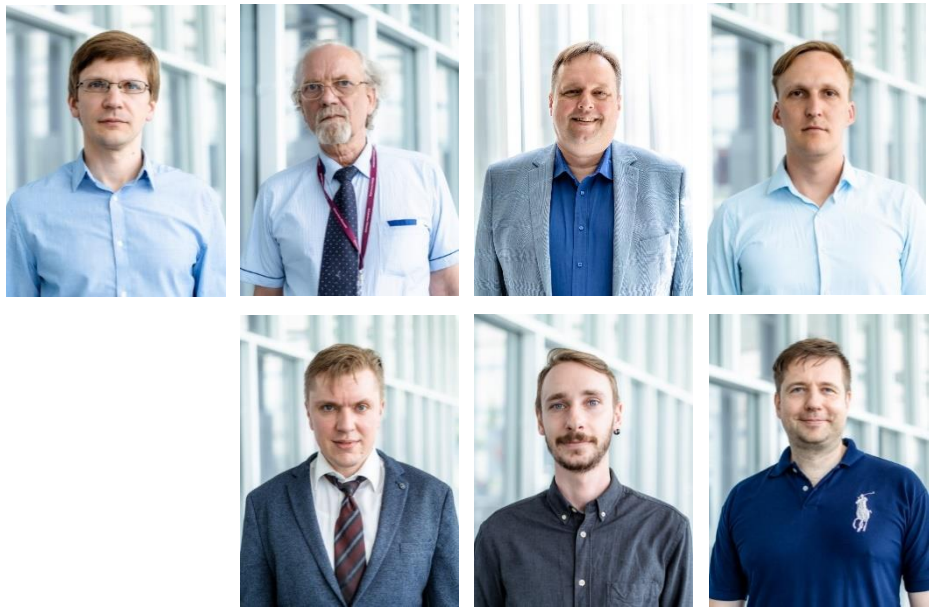
Study of radiation-hard semiconductor materials and radiation sensors for future colliders

T. Ceponis

Institute of Photonics and Nanotechnology, Vilnius University

Researchers

- dr. T. Čeponis
- prof. E. Gaubas
- prof. V. Tamošiūnas
- dr. V. Rumbauskas
- dr. J. Pavlov,
- dr. L. Deveikis
- dr. A. Mekys),
- Phd students – 1 (Ž. Vosylius),
- BC. students – 5
- Ms. students – 1.

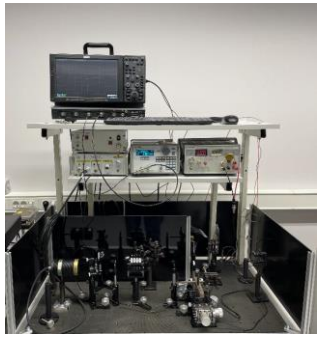
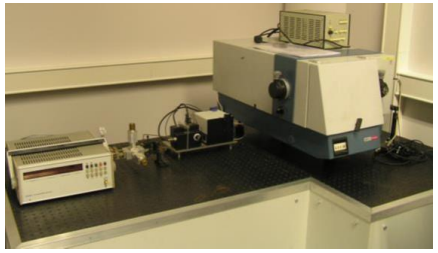


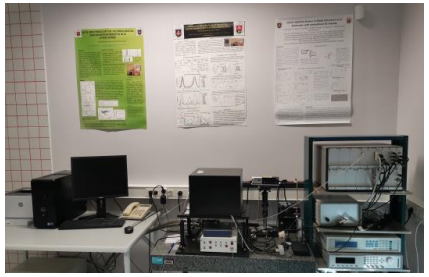
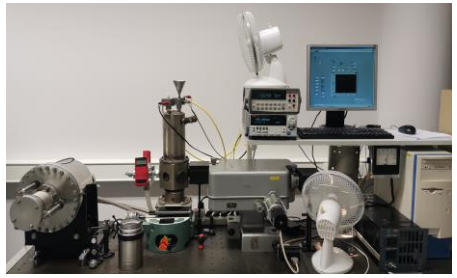
Major research activities

- Search of radiation hard materials and development of radiation tolerant sensor structures.
- Engineering of defects for development of radiation hard particle and photo sensors.
- Development of technologies and instrumentation for spectroscopy and contactless-remote dosimetry of the large fluences of high energy radiations.
- Development of technologies and instruments for the remote in situ measurements in harsh irradiation environments.
- Development of advanced material characterization techniques and instruments.

Facilities



- Instrumentation for testing the electric characteristics of radiation detectors
- Instrument for profiling of carrier drift current transients
- Instrumentation for measurement of pulsed barrier capacitance transients (BELIV)
- EPR scanner BRUKER-E-SCAN
- Instrument for pulsed spectroscopy of thermal and photo-ionization VUTEG-6
- Instrument for steady-state photo-ionization spectroscopy
- Instrumentation for simultaneous spectroscopy of time-resolved luminescence and microwave-probed photoconductivity
- DLTS spectrometer HERA-DLTS System FT 1030
- Pulsed photo-ionization spectroscopy

Activities at CERN

Research Programme

LHC
SPS
PS
AD
ISOLDE Facility
Irradiation Facility
Neutrino Platform
GRADE
CTF3
R&D
Non-accelerator experiments

Research Activities

Experiments and Projects under Study
External Experiments
Recognized Experiments
Completed Experiments

RD50

Development of Radiation Hard Semiconductor Devices for Very High Luminosity Colliders

