F I N A L R E P O R T

Related to solution of the project of programme NPU I

Project code:	**LO1402**
Project name:	CENTEM+
Recipient:	University of West Bohemia, Pilsen, Czech Republic
Other participant of the project:	
Other participant of the project:	
Author:	Doc. RNDr. Pavol Šutta Ph.D.
Time period:	from 1. 1. 2015 till 31. 12. 2019

Date 12. 2. 2020

Singature of principal inwestigator

Stamp and signature of statutory body of the recepient

Západočeská univerzita v Plzni
rektor
doc. Dr. RNDr. Miroslav Holeček

ASSESSMENT OF THE COURSE AND BENEFIT/IMPACT OF PROJECT SOLUTION

1. Staff

Category	Status as of project commencement		Status as of project termination		AverageFTE for the whole project
	No of persons	Total FTE	No of persons	Total FTE	
D.1	19	12,68 FTE	23	14,31 FTE	14,56 FTE
D.2	54	34,50 FTE	57	31,86 FTE	35,14 FTE
D.3	22	16,18 FTE	30	19,59 FTE	18,75 FTE

In 2015 in total 21 students of master and doctoral study programs participated in the project solution (based on the timesheets). In 2016 the same number of students participated as in the previous year, i.e. 21. Among which were 18 doctoral students and 3 master degree students. In 2017 number of students of both types of studies declined to 16. Among which 14 were enrolled for doctoral studies and 2 for master studies. In 2018 we had in total 11 students all of which were of doctoral study programs. In the last year in total 8 students participated in the project, 7 of them were doctoral students and 1 master student.

All 23 employees of D1 category have a scientific rank degree equivalent to Ph.D., 4 have professorial title, 5 has title of associate professor and 3 are associate professor candidates. The others comply with the requirements for associate professor title except for the requirement on lecturing. In D2 category there are 28 employees with Ph.D. qualification. It is assumed that majority of remaining 19 specialists would be awarded the Ph.D. title. Obtaining academic titles is rather difficult for the University Institute New Technologies – Research Center - NTC as it has no own Bc. or Mgr. students. Average FTE during the whole term of the project solution of the D1 category is 14,56 FTE, in the category D2 it is 35,14 FTE. Planned overall FTEs was 68 FTE, average value during the whole term of the solution was 68,45 FTE. At the beginning of the project realization 23 graduates of master degree programs participated in the project realization and during its course other 17 graduates of the master degree and doctoral degree participated in the project compared to the initial state.

During the following period, all research teams will continue in commenced research and their research objectives will be specified and adjusted.

Professorships:
Prof. Dr. Ing. Juraj Kosek (2016)
Prof. RNDr. Josef Voldřich CSc (2018)
Prof. Ing. Milan Honner Ph.D. (2019)

Habilitation:
Doc. Dr. Ján Minár (2018), doc. Jiří Martan, Ph.D. (2019), doc. Tomáš Křenek, Ph.D (2018), doc. Ing. Petr Kočí, Ph.D. (2015), Doc. Ing. Zdeněk Slouka, Ph.D. (2017).

Dissertation:
Sikander Azam(2016), Wilayat Khan (2016), Saleem Ayaz Khan (2017), Jiří Vrána (2019), Martin Kučera (2017), Marek Vostřák (2018), Tomáš Syka (2018), Václav Čibera(2018), Lenka Loukotová (2017), Andra Nistor(2019).

2. Implementation of planned aims

Aim 1: Research program **CT1** – **Morphology and surface structure of materials**
WP1 (basic research), **WP5** (applied research)

Aim WP1:

Experimental study of material morphology, morphology formation and characterization of selected application properties.
Extending the theoretical foundations of microtechnologies towards new non-standard materials, manufacturing processes and applications.
Influence of morphology of porous catalysts on transport rate, reaction, structure changes and overall catalyst efficiency.
Characterization of electrochemical activities of carbon-based materials and other model materials in relation to their surface structure.

Description of fulfillment The research program Morphology and Surface Texture of Materials (WP 01) carried out research in a number of seemingly heterogeneous areas whose common denominator is the experimental study of material morphology, morphology formation and characterization of selected application properties. This experimental study was often supplemented by advanced techniques of mathematical modeling performed usually with our own developed software. In the experimental work, not only the analysis of the structure of materials was carried out with the aid of different instruments, but also the actual apparatuses were designed, constructed and tested, allowing the original research to be carried out.

The XRadia uCT400 X-ray micro-tomography machine, purchased as part of the previous CENTEM project, was a key instrument for meeting of the WP01 research targets. Within the CENTEM + project, a number of methodologies have been developed to characterize the intrinsic morphology of difficult-to-scan materials, such as the methodology for scanning catalyst particles in an inert atmosphere, which prevents the catalyst particles from falling apart during scanning. Furthermore, a method of scanning swollen heterogeneous ion-exchange membranes embedded in a polymethylmethacrylate carrier, allowing characterization of the change in intrinsic morphology of individual membrane components for different conditions was developed. The use of this method enabled the creation of a series of 4 publications in the very prestigious Journal of Membrane Science (5th publication in review, 6th in preparation).

