GRAPHENE FLAGSHIP

Standardisation as a key tool for Graphene Industrialization: Terahertz Technology

Elena Taboada PhD, das-Nano

Graphene Week 2021, 23rd September 2021

Funded by the European Union

das-Nano, founded in 2012 with private financing and based in Navarra, Spain

- Entrepreneurs with experience in business and industries
- Team of more than 125 people
- 35% of our team with PhDs

Basic technologies:

- Software development
- Artificial Intelligence based on neural networks
- Terahertz waves

TERAHERTZ DEPARTMENT

www.das-nano.com/thz

Team of 28 people, 30% of our team with PhDs

Leading solutions based on **terahertz** waves:

- **Automotive**: measurement of paint thicknesses in multilayer systems
- **Aerospace and wind energy**: measurement of coating thickness on aircrafts and wind blades
- **Advanced materials**: physical and electrical characterization of bulk materials (polymers, composites, etc.), thin films and 2D materials such as **graphene**.

Video: https://youtu.be/3nkWitVKAZc

www.das-nano.com/thz

STANDARDISATION

Standardisation is a key tool for emerging technologies to gain industry confidence.

THz technology has been known since the beginning of the 20th century, but its application has not been possible until 3 decades ago.

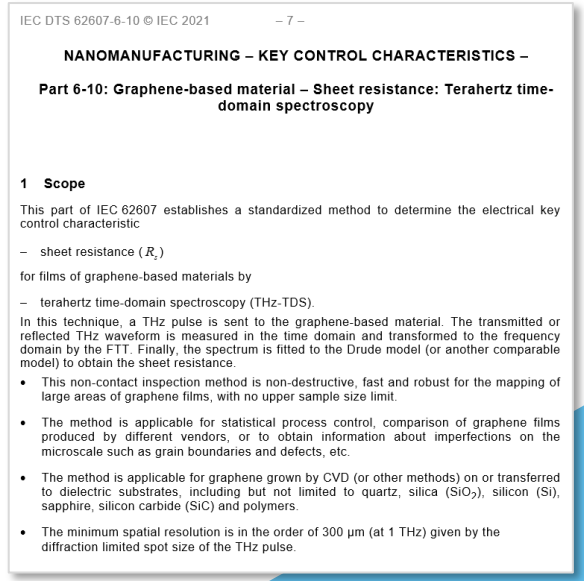
das-Nano is demonstrating the suitability of THz waves to solve industrial problems not only in the field, but also **developing standards** to show the customers an **international agreement of confidence in the technology** and to offer them **robustness in our products and inspection processes**.

www.das-nano.com/thz

STANDARDISATION

das-Nano co-leads the drafting of the **IEC TS 62607-06-10 Graphene-based material – Sheet resistance: Terahertz time-domain spectroscopy:**

- Drafting started in the beginning of 2018. Publication expected for Nov 2021.
- In collaboration with GF's scientific community, such as the Technical University of Denmark (DTU).
- Consensual, international and time-consuming, iterative process.
- Assistance from the Graphene Flagship Standardisation Committee (GFSC) (das-Nano is an Associated Member of the GF).
- Acknowledgement from the GFSC: *Certificate for authoring an International GRM Standard*.



IEC DTS 62607-6-10 © IEC 2021 – 7 –

NANOMANUFACTURING – KEY CONTROL CHARACTERISTICS –

Part 6-10: Graphene-based material – Sheet resistance: Terahertz time-domain spectroscopy

1 Scope

This part of IEC 62607 establishes a standardized method to determine the electrical key control characteristic

– sheet resistance (R_s)

for films of graphene-based materials by

– terahertz time-domain spectroscopy (THz-TDS).

In this technique, a THz pulse is sent to the graphene-based material. The transmitted or reflected THz waveform is measured in the time domain and transformed to the frequency domain by the FTT. Finally, the spectrum is fitted to the Drude model (or another comparable model) to obtain the sheet resistance.

- This non-contact inspection method is non-destructive, fast and robust for the mapping of large areas of graphene films, with no upper sample size limit.
- The method is applicable for statistical process control, comparison of graphene films produced by different vendors, or to obtain information about imperfections on the microscale such as grain boundaries and defects, etc.
- The method is applicable for graphene grown by CVD (or other methods) on or transferred to dielectric substrates, including but not limited to quartz, silica (SiO_2), silicon (Si), sapphire, silicon carbide (SiC) and polymers.
- The minimum spatial resolution is in the order of 300 µm (at 1 THz) given by the diffraction limited spot size of the THz pulse.

