

After the RISEnergy Transnational Access, Users are required to submit a User Report. This should be done within 4 weeks after the Access is completed unless otherwise agreed. The User Report will be given to the User(s) by the WP2 leader. The report contains sections related to the work performed, the main results and observations that were achieved.

This document should be completed, signed, and sent by e-mail to [risenergy@for.kit.edu](mailto:risenergy@for.kit.edu).

Summary questionnaire for Users who have been granted Transnational Access (TA) under the RISEnergy project Horizon Europe TA scheme. More information on RISEnergy TA can be found in "General Rules" and in "Access Policy" which can be found on the RISEnergy webpage.

Please complete, sign, and send this form, together with the Cost claim by e-mail to [risenergy@for.kit.edu](mailto:risenergy@for.kit.edu) with title: RISEnergy APPXXX - reports.

<b>General information about the project</b>	
Project title (as used in Application)	DiBONATE
Project number (APPXXX) and acronym (max 15 characters)	APP137
RISEnergy RI(s) accessed	CNR-IMA3
Keywords (up to five, free text)	thermionic emission, diamond, boron/nitrogen doping, energy conversion and storage, nanostructured carbon electrodes
Arrival date (in town where RI is located)	<u>25.05.2025</u>
Departure date (from town where RI is located)	<u>30.05.2025</u>
Starting date of Access (first day at RI)	<u>26.05.2025</u>
Finishing date of Access (last day at RI)	<u>30.05.2025</u>
Number of days not using the RI (during the above period)	1
Reason for not using RI those days (describe)	the day of arrival (25/5) was Sunday (afternoon), and the RI was closed.
Number of days using the RI	5
Number of Users granted Access (group size)	2
Comments	
<b>User</b>	
<b>User group leader or sole applicant (user group member 1)</b>	

First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
<b>User group member 2</b>	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
<b>User group member 3</b>	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
<b>User group member 4</b>	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
Please insert more fields if your groups had more than four members.	
<b>Access Summary Report - work performed and initial results</b>	
Brief description of the objectives of your project (up to 200 words)	
<i>[Please describe short the main objectives of your project]</i>	

The primary objective of the DiBONATE project is to develop and optimize hybrid diamondized boron/nitrogen-codoped nanocarbon materials for advanced thermionic emission applications. By integrating boron-doped diamond films with nitrogen-doped vertical graphene nanowalls, we aim to create a novel class of energy materials that combine low work function, high thermal stability, and superior electron emission properties. The project will systematically investigate the influence of dopant concentrations, nanoarchitecture, and interface engineering on emission characteristics under realistic conditions, including high-temperature operation and concentrated solar illumination. Using the advanced characterization infrastructure at CNR-IMA3 - ISM Diathema, we will evaluate current-voltage behavior, work function variation, and quantum efficiency up to 1800°C and 1000 suns. The hybrid material system is expected to outperform conventional thermionic emitters in both performance and cost-effectiveness. Ultimately, the project aims to deliver fundamental insights into emission mechanisms, establish scalable synthesis protocols, and provide performance benchmarks critical for future device integration. This research will accelerate the development of next-generation renewable energy technologies by enhancing solar-to-electric energy conversion and promoting sustainable energy innovation in Europe.

#### Activities performed (up to 600 words)

*[Please summarise the work carried you (steps taken, instrumentation used, techniques employed, data sources consulted etc.)]*

The work carried out involved a multi-step experimental approach combining advanced fabrication, material processing, and multi-instrument characterization to evaluate the thermionic emission properties of diamondized boron/nitrogen-codoped nanocarbon materials.

#### MPECVD Synthesis and Laser Microstructuring

Samples consisting of boron-doped diamond (BDD) and nitrogen-doped vertical graphene nanowalls (VGNs) were subjected to post-growth surface modification using a femtosecond (fs) pulsed laser. This enabled precise fabrication of 2D-3D micro/nanostructures, including laser-induced periodic surface structures (LIPSS), to enhance emission-active areas and tailor surface morphology.

#### Thermo-electrical Characterization (VTEC System)

Temperature-dependent electrical testing was conducted in the VTEC system, a high-vacuum chamber ( $<10^{-7}$  mbar) equipped with thermal stages capable of operating up to 1000 °C. Current-voltage (I-V) measurements were recorded across a wide thermal range to study the variation of emission current density, work function behavior, and material stability under elevated temperatures.

#### Solar Illumination Testing

A custom-designed solar simulator provided concentrated solar radiation (1-5000 suns) over small sample areas (5 mm spot size). This system was used to evaluate thermionic emission under simulated real-world solar operating conditions relevant for CSP (Concentrated Solar Power) technologies.

#### Surface and Structural Characterization

Raman spectroscopy and tip-enhanced Raman spectroscopy (TERS) were employed to analyze structural and bonding features, particularly assessing  $sp^2/sp^3$  hybridization and dopant incorporation. Atomic Force Microscopy (AFM) and Kelvin Probe Force Microscopy (KPFM) were used to map surface topography and work function distributions with nanometer-scale resolution.