The micro-tomography machine was also used to characterize the internal morphology of various types of catalytic monoliths and to determine the distribution of catalyst layers in automotive catalysts. The measured and reconstructed structures were used as real geometry for the mathematical models we developed describing the transport and reaction of exhaust gases in catalysts. The results were published in the prestigious Chemical Engineering Journal, Catalysis Today and others.

In the field of polymer morphology, we mapped the distribution of ethylene-propylene rubber (EPR) domains within a PP matrix using a Raman microscope. We have determined that the presence of block copolymers affects the structure of the rubber domains and the local chemical composition (ethylene and propylene distribution) at the interface between the domains and the matrix. We created and validated a model for predicting the

morphology of foams prepared by thermally induced phase separation. These foams have different structures and are also used to study the effect of morphology on thermal and acoustic insulation properties.
In the field of microfluidics, two-phase flow in microfluidic devices was studied. A mathematical model of a microfluidic chamber was created in parallel from two sides surrounded by microelectrodes. The presence of two immiscible liquid phases was considered inside the chamber. The electrically conductive phase forms a droplet and the non-conductive phase a surrounding liquid. If the droplet is electrically charged, it is attracted to the electrode of opposite polarity. The mathematical model allows to study the transfer of electric charge between the droplet and the electrode, as well as the deformation of the droplet at the surface of the microelectrode. The mathematical model is based on the use of the level-set method, mass balance, momentum and electric charge. The developed model is useful for studying the fundamental processes associated with targeted delivery of discrete volumes of fluid in spatially complex microfluidic arrangements.
The change in the morphology of the carbon electrode materials during their use has a great effect on the behavior of the final device, be it an electrochemical sensor, battery or fuel cell. The aim of this branch of the research was to prepare a set of morphological techniques enabling online and in-situ monitoring of changes in electrode surfaces and active components in electrode materials (eg, battery mass or active components of flow batteries). During the project, a concept allowing Raman microscopy of material surfaces in combination with electrochemical testing (cyclic voltammetry) in a highly corrosive sulfuric acid environment was prepared. The developed solution was used in the project GACR - GP14-33400P. The electrochemical cell for AFM was adapted to monitor the corrosion of the developed bipolar plates within the project TAČR - TA04011373. The results were published in the Journal of Power Sources.

Aim WP5:

Complementing experimental studies with advanced techniques of mathematical modeling performed usually with our own developed software.
Design, construct and test own apparatuses.
The aim is also to compare the results of mathematical models with real experiments and optimize the parameters of these models so that it is possible to predict the results of real experiments on the basis of modeling.

Development of innovative components for energy storage systems such as bipolar plates and electrodes with defined surface morphology.
Implementation of multilayer catalytic exhaust conversion systems combining different functions into one device.
Preparation of nano- and micro-structured foams and layered structures to improve thermal or acoustic insulation properties.

Description of fulfillment:

In the field of morphology formation and characterization of polymer foams, an apparatus for impregnation of a polymer sample and subsequent foaming with laser pulses was designed and constructed by the so-called "laser induced foaming" method. Experiments were carried out on non-impregnated polymer samples with or without additives. The methodology of analysis and characterization of such samples was proposed on these samples. Other polymer samples were impregnated with various blowing agents

and the effect of blowing agent concentration and various laser setting parameters on the resulting morphology was investigated. The model of nucleation process and foaming simulation was created, which includes effects such as cell coalescence and Ostwald maturation. The model results were compared with experimental results.

The electro-spraying method is an inexpensive method for preparing nanoparticles of uniform size and properties. Particle size is directly influenced by a number of process parameters such as temperature, ambient atmosphere composition, needle precursor flow rate, precursor conductivity and viscosity, and many others. In the NPU project, the current design of the electrospray device was modified, improving the temperature control of the pad and the dosing of the precursor solution. These treatments allowed the repetitive deposition of nanoparticle layers at temperatures from 20 to 350 ° C. The modified equipment was used for a) preparation of nanoparticles of metal oxide (Mn, Cu, Fe, Ni) and b) polymer (polystyrene) particles for hydrophobic layers.

Both of these model systems were used for learning and studying the influence of key parameters on deposited morphology. The morphology of the deposited layers was analyzed using SEM, AFM and Raman microscopy. Obtained dependencies of morphology on electro-spraying parameters were applied in design of model describing deposition of nanoparticles in electric field. The results of deposition of Mn nanoparticles were published in an impact journal.