GRAPHENE FLAGSHIP

Funded by the European Union

GRAPHENE FLAGSHIP STANDARDISATION COMMITTEE

CERTIFICATE FOR AUTHORING AN

International GRM Standard

PRESENTED TO

Elena Taboada

In recognition of the effort contributed to the standardisation of graphene and related materials

Sept 23rd, 2020

Thurid Gspann GFSC Chair

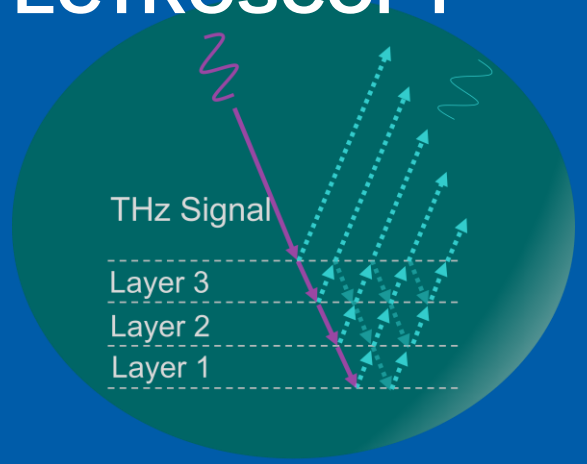
Jari Kinaret Graphene Flagship Director

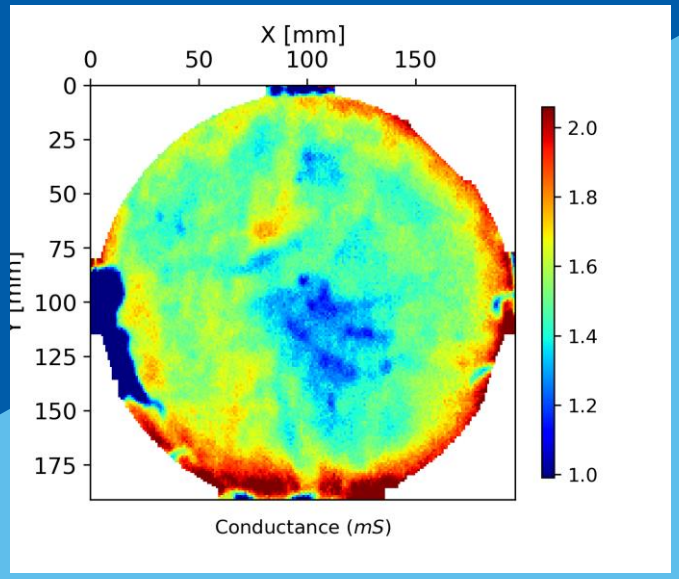
Visit www.das-nano.com/thz

www.das-nano.com/thz

IEC TS 62607-06-10 GRAPHENE-BASED MATERIAL – SHEET RESISTANCE: TERAHERTZ TIME-DOMAIN SPECTROSCOPY

- Non-ionizing
- Thickness and electrical properties
- Contactless and non-destructive method
- Multilayer information: able to characterize buried and stacked materials
- Fast method for the mapping of large areas of graphene films
- No upper sample size limit
- No sample preparation



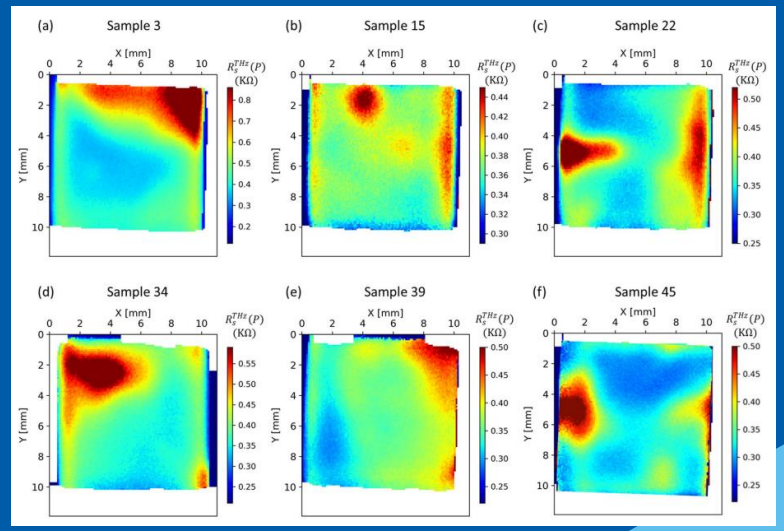


Graphene over quartz wafer (∅ = 20 cm)