Synonym:
Research Programme: R&D
Approved: 30-05-2002
Beam:
Status: In-Progress

Overview | Teams | Participations

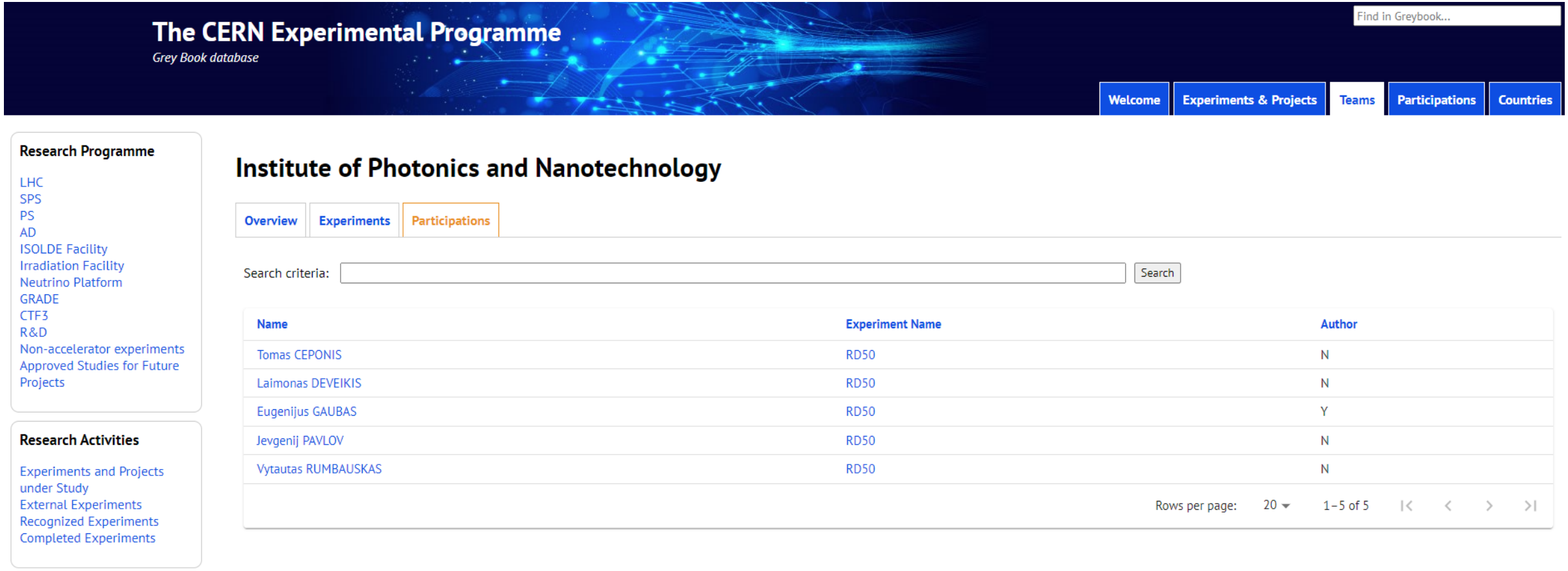
Spokesperson:	CASSE, Gianluigi MOLL, Michael
Contact person:	MOLL, Michael
Experimental Safety Officer (EXSO):	COSTANZI, Ruddy Alain
Experiment secretariat e-mail:	dt-secretariat@cern.ch

Number of Institutes:	66
Number of Countries:	25
Number of Participants:	238
Number of Authors:	191

Status History

Status	Start Date	End Date
Preparation	30-05-2002	25-01-2004
In-Progress	26-01-2004	

Activities at CERN



The CERN Experimental Programme

Grey Book database

Find in Greybook...

Welcome | Experiments & Projects | Teams | Participations | Countries

Research Programme

LHC
SPS
PS
AD
ISOLDE Facility
Irradiation Facility
Neutrino Platform
GRADE
CTF3
R&D
Non-accelerator experiments
Approved Studies for Future Projects

Research Activities

Experiments and Projects under Study
External Experiments
Recognized Experiments
Completed Experiments

Institute of Photonics and Nanotechnology

Overview | Experiments | Participations

Search criteria: Search

Name	Experiment Name	Author
Tomas CEPONIS	RD50	N
Laimonas DEVEIKIS	RD50	N
Eugenijus GAUBAS	RD50	Y
Jevgenij PAVLOV	RD50	N
Vytautas RUMBAUSKAS	RD50	N

Rows per page: 20 1–5 of 5

Participation in common R&D projects within RD50 collaboration

RD50 funding request

Date:
17.05.2022

Title of the project: *Defect engineering in PAD diodes mimicking the gain layer in LGADs*

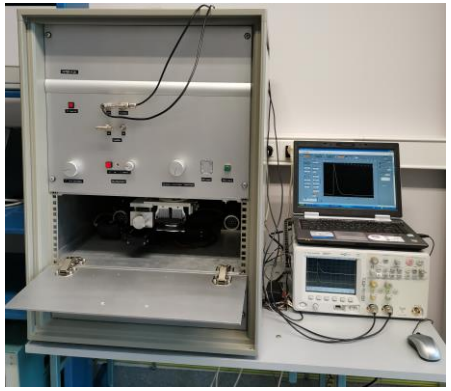
RD50 Institutes:

- NIMP, Ioana Pintilie, ioana@infim.ro
- CERN, Michael Moll, Michael.moll@cern.ch
- CiS, Kevin Lauer, klauer@cismst.de
- JSI, Gregor Kramberger, Gregor.Kramberger@ijs.si
- HH, Eckhart Fretwurst, Eckhart.fretwurst@desy.de
- INFN-Torino, Valentina Sola, sola.valentina@gmail.com
- Vilnius University, Tomas Ceponis, tomas.ceponis@ff.vu.lt

Request to RD50: 26665 EUR

Total project costs: 51165 EUR

Project in progress



- In 2022 the VU group joined the project "*Defect engineering in PAD diodes mimicking the gain layer in LGADs*" within the frame of CERN RD50 collaboration.
- The research is important in developing the semiconductor detectors with internal gain for CERN experiments. The VU group is responsible for direct measurements of carrier recombination lifetime and correlation with parameters obtained by electrical measurements in LGAD structures.
- The unique instruments and techniques (developed by VU group) of carrier lifetime profiling and electrical characterization will be employed in this study.

Participation in common R&D projects within RD50 collaboration

RD50 Common Project Proposal
Partial Activation of Boron to enhance the radiation tolerance of the gain implant
PAB

V. Sola, Torino University and INFN

Abstract
The partial activation of the boron atoms implanted in the gain layer region will be investigated to mitigate the effect of radiation on the gain implant in LGAD sensors [1, 2]. Atoms of boron in the gain layer volume left as interstitials can interact with other impurities present in the silicon lattice, preventing the removal of boron atoms from substitutional positions.
The goal of the project is to investigate the effect of partial activation of boron (PAB) to mitigate the boron removal due to irradiation and to extend by more than a factor of 2 the radiation tolerance of the LGAD sensors.

The groups intend joining common R&D project "Partial activation of boron to enhance the radiation tolerance of the gain implant".
The VU researches will perform:
- carrier lifetime measurements,
- defect spectroscopy,
- electrical characterization.

Project under preparation.