Within the CENTEM + project, the development and optimization of components for the vanadium flow battery pack continued, in particular for the carbon porous electrode and composite bipolar plate. The properties of the graphite felt porous electrode have been optimized with respect to electrical conductivity, felt thickness and catalytic activity for the electrode reactions of the vanadium flow battery. Furthermore, optimum felt conditioning conditions have been found for the positive and negative electrodes of the battery, and this optimum was strongly dependent on the origin and characteristics of the felt. A series of polyolefin-based composite boards containing 1-3 different carbon fillers were prepared, and the effect of granulate composition and board forming conditions on the resulting electrical and mechanical properties of the boards was investigated. An optimum granulate composition has been found to produce sufficiently conductive and solid composite plates for flow-through application at significantly lower fill rates than commercial plates. Due to intensive testing of new materials, the internal resistance of the laboratory cell was reduced below 0.5 Ohm.cm2. Furthermore, a flow cell was constructed to allow online monitoring of the electrolyte properties of the vanadium flow battery. This solution allows us to monitor changes in concentration and composition during real battery operation. Within the project TAČR TA04011373, 6 applied results dealing with components for energy storage systems were developed.

Combination of internal structure imaging techniques (SEM, TEM, microCT), mathematical modeling and measurement on specially designed apparatus were used to investigate and evaluate the effects of internal diffusion on transport characteristics of prepared multilayer catalytic systems. The results were published in the Catalysis Today journal.

Highlights of the WP1, WP5:

The objectives of WP1 and WP5 overlap in many topics and there is no distinct boarder to determine which results belong to basic or applied research and therefore we present the results in summary. In total, 31 impacted publications and 8 applied results were produced within WP1 and WP5. Of the above-mentioned impacted publications, 4 publications in the Journal of Power Sources (IF 7.467), 5 publications in the Journal of Membrane Science (IF

7.015), 2 publications in the Chemical Engineering Journal (IF 8.355) and 3 publications in Catalysis Today (IF 4,888) were published. Of the applied results, the most significant result is the prototype of the vanadium flow battery pack, which was created in cooperation with Pinflow energy storage, s.r.o., which has licensed know-how from the UWB for vanadium battery packs. During the CENTEM+ project a prototype of the vanadium flow battery stack was developed, which is expected to be commercially produced in 1Q / 2020.

[1] Dudák M., Novák V., Kočí P., Marek M., Blanco-García P., Thompsett D.: Impact of zeolite and γ-alumina intra-particle diffusion on the performance of a dual layer catalyst, Chemical Engineering Journal 301 (2016) p. 178-187, AIS: 1.064**, IF: 6,216;** Q1; Q1; DOI: 10.1016/j.cej.2016.04.085

One of the important goals in the development of automotive catalysts is to save space and costs by combining different catalytic functions into a single multilayer monolithic reactor. However, the overall catalyst performance, and in particular the performance of the bottom layer, can be adversely affected by the low transport rate through the top catalyst layer. We have previously introduced a new approach to predicting efficient diffusion coefficients in porous layers containing both small intra-particle pores and large macropores between particles, allowing rapid global mass transport. The method is based on realistic 3D reconstruction of the porous structure and subsequent solution of the diffusion equation in the reconstructed domain. In this paper, we extend the application of this approach to zeolite/□-alumina + Pt/□-alumina multilayer structures and seek to clarify the contribution of large and small pore diffusion within zeolite or alumina microparticles to overall transport, which is particularly important for the construction of multilayer catalysts.

The result is of international significance, as it has been published in the International Impacted Journal (Chemical Engineering Journal) with an impact factor of 6.216 (2016) and has been cited 10 times so far. The present work shows that it is important to understand the factors affecting the performance of a catalyst. In the case of a dual layer catalyst, a poor design of the system can lead to low activity as the gas does not come into contact with the active sites. The combined experimental and modeling approach shown here can help to improve the performance of a dual layer system as it can be used to determine the impact of micro-, meso- and macropores on the catalyst performance.

[2] Mazúr P., Mrlík J., Beneš J., Pocedič J., Vrána J., Dundálek J., Kosek J.: Performance evaluation of thermally treated graphite felt electrodes for vanadium redox flow battery and their four-point single cell characterization, Journal of Power Sources 380 (2018) p. 105-114, AIS: 1.186, **IF 7,467;** Q1, Q1, Q1, Q1; DOI: 10.1016/j.jpowsour.2018.01.079

The developed and applied method of complex characterization of the cell of the flow battery enables to quantify the efficiency losses on individual internal components of the battery cell. These are evaluated from impedance and polarization measurements using platinum measurement electrodes embedded directly in the flow cell.

The method was used to study the effect of functionalization of felt electrode fibers on catalytic activity for vanadium redox flow battery reactions. It has been clearly shown that the effect of functionalization of the felt fibers is only beneficial for the negative electrode reaction, whereas in the case of a positive electrode, functionalization is undesirable. The developed method and the results obtained by this method allow to identify the main sources of inefficiency of the battery cell and on the basis of this information subsequently

optimize the cell parameters in order to increase its efficiency. The method can be used to study the performance and durability of the cell's internal components, i.e. electrodes and membranes, and can be easily adapted for research into flow batteries of any chemistry.
The result is of international significance, as it has been published in the International Impacted Journal (Journal of Power Sources) with an impact factor of 7.467 and has been cited 15 times so far.