www.das-nano.com/thz

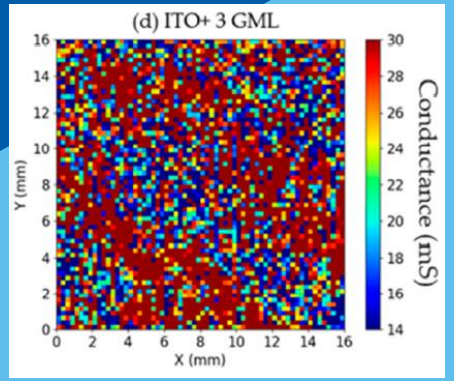
IEC TS 62607-06-10 GRAPHENE-BASED MATERIAL – SHEET RESISTANCE: TERAHERTZ TIME-DOMAIN SPECTROSCOPY

- The method is applicable for statistical process control, comparison of graphene films produced by different vendors, or to obtain information about imperfections on the microscale such as grain boundaries and defects, etc.



Melios et al, Scientific Reports 10:3223 (2020)

- The method is applicable for graphene grown by CVD (or other methods) on or transferred to dielectric substrates, including but not limited to quartz, silica (SiO_2), silicon (Si), sapphire, silicon carbide (SiC) and polymers

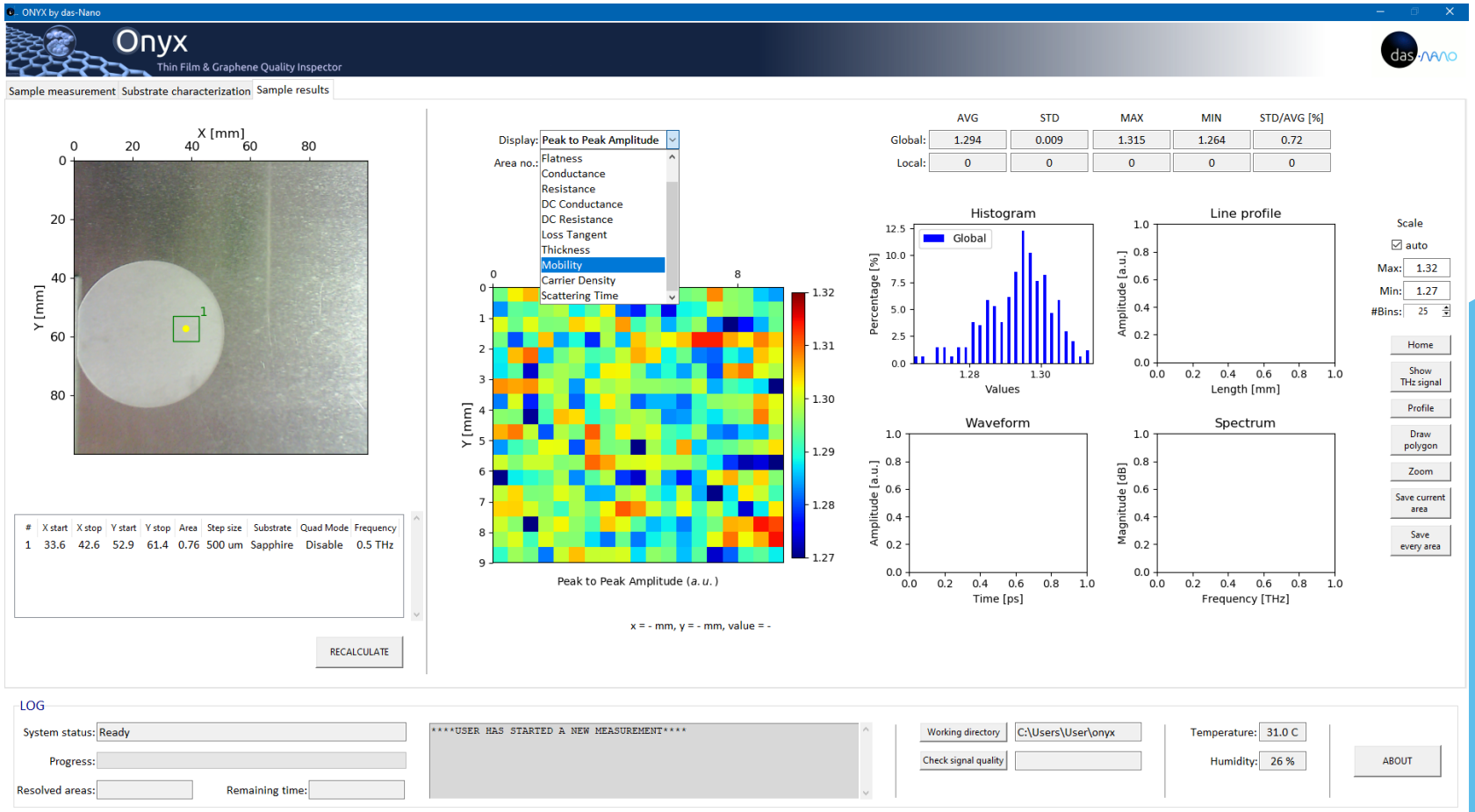


Torres et al, Materials 14, 4833 (2021)

ADVANCED MATERIALS SOLUTION: ONYX

www.das-nano.com/thz

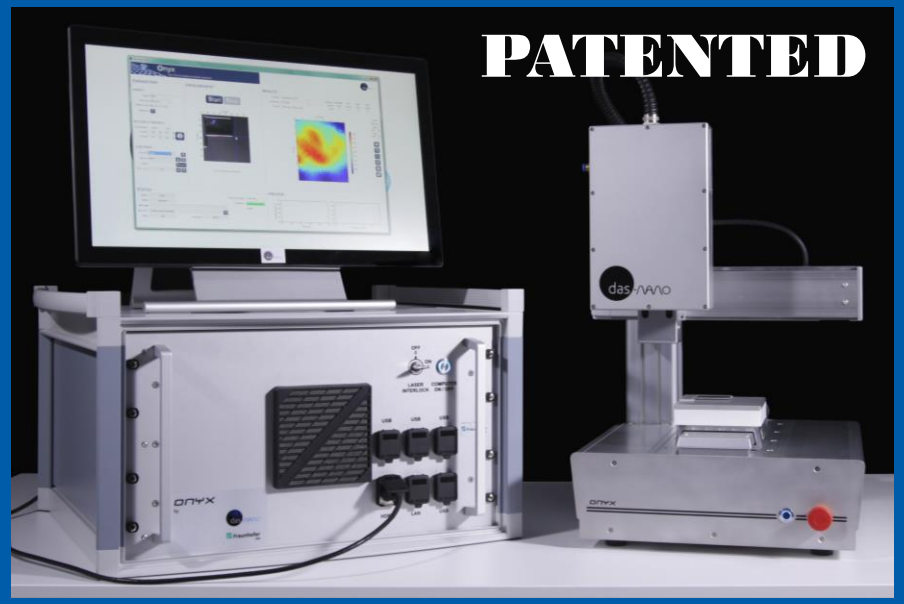
- Contactless
- Fast: up to 12 cm^2/min
- No sample preparation
- Buried and stacked materials
- Versatile, user-friendly interface