#### Scientific results (up to 800 words)

*[Summarise the (initial) outcomes of your study at the RI(s).]*

Scanning probe microscopy revealed surface heterogeneity in the nanostructured samples, with AFM/KPFM measurements indicating variable work function values ranging from 4.9 to 5.1 eV across sp<sup>2</sup>-rich nanowall regions. These differences suggest localized electronic property variations linked to morphology and doping distribution.

Thermionic emission tests were conducted on two representative samples using high-temperature vacuum characterization. Emission data were analyzed using the Richardson-Dushman equation to extract the effective work function and Richardson constant. Results indicated low work function values of approximately 1.5–1.6 eV when fitted over the full thermal range, with one sample showing slightly superior performance. These values are significantly below those typically reported for undoped carbon materials and suggest enhanced emission properties resulting from boron and nitrogen cooping. Further analysis, by isolating distinct temperature regimes, yielded work function values around 3 eV and Richardson constants on the order of a few A·cm<sup>-2</sup>·K<sup>-2</sup>—both consistent with high-performance emitter characteristics.

#### Interpretation of the results (up to 400 words)

*[Discuss the data obtained and describe the major scientific conclusions drawn.]*

Surface analysis using AFM and KPFM revealed nanoscale heterogeneity in topography and work function distribution across the different graphene nanowall regions. Work function values ranged from 4.9 to 5.1 eV, indicating spatial variability linked to local bonding environments and dopant distribution. These variations suggest that emission-active zones may be selectively enhanced through targeted morphological tuning, a finding supported by TERS. However, KPFM can overestimate the absolute value of work function since it is performed in air and can be subjected to charging issues.

Thermionic emission measurements performed in ultra-high vacuum yielded emission currents and I-V characteristics consistent with low effective work function behavior. Data fitting using the Richardson-Dushman equation indicated effective work function values of ~1.5–1.6 eV across the full temperature range for both samples studied. These values are notably low for carbon-based materials and support the hypothesis that the hybrid architecture—combining boron-doped diamond with nitrogen-doped vertical graphene nanowalls—facilitates enhanced electron emission.

Further segmentation of the data into distinct thermal regimes revealed an increase in the extracted work function to ~3 eV, with Richardson constants in the range of a few A·cm<sup>-2</sup>·K<sup>-2</sup>. These figures are within the expected range for efficient thermionic materials and suggest temperature-dependent transport regimes, possibly governed by surface barrier modulation and dopant activation.

Electrical resistivity measurements as a function of temperature will be performed to better understand the results and validate the analysis.

#### Main achievements during the TA related work (up to 250 words)

*[Describe the main achievements during your stay at the site(s), Outputs (results, publications, models, etc.), conclusions, next steps, potential impact]*

During the Transnational Access (TA) stay at CNR-IMA3 - ISM Diathema, several key achievements were realized that significantly advanced the goals of the DiBONATE project. The experimental activities yielded promising results, confirming the viability of diamondized boron/nitrogen-codoped nanocarbon materials as a new and previously unexplored class of emitters for thermionic energy conversion applications. Surface structuring via femtosecond laser treatment, open up the possibility of tailor surface morphology with subtle bonding modifications, as highlighted by Raman spectroscopy. In particular, the nitrogen-doped vertical graphene nanowalls demonstrated enhanced emission characteristics that merit deeper investigation and development. Based on the outcomes of the TA activities, we are now preparing high-impact scientific publications to disseminate these results. Furthermore, the collaboration has laid the groundwork for future joint research. In particular, we plan to refine synthesis parameters in our home laboratory to further optimize doping levels, morphology, and interface quality based on insights gained at CNR-IMA3.

### Data Management

*[Describe the further usage and storage of project data. State where the data will be kept and name a person responsible for the data. Define data]*

All project data generated during the RISEnergy TA stay—including raw measurement files, processed datasets, spectral maps, microscopy images, and thermionic emission results—will be securely stored on institutional servers at both Gdańsk University of Technology and CNR-IMA3 - ISM Diathema. Data will be organized with complete metadata, including sample identifiers, measurement conditions, instrumentation parameters, and analysis procedures to ensure full reproducibility.

A copy of the data will be deposited in the Gdańsk University of Technology's institutional research data repository (<https://pg.edu.pl/most/danych>) in accordance with FAIR data principles. Sensitive or unpublished data will remain under embargo until the corresponding publications are released. All datasets will be retained for a minimum of five years after project completion.

The designated data manager for the project is Dr. Robert Bogdanowicz, Professor at the Faculty of Electronics, Telecommunications and Informatics, Gdańsk University of Technology.

For this project, "data" refers to all digital outputs from experimental work, including numerical files from thermionic and electrical measurements, AFM/KPFM/Raman datasets, image files, calibration records, and associated metadata and notes relevant to the interpretation and reuse of results.

### Difficulties during the TA related work (up to 250 words)

*[List problems and issues, you had, completing out your research project: Did you get access to all the necessary equipment, facilities, databases, etc.?*

*If not, please specify the problems that occurred and list equipment the was not working or accessible.]*

No difficulties were noticed.