[3] Mazur P., Mrlik J., Pocedic J., Vrana J., Dundalek J., Kosek J., Bystron T.: Effect of graphite felt properties on the long-term durability of negative electrode in vanadium redox flow battery, Journal of Power Sources 414 (2019) p. 354-365, AIS: 1.186, **IF 7,467**; Q1, Q1, Q1, Q1; DOI: 10.1016/j.jpowsour.2019.01.019

In this publication, we study the long life of two different graphite felt (commercial polyacrylonitrile and silk-based laboratory), which serve as a negative electrode in vanadium flow batteries. Both electrodes differ in the precursor material and the mode of activation, causing significant differences in the respective properties. The performance stability of the felt during the charging cycles performed in laboratory single cells is evaluated using the four-point characterization method developed in the above-mentioned publication. Furthermore, a complex post-mortem characterization is performed to identify the causes of different durability of both negative electrodes. The results show that the silk-based felt we have, thanks to the large active surface area, has excellent performance stability, which will be used in the construction of new types of flow-through vanadium batteries.The result is of international significance, as it has been published in the International Impacted Journal (Journal of Power Sources).

[4] Svoboda M., Beneš J., Vobecká L., Slouka Z.: Swelling induced structural changes of a heterogeneous cation-exchange membrane analyzed by micro-computed tomography, Journal of Mebrane Science 525 (2017) p. 195-201, AIS: 1.189**, IF 6,578;** Q1, Q1; DOI: 10.1016/j.memsci.2016.10.046

Heterogeneous ion exchange membranes are a major component of electromembrane units, which are one of the most common technologies for both desalination and high salt concentration water treatment (e.g. seawater desalination) and also for concentration gradients energy recovery. The quality of the membranes is essential for the proper functioning of the modules. The publication presents a completely new approach to the study of the internal microstructure of heterogeneous membranes by X-ray computed microtomography. Our method allows 3D reconstruction of heterogeneous ion-exchange membranes not only in the dry state, but also in the swollen state in which they are used in the given modules. As far as the authors know, no other scientific group in the world is able to carry out full 3D reconstruction of membranes in swollen state and therefore the result is of worldwide importance. The method based on the described technique can easily be used to scan other swollen or wet samples and allows not only their spatial morphological analysis, but also the detection of structural defects that may be associated with the sample exposure to a humid environment. We use this method to characterize the morphology of studied membranes and in research in which the behavior of the membranes in the electric field is related to their structure. These methods serve for further development of membranes with optimized structure for the chosen application. As a result, the described method of studying 3D membrane structures will contribute to the intensification of

desalination processes in electrodialysis modules. It has been published in the International Impacted Journal (Journal of Membrane Science) and has been cited 22 times so far.
[5] Vrána J., Charvát J., Mazúr P., Bělský P., Dundálek J., Pocedič J., Kosek J.: Commercial perfluorosulfonic acid membranes for vanadium redox flow battery: Effect of ion-exchange capacity and membrane internal structure, Journal of Mebrane Science 552 (2018) p. 202-212, AIS: 1.175**, IF 7,015;** Q1, Q1; DOI: 10.1016/j.memsci.2018.02.011

In contrast to previous works in this field, the method used represents a comprehensive set of experiments, on the basis of which it is possible to directly characterize complex membranes for redox flow batteries. This allows, for example, direct comparison of membranes of different origins. In this work, the testing method was demonstrated on a series of membranes of the same thickness and different ion-exchange capacity. The resulting study is the first to follow the ion-exchange capacity and membrane morphology, as well as a comprehensive evaluation of a series of commercially available perfluorosulfonated membranes from various manufacturers for use in a vanadium redox flow battery. The work reveals the relation of ion-exchange capacity and membrane morphology and its direct impact on the operational characteristics of vanadium redox flow battery. It therefore defines a coherent direction in which the newly developed membranes are to be tested. In addition, the developed method makes it possible to decide directly and quickly whether the tested membrane is suitable for use in a vanadium redox flow battery or not. Among other things, the results obtained from the measurement of commercial ion-exchange membranes provide valuable data for subsequent mathematical models of both partial events (vanadium permeation, osmotic and electroosmotic phenomena on the membrane, etc.) and the whole vanadium redox flow battery. The ion-exchange membrane in redox flow batteries is a component dominantly affecting the internal resistance of these batteries, which defines the energy efficiency of the system. The published method represents a method leading to rapid pre-selection of suitable membranes even in systems with other chemistry, thus greatly simplifying the process of membrane selection. Simultaneously, when measuring membranes according to a defined method, experimental data are obtained as input for technological models of vanadium redox flow battery. The field of impact is thus extremely wide and goes well beyond the area of membrane development. The result has an international significance, it has been published in the International Impacted Journal (Journal of Membrane Science) and has so far been cited 10 times.

