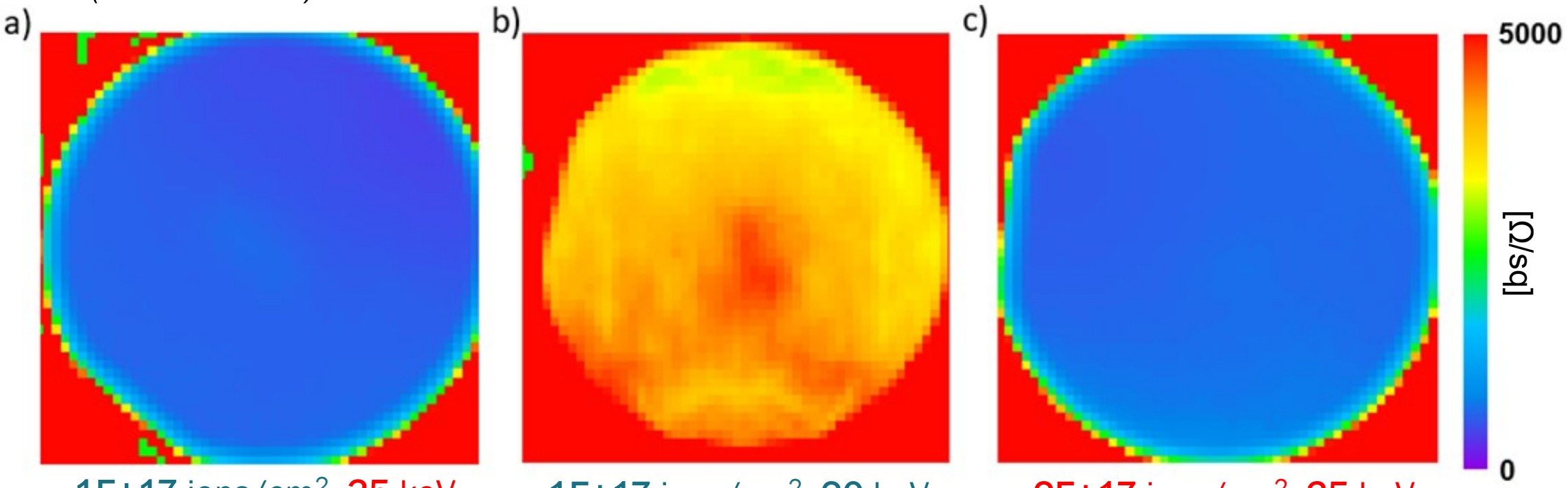


LEII increases conductivity and improves uniformity; LEII at higher energy works better

Process of characterizing thin-film-solid-state battery materials

Ion Implantation – without Ref. Sample (diffrent scale)

Extraction of 2D Maps of Surface Resistance



1E+17 ions/cm^2, **35** keV

Sheet Resistance from **429.93** to **674.50** Ω/sq.

Average Sheet Resistance **588.59** Ω/sq.

1E+17 ions/cm^2, **20** keV

Sheet Resistance from **3066.78** to **4751.83** Ω/sq.

Average Sheet Resistance **3969.37** Ω/sq.

2E+17 ions/cm^2, **35** keV

Sheet Resistance from **565.53** to **843.3** Ω/sq.

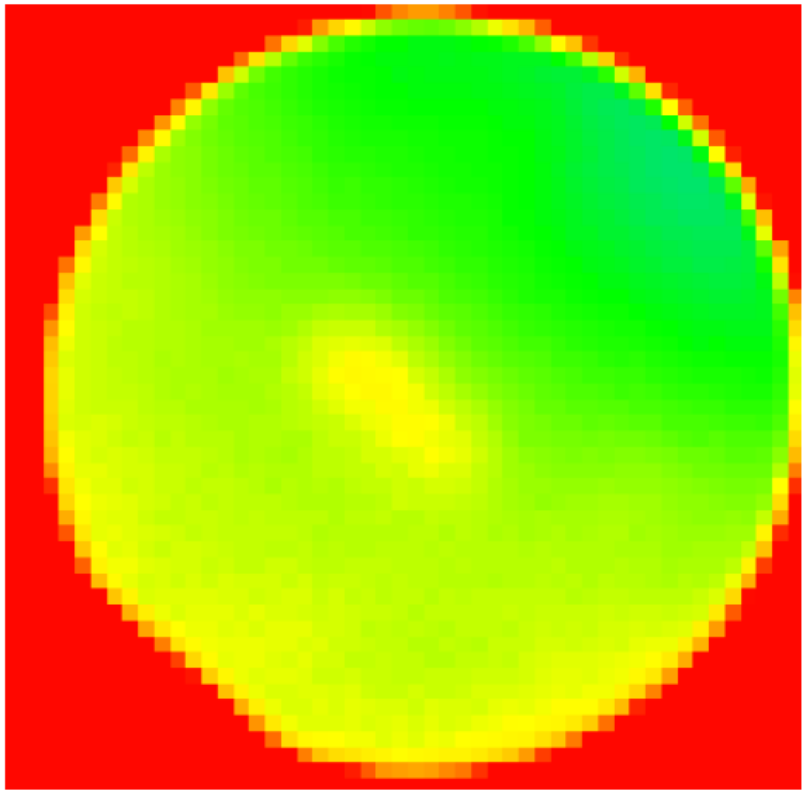
Average Sheet Resistance **676.59** Ω/sq.