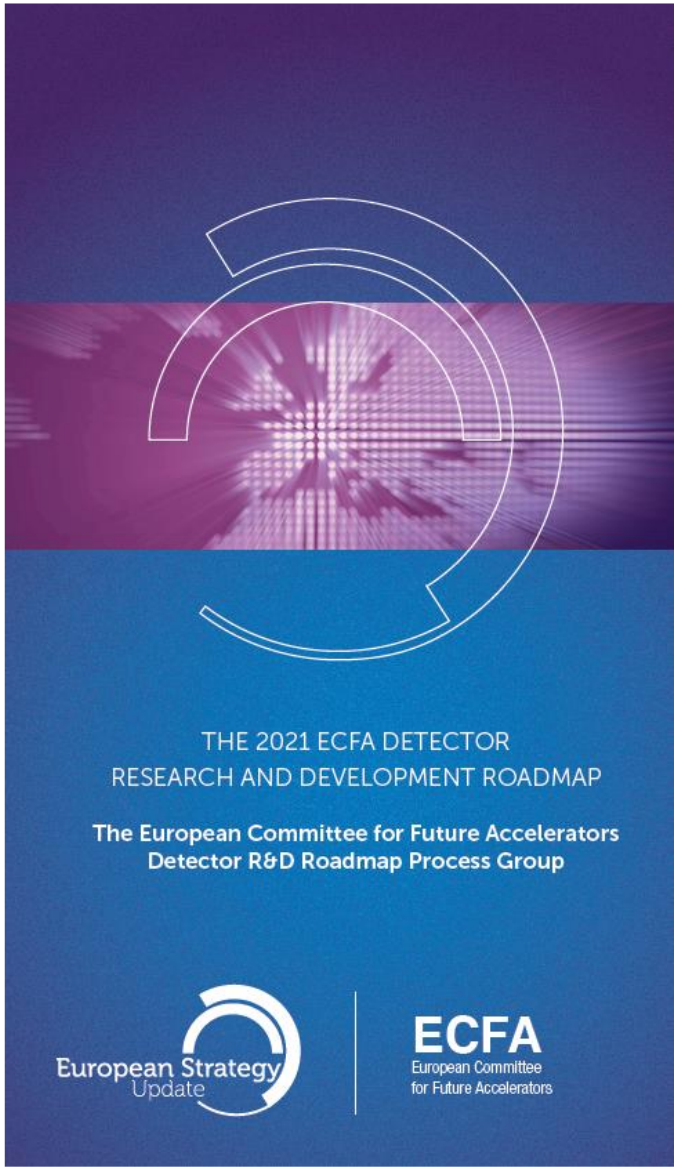
Transfer to DRD3 collaboration after RD50 program terminated at the end of 2023

EUROPEAN STRATEGY FOR PARTICLE PHYSICS
DETECTOR R&D ROADMAP

In the context of the implementation of the 2020 update of the European Strategy for Particle Physics, the European Committee for Future Accelerators (ECFA) was mandated by the CERN Council in 2020 to develop a detector R&D roadmap. The 2021 ECFA Detector Research and Development Roadmap was presented to the Council at its meeting in December 2021 and the Council invited ECFA to elaborate a detailed implementation plan.

1 Scope of the DRD3 collaboration

The DRD3 collaboration has the dual purpose of pursuing the realization of the strategic developments outlined by the Task Force 3 (TF3) in the ECFA road map [1] and promoting blue-sky R&D in the field of solid-state detectors.



Transfer to DRD3 collaboration after RD50 program is terminated at the end of 2023

DRD3 - Solid State Detectors
- Research Proposal -

DRD3 Proposal Team

September 20, 2023

Contents

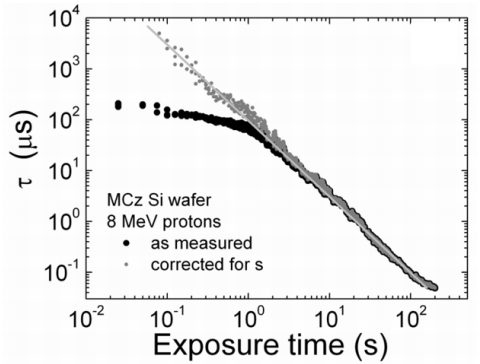
1

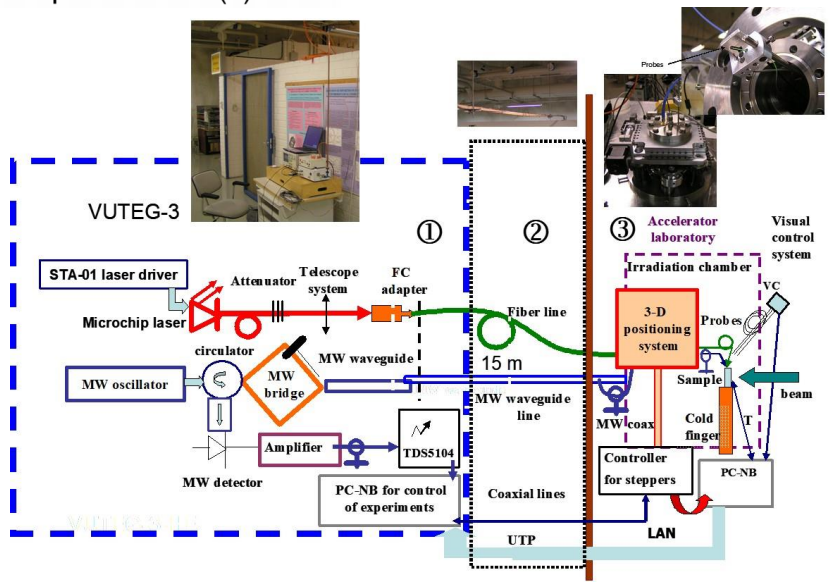
The VU groups are anticipated to join the DRD3 collaboration with the dedicated tasks (defect spectroscopy, carrier lifetime profiling/mapping, electrical characterization of novel sensor test structures) within the following Working Groups (WG) defined in the DRD3 proposal document:

- WG2: Sensors for tracking and calorimetry;
- WG3: Radiation damage and extreme fluences;
- WG6: Wide bandgap and innovative sensor materials.

Technologies for the in situ monitoring of evolution of radiation defects

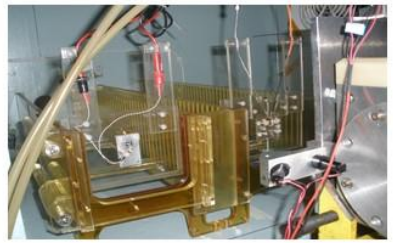
In situ control of evolution of the radiation defects introduced by 8 MeV protons at Helsinki University accelerator laboratory.