[6] Pocedič J., Mazúr, P., Dundálek, J., Vrána, J.: Pack of vanadium flow battery, Plzeň 2019, NTC-PRT-19-003,CENTEM+. License provided by company Pinflow energy s.r.o.

Aim 2: Research programme **CT2** – **Engineering of special materials WP2**(basic research, **WP6**(applied research)

Aim WP2:

The research and development is focused on the investigation of mass and charge transport in the PEM fuel cells and diagnostics & testing of the Nafion membrane. The obtained data will be compared with these for synthetized composite membranes. The theoretical description based on non-equilibrium thermodynamics will be developed to

investigate the mass and charge transport processes. Preparation and characterization of microcomposites, study of phase thermodynamics and phase transformations of components (filler, matrix, composite). Synthesis of nanoalloys with unique phase composition and structure and preparation of other metastable amorphous and crystalline phases with catalytic and bioactive properties via laser deposition.

Description of fulfillment:

A series of fundamental tests were conducted to determine electrical, sorption and surface properties of synthetized membranes, modified commercial membranes and pristine Nafion-type membranes. A novel catalyst suitable for hydrogen fuel cells was prepared. The performance tests of the catalyst were conducted using developed fuel cell prototype. The accelerated stress test protocol was finalised and used for low temperature fuel cell testing. The artificial degradation of gas diffusion layers for PEM fuel cells was studied. Project activities were focused on precise formulation of the theoretical model. In 2019, the theoretical model of hydrogen fuel cell with polymer membrane was published. The model is based on non-equilibrium thermodynamics (to be more specific - endoreversible thermodynamics). The theoretical model was validated by calculating the polarisation curve and measurement of the same curve using the commercial membrane electrode assembly. The comparison of the curves confirmed the theoretical approach used for the model construction. The investigation of adsorption material for hydrogen pollution removal was conducted and the material was tested in chemical reactor with simulated stream of polluted hydrogen. The adsorption material was prepared as a surface modification of activated carbon.

Research activities in the field of microcomposites and thermodynamics were focused on a detailed description of the chemical-physical properties of calcined clays and mixed systems based on fine-granulated blast furnace slag and thermally / mechanically treated metakaolin - structural and chemical analyses, surface activity and reactivity. The relationship between equilibrium, heat transfer and process kinetics on the one hand and the resulting thermos-analytic curve on the other hand for solid phase materials and solid dispersion systems has been elucidated. Further research was focused on the description of rheological properties of geopolymer materials and characterization of thermomechanical properties of particulate composites up to 1000 ° C. Subsequently, the research was focused on the kinetics of degradation of porous polymer carriers during thermal treatment of particle reinforced composites, measurement of rheological properties of materials in dependence on kinetics of hardening and determination of mechanical parameters (compressive and tensile strength) after temperature exposures.

Immiscible binary alloys (eg Al-Sn) and unique crystalline metastable FeS phases, amorphous Ti, nano-crystalline TiO + SiO suboxides were deposited under equilibrium conditions using laser ablative deposition (with Nd: YAG laser). Emission spectra during FeS deposition were obtained and interpreted and compared with the calculation of properties of metastable FeS structures. Laser ablation of bioactive nanoparticles based on hydroxyapatite and titanium on selected porous precursors was successfully performed. Furthermore, laser assisted deposition of nanostructured films and nanoparticles with catalytic (eg. CoS, FeS) and bioactive (ZrO, $CaTiO_3$, TiO, Si_5Ti_3) properties was tested. Bioactivity and osseointegration was tested by research of stem cell interactions with prepared biomaterial. The objectives were fulfilled by foreign impacted publications in the field of eg. metastable crystalline phases based on FeS, laser induced amorphization of pure Ti, synthesis of nanostructured photocatalytic TiO-SiO suboxides, laser deposition of

catalytic CoS or ablative deposition of biocompatible ZrO nanoparticles.

Highlights of the WP2:

[1] Josef Chmelař, Petr Bělský, Jiří Mrázek, Daniel Švadlák, Martina Hermannová, Miroslav Šlouf, Ivan Krakovský, Daniela Šmejkalová, Vladimír Velebný: Nanostructure of hyaluronan acyl-derivatives in the solid state, Carbohydrate Polymers 195 (2018) 468–475; **IF 6,044**; Q1, Q1, Q1; https://doi.org/10.1016/j.carbpol.2018.04.111

The paper contributes to elucidation of the structure of acylated hyaluronans, which are promising nanomaterials for biomedical applications. The work was created in cooperation with the Czech company Contipro a.s., Dolní Dobrouč, which is a large producer and exporter (one of the largest in the world) of hyaluronan and various products based on it for cosmetic, pharmaceutical, biomedical and veterinary applications. The NTC team used knowledge in the field of characterization of composite materials and nanomaterials and described the properties of the developed material using the SAXS technique. SAXS analyzes are carried out in the Czech Republic by only a few specialized workplaces.