### Intended publications

*[Explain where and how you expect to publish the outcomes of your project work. Include also anything already published (What and where?)]*

The outcomes of the DiBONATE project are intended for dissemination through high-impact, peer-reviewed journals in the fields of nanomaterials, surface science, and energy conversion. Specifically, we plan to submit at least two original research articles based on the thermionic emission results, laser-induced surface modifications, and structure-property correlations identified during the RISEnergy TA stay. Target journals include Carbon, Applied Surface Science, and Solar Energy Materials and Solar Cells, which are well-suited for the interdisciplinary scope of the work. At present, no results from the project have been published yet, but two manuscripts are actively under development, with anticipated submission in Q4 2025.

### Expected impact

*[The impact the expected results will have on current and future research or practice, public safety, European standardization, competitiveness, integration and cohesion and on sustainable growth. any follow on proposals, projects, collaborations, commercialisation]*

The materials developed during this project show great potential for use in thermionic and hybrid solar energy systems, especially in concentrated solar power (CSP) technologies. Their thermal and emission stability under extreme conditions offers advantages for next-generation devices that aim to increase the efficiency and cost-effectiveness of converting solar energy into electricity. These advances directly align with the objectives of the European Green Deal, contributing to the development of sustainable energy technologies and reduced carbon emissions. The results could inform the development of new characterisation and performance benchmarks for carbon-based thermionic materials, thereby helping to establish emerging European standards in energy materials metrology. Follow-up proposals are currently being planned, including applications to international calls focused on advanced materials and renewable energy systems.

### Conclusions / additional comments

*[Provide any other comments you might have on your work]*

Did you complete the European Commission User questionnaire  
<https://ec.europa.eu/eusurvey/runner/RIsurveyUSERS?>

Yes    No

### Feedback - HSE, Ethics and Satisfaction

Please rate on a scale from 1 (excellent) to 5 (poor). Feel free to provide additional comments

Practical information on how to apply for Transnational Access and the overall application process	1 (excellent)	2	3 (neutral)	4	5 (poor)
	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Comment

Information provided, once your project was accepted, on how to proceed	1 (excellent)	2	3 (neutral)	4	5 (poor)
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	<input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
<i>Comment</i>	
Support received at the site(s) regarding technical/scientific matters and logistics	Have you got sufficient support from the RI staff during the project? If not, please, specify the problems. <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
<i>Please specify any problems</i>	
RI extension / upgrades required	In your opinion, is the RI needed to be upgraded? If yes, please give an explanation. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
<i>Please specify</i>	
Problems with local regulations	Have you had any problems with regulations of the visited RI owner (HSE, lab working hours, etc.)? If yes, please, specify <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
<i>Please specify</i>	
Health and safety issues	Did you encounter any health or safety issue during your research? Please provide details. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
<i>Please provide details</i>	
<b>Environment &amp; Ethics</b>	Did your research involve the use of elements that may cause harm to the environment, to animals or plants? Please provide details. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
<i>Please provide details</i>	
Environment & Ethics	Did your research deal with endangered fauna and/or flora and/or protected areas? Please provide details. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
<i>Please provide details</i>	
Environment & Ethics	Did your research involve the use of elements that may cause harm to humans, including research staff? Please provide details. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No
<i>Please provide details</i>	
Environment & Ethics - Dual use	Does your research have the potential for military applications? Please provide details.

	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				
<i>Please provide details</i>					
Environment & Ethics - Misuse	Does your research have the potential for malevolent /criminal/terrorist abuse? Please provide details. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				
<i>Please provide details</i>					
Environmental issues	Were any potentially dangerous substances (materials / gases etc.) released into the environment (atmosphere, water, or land)? Please provide details. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				
<i>Please provide details</i>					
Ethics issues	Are there any other ethics issues that should be taken into consideration? Please specify <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				
<i>Please provide details</i>					
Overall impression of communication and interaction after finishing your TA and related work	1 (excellent)	2	3 (neutral)	4	5 (poor)
	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Comment					
Suggestions for facilities not included in RISEnergy which you would use for your research					
[Please provide suggestions for specific type of facilities missing (RI gaps) or measurement / experiments you would like to perform which can not be done on current RISEnergy facilities.]					
Suggestions how RISEnergy can improve future TA programme, how to make the TA more impactful and how to enable the achievement of high TRL levels					
<b>Feedback - Pro-active Innovation Support</b>					
Awareness	Did you know about the pro-active innovation support of RISEnergy? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				

<i>[Please specify how you learned about the pro-active innovation support]</i>						
Personal experience		Have you taken advantage of or benefited from the pro-active innovation support? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				
<i>[Please provide details]</i>						
Information/service provided by the pro-active innovation support?		1 (excellent)	2	3 (neutral)	4	5 (poor)
		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>[Please provide details]</i>						

I declare that the above provided information and especially that information on the number of days visited the RI is correct.

I have read the [RISEenergy privacy policy](#) for participation in the RISEenergy TA and consent to participation and the associated data processing.