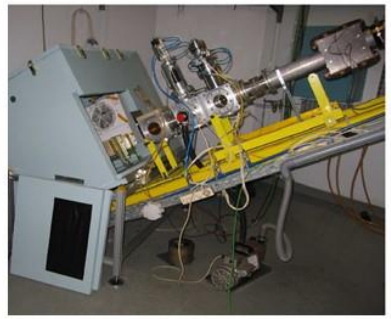


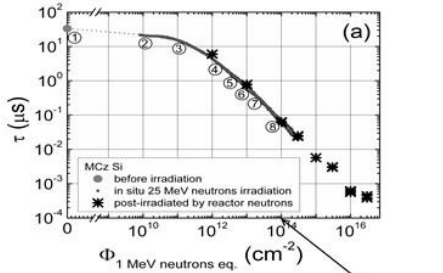


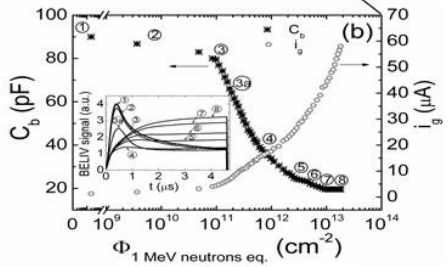
In situ variations of carrier recombination (a- MW-PC), of barrier capacitance (b-BELIV) and of detector response (c-TCT/ICDC) during irradiation by spallator neutrons.

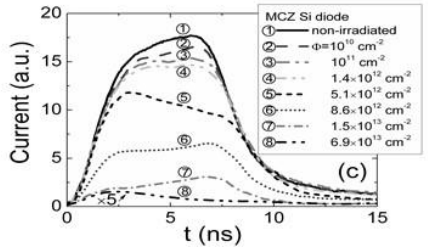
Correlated evolution of the MW-PC, BELIV and ICDC characteristics during spallator neutrons irradiation:
transients registered every 10 ms, irradiation - bunches of 4 ns duration.











E. Gaubas, T. Ceponis, A. Jasiunas, A. Uleckas, J. Vaitkus, E. Cortina, and O. Militaru, *Correlated evolution of barrier capacitance charging, generation, and drift currents and of carrier lifetime in Si structures during 25 MeV neutrons irradiation*, Appl. Phys. Lett. **101** (2012) 232104.

Technologies and instruments for the radiation dose and flux measurements in a wide range

- Patented method and equipment for the measurements of high cumulative doses collected under ionizing irradiations.


URKUNDE | CERTIFICATE | CERTIFICAT

Europäisches Patent | European patent | Brevet européen

Es wird hiermit bescheinigt, dass für die in der Patentschrift beschriebene Erfindung ein europäisches Patent für die in der Patentschrift bezeichneten Vertragstaaten erteilt worden ist.

It is hereby certified that a European patent has been granted in respect of the invention described in the patent specification for the Contracting States designated in the specification.

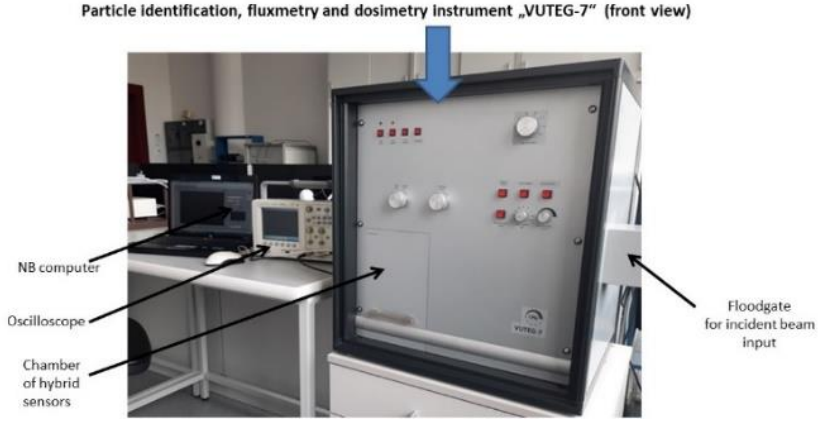
Il est certifié qu'un brevet européen a été délivré pour l'invention décrite dans le fascicule de brevet, pour les Etats contractants désignés dans le fascicule de brevet.

Europäisches Patent Nr. / European patent No. / Brevet européen n°: 3594723

Patentinhaber / Proprietor(s) of the patent / Titulaire(s) du brevet: Vilnius University, Universiteto g. 3, 01513 Vilnius/LT

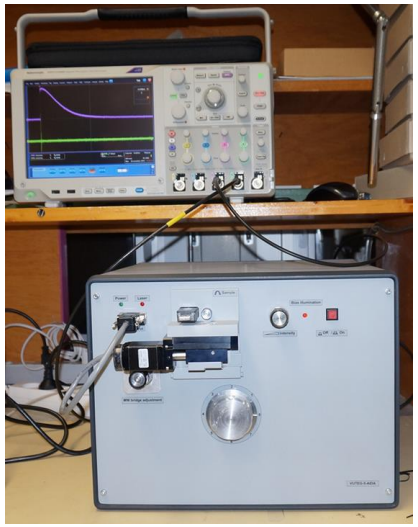
EU patent: E. Gaubas, T. Čeponis, et al, „DOUBLE RESPONSE IONIZING RADIATION DETECTOR AND MEASURING METHOD USING THE SAME“- App No.: 18213254.8, Patent No.: 3594723.

- Instrument and technology for dosimetry and fluxmetry of high energy electromagnetic and particle radiations.

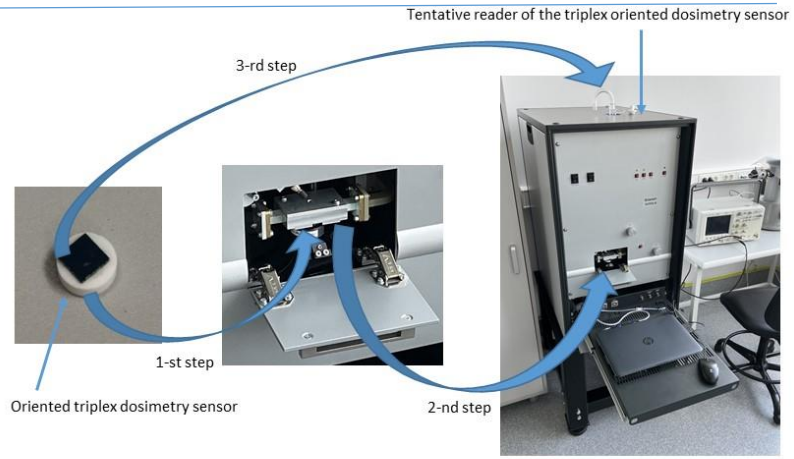


HYBRID MULTI-LAYER SENSOR AND METHOD FOR LARGE FLUENCE DOSIMETRY AND FLUXIMETRY, Authors: Eugenijus Gaubas, Tomas Čeponis, Laimonas Deveikis, Jevgenij Pavlov, Vytautas Rumbauskas. Application No. 21 165 145.0, submission date: 2021 03 26.