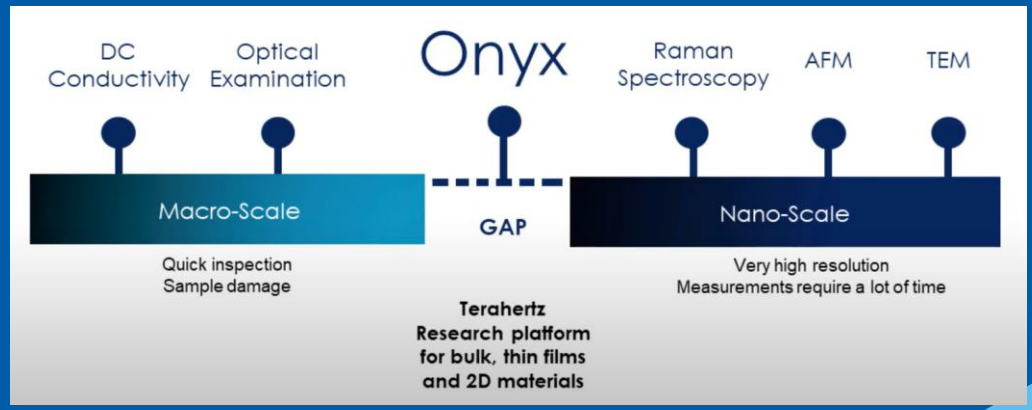
Visit www.das-nano.com/onyx

www.das-nano.com/thz

ADVANCED MATERIALS SOLUTION: ONYX



Onyx is the first system in the market designed to provide a full-area non-destructive characterization of graphene, thin-films, and other 2D materials.



- Successful European project GRACE (EMPIR): *Developing electrical characterisation methods for future graphene electronics*.
- Scientific papers: Fernandez et al, ***Nanotechnol Adv Mater Sci*** Volume 2(3): 1–3 (2019); Cultrera et al, *Scientific Reports*, 9(1), 1-9 (2019), and more.

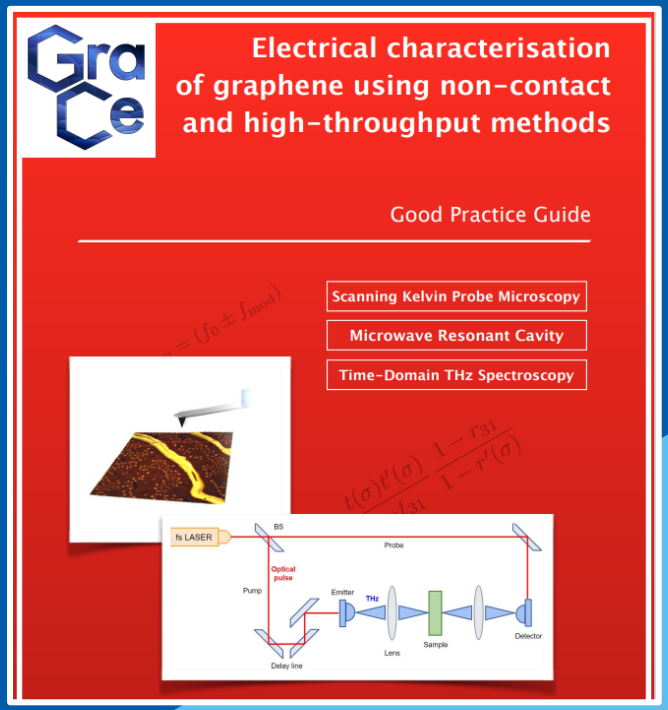
Visit www.das-nano.com/onyx

www.das-nano.com/thz

OTHER STANDARDISATION PROJECTS

EMPIR Project GRACE

- Good Practice Guide: Electrical characterisation of graphene using non-contact and high-throughput methods. ISBN 978-88-945324-2-5 (2020).



British Institute of Non-Destructive Testing (BINDT) THz group

- Just created in August 2021!
- Aim: To promote and advance techniques utilising THz signals to inspect components and to recommend **standardisation** and best practice as appropriate.
- 44 members
- Membership of the Group is open to anyone who has an interest in THz for inspection or associated techniques.
- Contact Karen Cambridge: karen.cambridge@bindt.org

BINDT
THE BRITISH INSTITUTE OF NON-DESTRUCTIVE TESTING

TAKE AWAY MESSAGE: INVEST IN STANDARDISATION

Standardisation is a key tool for emerging technologies to gain industry confidence

Not only scientists but also technicians and industry experts must join forces with the standardisation community and of course with the GFSC to advance graphene standardization

To find the best and least time-consuming methods for industry to advance industrial uptake of this exciting new material that is graphene

Funded by
the European Union

Thank you!

www.das-nano.com

terahertztechnology@das-nano.com

For information regarding Standardisation please contact
Thurid Gspann, thurid.gspann@kit.edu

Funded by
the European Union