[2] Kovařík T., Pokorna D., Urbanova M., Bezdicka P., Bastl Z., Kupcik J., Krenek T., Pola M., Kullova L., Pola J.: Formation of TiO/Al2O3/C Composite in Thermal Co-decomposition of Aluminium(III) Acetylacetonate and Titanium(IV) Oxyacetylacetonate. (Eng) J. Anal. Appl. Pyrolysis 117, 182-190 (2016). **IF 3,471**; Q1, Q1; DOI: 10.1016/j.jaap.2015.12.00

The contribution of this work is especially in the research of thermal decomposition of volatile precursors of alumina and titanium dioxide. This original work fulfills the assignment of the research WP02: Nanoalloys. The formation of various amorphous and crystalline phases of the Ti-Al-C compound has been demonstrated. Contribution is found especially in detailed structural and chemical analysis of the obtained structures.

[3] PAVELKA, M., WANDSCHNEIDER, F., MAZÚR, P. Thermodynamic derivation of open circuit voltage in vanadium redox flow batteries. Journal of Power Sources, 2015, roč. 293, č. říjen 2015, s. 400-408. ISSN: 0378-7753, **IF 6,333**; Q1, Q1, Q1, Q1; DOI: 10.1016/j.jpowsour.2015.05.049

The publication contributes to the elucidation of thermodynamic processes occurring in flow batteries. The output builds on the basic research activities of the Membranes and Fuel Cells and Thermodynamics group. The calculations verify and confirm the thermodynamic relationship of the voltages in the open circuits of vanadium redox batteries and reveal the difference between the voltages for the anionic and cationic membranes.

Published works are focused on refining the models of transport processes in the fuel cell. A societal benefit is the clarification of thermodynamic processes taking place inside the fuel cell and the implementation of these results in the preparation and optimization of prototypes. The use of hydrogen technologies is clearly associated with a detailed study of the processes taking place in fuel cells and their control and management. The safe use of hydrogen technologies is linked to ongoing research and publishing in this field contributes to the exploitation of results in this field. The publication outputs in the field of material chemistry are focused on the development of socially beneficial materials in the field of promising nanomaterials for biomedical applications (cosmetics and pharmaceutical industry). Contribution is found especially in detailed structural and chemical analysis of obtained structures. The NTC team uses knowledge in the area of nanocomposite materials

and nanomaterials characterization.

Aim WP6:

This work package is focused on fuel cell prototype construction and the development of methodical document for the degradation of polymer membrane, gas diffusion electrodes, catalysts and gas diffusion layers. The main goal of the work package is to synthetize a composite polymer membrane suitable for application in hydrogen fuel cells. The aim is to develop equipment and to verify the technological possibilities of electro-resistance curing (electric boosting method) of aluminosilicate, micro-composite mixtures with respect to equipment parameters (current, voltage, temperature) and with regard to product type (size, volume, weight).

Description of fulfillment:

The prototype of low temperature hydrogen fuel cell unit with active area 1 square centimeter was constructed. The prototype can be used for testing of promising materials like membranes or gas diffusion layers and a small amount of investigated material is needed. Furthermore, the methodical document for diagnostics and testing of fuel cell was finalised and the outcomes of this document were used for construction of fuel cell stack (approx. power output 1 kW). Then, the commercial partners were contacted to employ the stack into the pilot scale application. As an example, the pilot scale unit consisting of vanadium redox flow battery of power 10 kW is prepared to implement the fuel stack as a back-up system for recharging. The battery is meant to be an energy source for electric vehicles recharge station. The fuel cell stack is enriched by peripheral components and software system control to ensure the stand-alone application. Moreover, the fuel cell stack has been immunised against the pollution (carbon oxides, sulphur) in hydrogen by implemented adsorption unit. The system of fuel cell stack with peripheral devices was presented to commercial partners (Unipetrol, Devinn, ČEZ). The adsorption unit is promising device for companies which are producing large amount of polluted hydrogen (Unipetrol). The material used in adsorption unit can be used for carbon oxides removal in industrial processes to produce a clean hydrogen for electric vehicles (cars, trucks, trains etc.).

Testing of molds for curing by means of electro-resistance method with controlled parameters was successfully tested. 20 series of test specimens were prepared. Material parameters of test specimens and device parameterization were evaluated. This was followed by successful optimization of the cure mode (80 °C) with reduced temperature and humidity losses using graphite electrodes and laminate body mold design. We managed to produce composite boards with larger dimensions 50x50cm and weight > 10 kg. The repeated functionality of the curing process was successfully solved and the effectiveness of the molds was tested. The solution eliminated moisture losses. This was followed by a comprehensive evaluation of the technical parameters with respect to the state of the samples and the publication of the results obtained.