- Dosimeter VUTEG-5-AIDA has been installed at CERN in 2012 for the RD50 program and other CERN research. The dosimeter VUTEG-5-AIDA is devoted for dosimetric control of hot irradiation zones of large areas. This dosimeter is also equipped with precision scanning devices for evaluation of local fluence exposure. It can also be adapted for imaging of narrow irradiated beams.



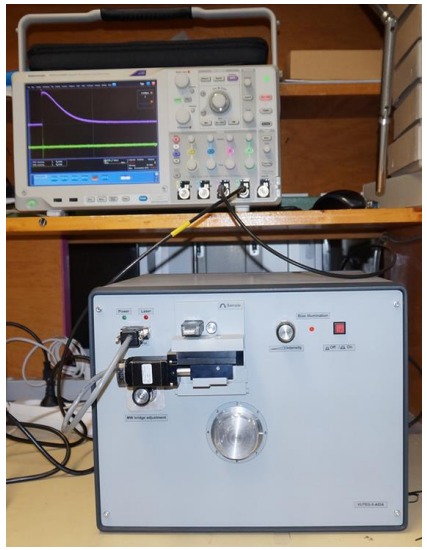
- The prototype system for the control of radiation doses in a wide range. This prototype system allows measuring low and very high fluences and to identify the spectrum of high energy radiations.



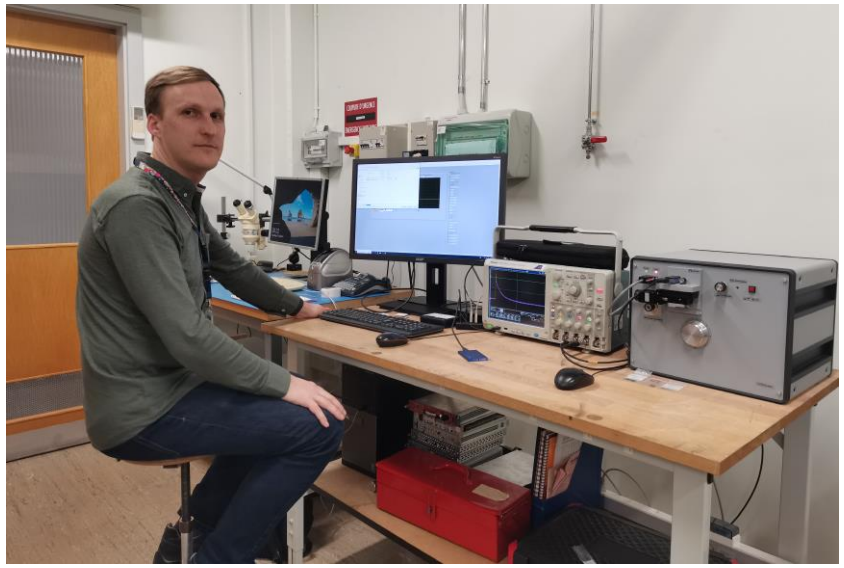
The oriented sensor is in succession set in PL as well as MW-PC opening and into the EPR insert of the tentative reader

E. Gaubas, T. Čeponis, L. Deveikis, J. Pavlov, V. Rumbauskas, Oriented triplex sensor and method of identification of the radiation source location and its dosimetry, EU patent application No. EP22171639.2, submission date: 2022 05 04.

Multipurpose instrument VUTEG-5-AIDA installed at CERN



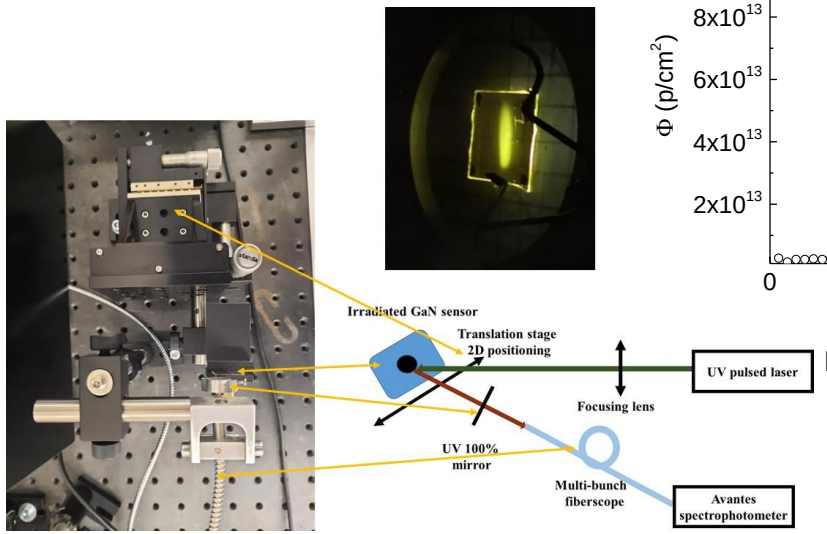
Instrument VUTEG-5-AIDA has been installed at CERN in 2012 for the RD50 program and other CERN research. The instrument VUTEG-5-AIDA is devoted for dosimetric control of hot irradiation zones of large areas. This dosimeter is also equipped with precision scanning devices for evaluation of local fluence exposure. It can also be adapted for imaging of narrow irradiated beams and for materials characterization.

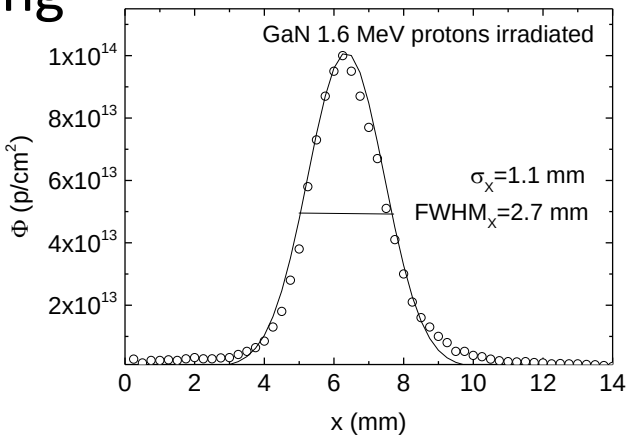


Dr. V. Rumbauskas is preparing instrument VUTEG-5-AIDA for CERN staff training in March 2023.