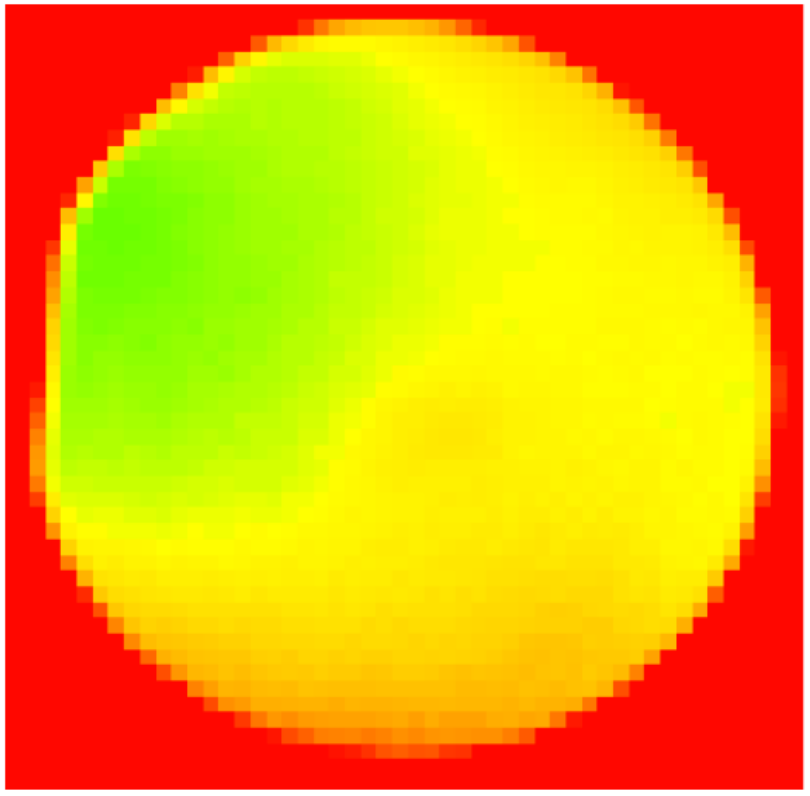
In the expanded scale, higher effectiveness of higher-energy (35keV) as compared to lower-energy (20keV) is clearly visible (sheet resistance 6-7x lower after LEII 35keV than after LEII 20keV).

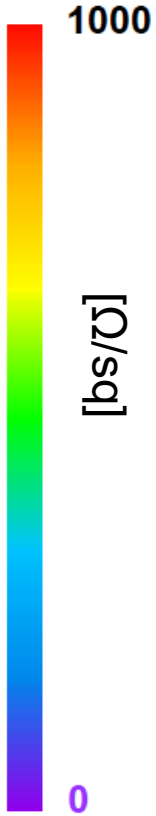
Process of characterizing thin-film-solid-state battery materials

Ion Implantation – Effects of Diffrent Fluence Range

Extraction of 2D Maps of Surface Resistance







1E+17 ions/cm^2, 35 keV

2E+17 ions/cm^2, 35 keV

Somewhat surprisingly, lower dose (1E17) appears more effective in increasing conductivity that higher (2E17) dose.

Conclusions

1. Carbon coatings for TFSSB (Thin-Film Solid-State Batteries) are produced by MateriaNova and characterised by QWED.

2. MateriaNova develops and evaluates different thin-film deposition processes, followed by low-energy ion implantation (LEII).

3. For TFSSB prior is LEII (thin carbon layers on quartz):
electrical parameters needed for TFSSB applications improve for thicker carbon layers
(lower surface resistance, higher effective conductivity, lower spatial nonuniformity.

4. LEII allows improving the above electrical parameters without increasing carbon thickness.

Specifically:
the considered N2implantation at fluence range 1E17 .. 2E17 ions/cm2 and energy 20-35keV
leads to comparable effect as doubling the thickness of carbon,
at comparable fluence, higher-energy(35keV) implantation is more effective than lower (20keV) energy
(6-7 x in terms of sheet resistance reduction), but effects of particular fluence ranges remain to be investigated.

Acknowledgment

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