Highlights of the WP6:

[1]NTC-FVZ-2016-004

POKORNÁ, D., CUŘÍNOVÁ, P., FAJGAR, R., POLA, J., KŘENEK, T., KOVÁŘÍK, T., POLA, M., DUCHEK, P., VÁLA, L., NOVÁK, L., JANEČEK, V. **Functional sample** of porous catalysts, 2016

Functional samples of composite catalysts for Fenton degradation of antibiotics in waste water were prepared by sorption of hercynite on porous ceramic filter Vukopor, laser ablative deposition of magnetite on porous geopolymer, and laser ablative deposition of

magnetite on extruded high-density polyethylene PAQ 800+.
Samples are usable as fixed filtration bed and the latter as suspended bodies in a flow reactor for degradation of antibiotics and other pollutants in waste water.

[2]NTC-FVZ-2017-002
TOMÁŠ, M., KŘENEK, T., POLA, M., 2017, **Functional sample**
A measurement device for the electric and/or ionic conductivity determination using thin platinum layer.

The device can be used to determine electrical properties of thin film polymer membranes. The device was connected to electrochemical impedance spectroscopy and the impedance spectra were measured. These spectra were analyzed in order to study structural parameters. An equivalent circuit analysis was applied and the numerical simulation was conducted. Then, the diffusion coefficient was calculated by comparison of measured spectra and simulated curves.

[3]NTC-FVZ-2018-005
REMIŠ, T., KADLEC, J., POLA, M.
The device for membrane casting, 2018, **Functional sample.**
Our device (casting knife) is supposed to form membranes of defined thickness and can be used for any backing plate (glass, plexiglass, teflon). The membranes are prepared by the casting solution method and subsequently cured. The thermodynamic properties of the membranes depend on the thickness of the membrane.

Aim 3: Reserach programme CT3 – Laser technologies, **WP3** (basic research),**WP7** (applied research)

Aim WP3:

To clarify the relationship between laser beam parameters, ongoing processes and resultinghanges in the structure and properties of material surfaces. To clarify the interrelationship of ongoing material processing processes and IR radiation emission / reflection processes. To clarify the relationship between the structure and composition of the surface of the material on the one hand and the resulting optical, thermal, mechanical and tribological properties on the other. To clarify the possibilities of developing new materials and their applications in new areas. To explain possibilities of development of new experimental methods based on intensive heat sources and fast infradetectors. Knowledge support of applied research activities. Explain the possibilities of using various methods of material properties analysis for evaluation of samples processed by laser technologies. Modify laser application laboratories for simultaneous use in basic research projects.

Description of fulfillment:

Fulfillment of the objective was realized through internal basic research projects solved in accordance with the topics of doctoral dissertations of students involved in the project and in connection with applied research. Laser application laboratories have also been adapted for this basic research. Research was conducted in laser welding, micro-machining and surface treatment. The result is new knowledge about the relationship between the parameters of the laser process and the resulting changes in the processed material, as well

as proposals for new methods of laser processing of materials. Research was conducted on the emission / reflection of IR radiation in connection with laser material processing processes. The result is the design of new measuring systems with expected use in diagnostics or control of laser technological processes. The possibilities of developing new experimental methods using intensive heat sources and infradetectors were analyzed. The results are proposals for new methods for determining the optical-thermal properties of materials (emissivity, diffusivity) and new methods for non-destructive testing of materials. Part of the research was devoted to the development of new materials. The result is the design of layers with suitable properties for use in thermography and measurement of material properties. In the period 2015-2019, the research team published 29 articles in impacted journals, the research also resulted in 5 patents received.

Highlights of the WP3:

[1] Honner M., Honnerova P. Survey of emissivity measurement by radiometric methods. Applied Optics, Vol. 54, 2015, pp. 669-683**. IF 1.784**

A survey of the state of the art in the field of spectral directional emissivity measurements by using radiometric methods is presented. Individual quantity types such as spectral, band, or total emissivity are defined. Principles of emissivity measurement by various methods (direct and indirect, and calorimetric and radiometric) are discussed. The paper is focused on direct radiometric methods. An overview of experimental setups is provided, including the design of individual parts such as the applied reference sources of radiation, systems of sample clamping and heating, detection systems, methods for the determination of surface temperature, and procedures for emissivity evaluation.

[2] D. Moskal, J. Martan, V. Lang, M. Švantner, J. Skála, and J. Tesař, “Theory and verification of a method for parameter-free laser-flash diffusivity measurement of a single-side object,” Int. J. Heat Mass Transf., vol. 102, pp. 574–584, 2016. ID: 43914409, **IF 2.857**

A new single-side flash method for thermal diffusivity determination is presented. The method is based on a laser-flash pulse excitation and infrared thermography non-contact temperature measurement of a thermal response of a studied object. Using this method, the both excitation and measurement at one side (front side) of the studied object are provided. An exact knowledge of the thickness, absorbed energy, emissivity or other material parameters of the object as well as temperature measurement on the opposite side (back side) of the object are not required. Thus, the method can be described as an object parameter-free single-side thermal diffusivity measurement method. The thermal diffusivity measurement procedure and data processing using an approximation algorithm are described in the paper. Simulation and experimental verification of the method is presented for several materials.