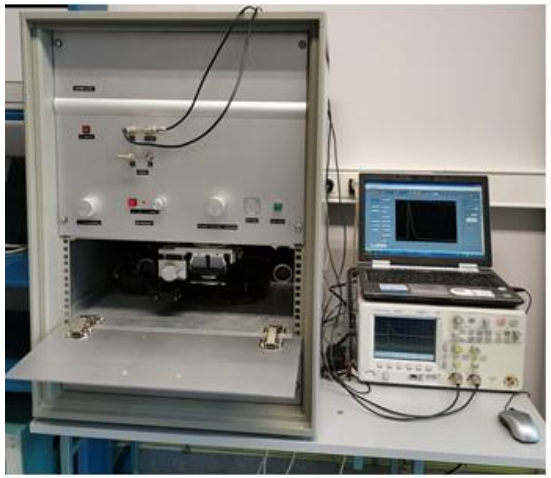
Technologies and instruments for particle beam profiling

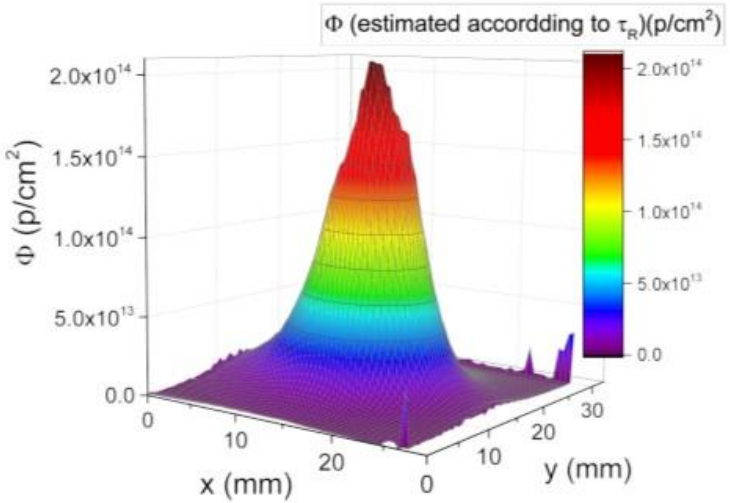
The particle beam profiling techniques based on dosimetry of the hadron irradiated Si and GaN sensors have been developed. The fluence distribution profiles for high energy penetrative particles are recorded by carrier lifetime measurements within Si wafer. For beams of rather low energy particles, sensors with thin active layers are preferable. Then, the scintillation techniques are eligible to have recordable responses from thin sensor layers.





Recorded profile of 1.6 MeV proton beam.

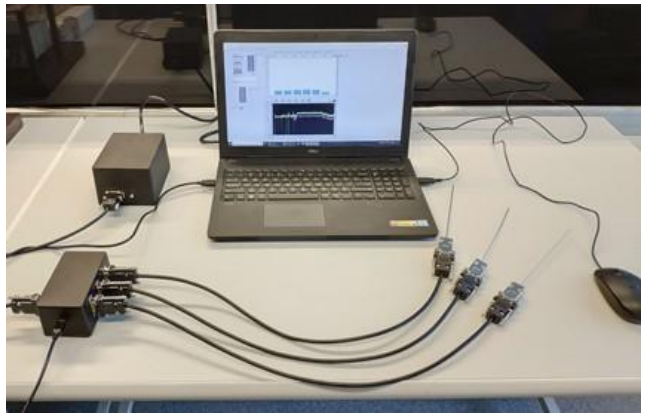


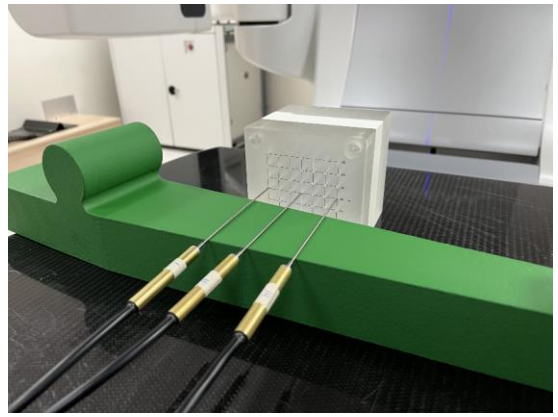


Recorded profile of 26 GeV/c proton beam.

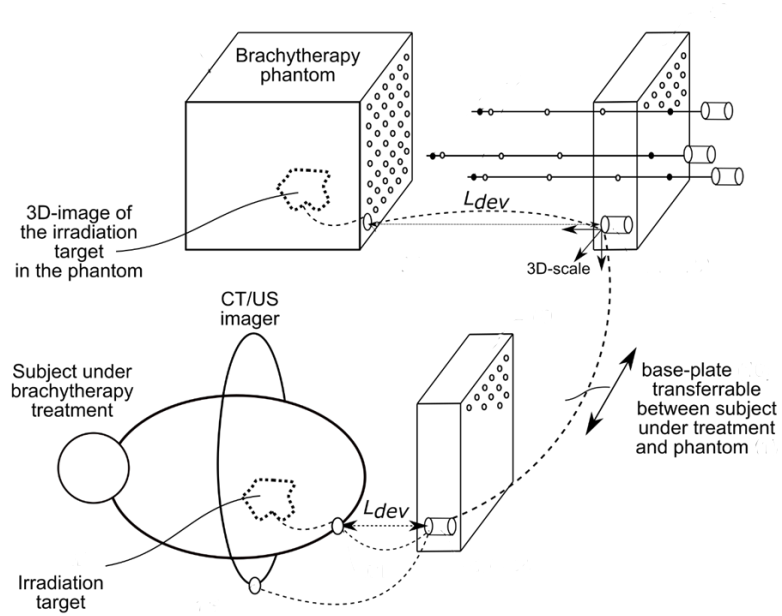
- L. Deveikis, J.V. Vaitkus, T. Čeponis, M. Gaspariūnas, V. Kovalevskij, V. Rumbauskas, E. Gaubas, *Profiling of proton beams by fluence scanners*, Lith. J. Phys. **61** (2021) 75–83.
- T. Ceponis, L. Deveikis, E. Gaubas V. Rumbauskas, M. Moll, Particle beam profilers based on fluence dependent variations of carrier lifetime and scintillation intensity in Si and GaN materials, Presentation at RD50 workshop, CERN 2022-06.

Radiation dose monitoring systems for medical applications





- Development of technology and instrumentation for time-resolved positioning of radiation emitters and for dosimetry during the brachytherapy planning and a subsequent in vivo brachytherapy treatment stages, where the method and apparatus are based on triangulation of needle-type probes fixed within time-space resolved coordinates.
- The technology and instrumentation have been approved at The National Cancer Institute (Lithuania).
- In vivo tests of radiation dose monitoring during brachytherapy therapeutic procedure are being performed at National Cancer Institute (Lithuania) since October 2022.



E. Gaubas, T. Čeponis, K. Pūkas, V. Rumbauskas, M. Užgirytė, J. Venius, K. Akelaitis, A. Cicinas. SYSTEM AND METHOD FOR BRACHYTHERAPY PROCEDURE PLANNING AND VERIFICATION, EU patent application No. EP21210650.4, submission date: 2021 11 26.

Main achievements during 2022-2023 years (1)

List of scientific publications related with CERN activities:

1. J. Pavlov, T. Ceponis, K. Pukas, L. Makarenko, E. Gaubas, *5.5 MeV electron irradiation-induced transformation of minority carrier traps in p-type Si and $Si_{1-x}Ge_x$ alloys*, Materials **15** (2022) 1861.
2. T. Ceponis, J. Pavlov, A. Kadys, A. Vaitkevicius, E. Gaubas, *Luminescence characteristics of the MOCVD GaN structures with chemically etched surfaces, Materials* **16** (2023) 3424.
3. T. Ceponis, M. Burkanas, A. Cicinas, L. Deveikis, J. Pavlov, V. Rumbauskas, J. Venius, E. Gaubas, *Combined techniques for recovery of radiation damaged detectors*, accepted for publication in Mat. Sc. Sem. Proc. journal.

(19 during 2018-2023)

List of patents and patent applications:

1. Lithuanian patent – E. Gaubas, T. Čeponis, V. Kalesinskas, V. Rumbauskas, L. Deveikis „Magnetinis reliatyvistinių elektringųjų dalelių analizatorius“ (*Magnetic analyzer for relativistic charged particles*), Patent No. 6929, date of publication 2022-08-10.
2. Lithuanian patent - E. Gaubas, T. Čeponis, L. Deveikis. J. Pavlov, V. Rumbauskas „Hibridinis daugiasluoksnis jutiklis ir didelių įtėkių bei srautų matavimo metodas“ (*Hybrid multi-layer sensor and method for large fluence dosimetry and fluxmetry*), Patento No. 6931, date of publication 2022-08-10.
3. European patent application – E. Gaubas, T. Čeponis, L. Deveikis, J. Pavlov, V. Rumbauskas, „Oriented triplex sensor and method of identification of the radiation source location and its dosimetry“, Application No. EP22171639.2, submission date: 2022 05 04.

(8 during 2018-2023)

Presentations at conferences:

- 5 during 2022-2023;

(9 during 2018-2023)

Main achievements during 2022-2023 years (2)

Implemented projects:

1. LMT „SMART“ project 01.2.2.-LMT-K-718-01-0013 „Creation of the prototype wide-spectrum dosimetry system for various purpose monitoring of irradiations“, 600000 EUR/2018-2022 yr.
2. Lithuanian Academy of Science project CERN-VU-2022-4 „Radiation tolerant semiconductor detectors for high luminosity colliders“, 33700 EUR/2022 yr.

(7 during 2018-2023, overall budget >2 mln. EUR)

List of dended PHD thesis in the field related with CERN activities:

1. L. Deveikis, Electrically active defects and their transformations in GaN structures, thesis defended in 2022 yr.
2. K. Pūkas, Technologies of dosimetry in applications of high energy physics and radiation medicine, thesis defended in 2022 yr.

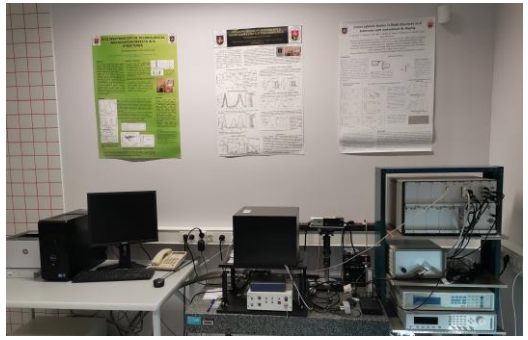
(3 during 2018-2023)

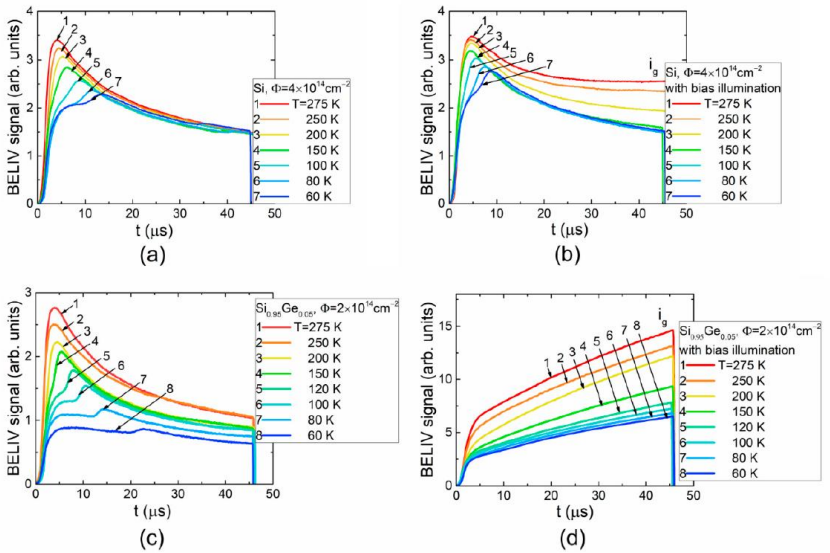
Rewards:

In 2022 T. Ceponis, E. Gaubas, J. Vaitkus received the Lithuanian National Science Prize for the cycle of work on “Study of impact of high radiation fluences on matter for development of dosimetry and radiation technologies (2006-2020)”.

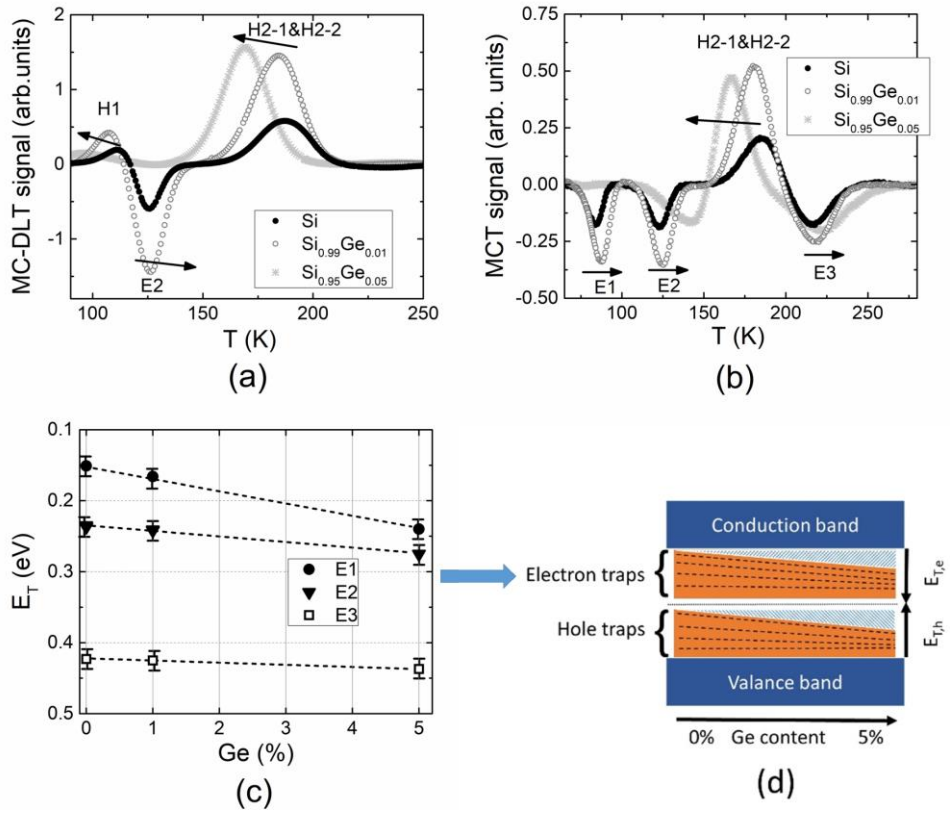
Thank you for your attention

Spectroscopy of defects in irradiated sensors





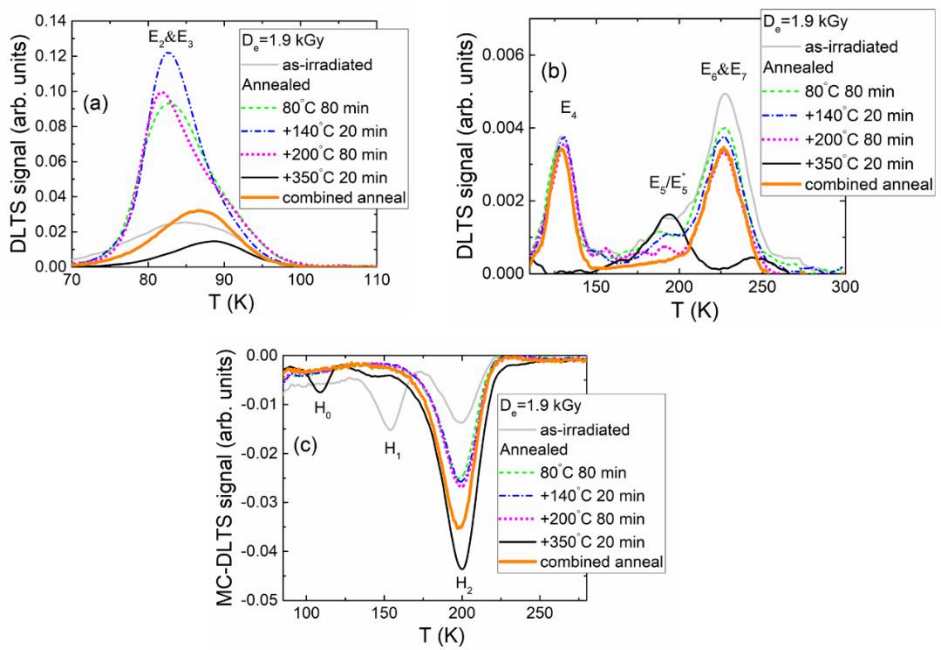
Temperature-dependent BELIV transients in Si and $Si_{1-x}Ge_x$ diodes measured in dark (a,c) and under (b,d) laser illumination.



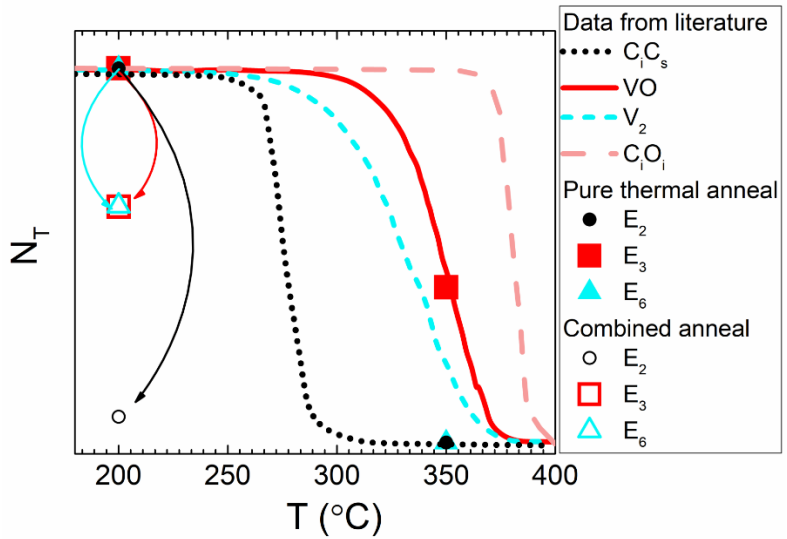
Comparison of MC-DLT (a) and MCT (b) spectra obtained in the 5.5 MeV electron-irradiated Si, $Si_{0.99}Ge_{0.01}$ and $Si_{0.95}Ge_{0.05}$ diodes; (c) The activation energy values (E_T) of the radiation-induced traps (E1–E3) of minority carriers as a function of Ge content; (d) A tentative scheme of the band gap variation in p-type $Si_{1-x}Ge_x$ material and related activation energy changes in the minority carrier traps depending on the Ge content.

J. Pavlov, T. Ceponis, K. Pukas, L. Makarenko, E. Gaubas, *5.5 MeV electron irradiation-induced transformation of minority carrier traps in p-type Si and $Si_{1-x}Ge_x$ alloys*, Materials **15** (2022) 1861.

Techniques for recovery of radiation damaged detectors



Thermal processing regime dependent variations of the deep-level transient (DLT) spectra of majority (a) and (b) and minority (c) carrier traps recorded on the pristine and electron irradiated Si PIN diodes.



Temperature ranges (according to literature data) where various carrier traps in Si materials can be isochronally 15-30 min annealed out (solid curves) are compared with the data obtained in this work using pure thermal (solid symbols) and combined furnace-laser (open symbols) anneal technology. It can be seen that the combined anneal leads to more efficient transformations of defects when compared with the pure thermal anneals by reaching the same temperature $T_{furnace}$.

T. Ceponis, M. Burkanas, A. Cicinas, L. Deveikis, J. Pavlov, V. Rumbauskas, J. Venius, E. Gaubas, *Combined techniques for recovery of radiation damaged detectors*, accepted for publication to Mat. Sc. Sem. Proc. journal.