[3] MARTAN, J., MOSKAL, D., KUČERA, M. Laser surface texturing with shifted method – Functional surfaces at high speed. JOURNAL OF LASER APPLICATIONS, 2019, roč. 31, č. 2, s. NESTRÁNKOVÁNO. ISSN: 1042-346X, https://doi.org/10.2351/1.5096082, Q3, Q3, Q3; **IF 1.443**; AIS 0,386

Laser surface texturing is a promising technology for future wide applications of functional surfaces with specific properties like hydrophobic, antibacterial, adhesive, self-cleaning, anticorrosion, light absorbing, low friction, etc. Great advancements have been

made in this field in the last few years, but in most cases, it takes from minutes up to 1 h to produce 1 cm2 of a functional surface. Even the availability of high-power ultrashort pulsed lasers in the last few years did not dramatically increase productivity, because there are physical limitations of current processing methods: heat accumulation and oxidation, plasma shielding effect, and precision at high speeds. In order to solve these limitations, there have been developed a new method called a shifted laser surface texturing (sLST) method. The new method has a potential to be at least 100 times more productive with no heat accumulation effect and virtually unlimited number of complex shape objects produced with high precision on the surface. In the present work, the principle and advantages of the method are described. The results of the method are compared with two standard methods (path filling of objects and hatch over all objects). The sLST method is presented in both single pulse and burst variants. Examples of its application on different materials for increased adhesion of surface coatings are shown.

Aim WP7:

To develop new, especially remote, laser materials processing technologies (welding, cutting, machining, marking, surface treatment, etc.) for the development of new products and for their industrial production. To develop new IR measuring systems for on-line / off-line control and control of industrial processes. To develop new measuring systems based on IR measuring methods and laser technologies for laboratory and industrial use for measuring material properties and product testing. Ensure research cooperation and application of research results also in areas outside the main focus of the project. In connection with the application of the research results to address education and popularization in the topics of the project focus. Apply new methods of internal and external communication (eg based on social software) to increase the efficiency of activities and support teamwork.

Description of fulfillment:

Fulfillment of the objective was carried out in close cooperation with users of research results, especially in the framework of purpose-oriented projects and contractual research projects. The focus of the activity has gradually shifted from the research of laser materials processing technologies to the research of measuring systems for laser technologies and advanced materials. This change is demanded by the needs of the application sphere as well as by the evaluation according to the results of international significance with high economic impact or social relevance. The focus of the research was on laser welding, surface treatment and machining technologies for the development of new products and for their industrial production. The result is verified technologies and pilot plants. In the area of measuring system development, the work focused on on-line / off-line control and management of industrial processes. The results are functional samples of new measuring systems, software for thermographic measurement and prototypes of thermographic paints. Research results include functional samples and software for laboratory and industrial use to measure material properties and test products. Between 2015 and 2019, the research team participated in the creation of 6 verified technologies, 2 pilot plants, 10 functional samples, 6 prototypes and 7 software.

Highlights of the WP7:

[1] Honnerová P., Martan J., Veselý Z., Honner M. Method for emissivity measurement of semitransparent coatings at ambient temperature, Scientific Reports, Vol. 7, 2017, p. 1386,

IF: 4.259

Coatings deposited on a material surface are effective way of changing its surface properties. For increasing or decreasing radiation heat transfer, coatings with high or low emissivity are, used. Measurement of spectral emissivity is a fundamental step to effective use of coatings for this application. Up to now the measurement methods are focused on bulk samples and mainly opaque ones. Here we present a method enabling measurement of emissivity of semitransparent coating itself, although it is deposited on a substrate. The method is based on measurement of transmittance and reflectance using an integration sphere system and Fourier transform infrared (FTIR) spectrometer for samples with two different coating thicknesses deposited on transparent substrates. Measured transmittance of the coating indicates spectral regions of potential emissivity differences using different substrates. From all the measured values, spectral emissivity can be characterized for different coating thicknesses. The spectral range of the method is from 2 μm to 20 μm. The measurement is, done at ambient temperature enabling measurement of samples sensitive to heating like biomedical or nanocoatings. The method was validated on known bulk samples and an example of semitransparent coating measurement is shown on high-temperature high-emissivity coating.

[2] HONNEROVÁ P., HONNER M.: Prototype of reference thermographic paint HERP-HT-MWIR-BK-11. **Prototype** NTC-PRT-17-001, University of West Bohemia, Pilsen, 2017.

The result of research and development there are two prototypes of specially designed high emissivity paints for thermographic use from room to high temperatures. In collaboration with the industrial manufacturer of paints and sprays, the result was completed in the form of the product (spray paint), which is currently marketed by our research center under LabIR Paints and distributed to those interested in its use.

The paints have an appropriate combination of physical properties (transmissivity, emissivity, adhesion, temperature stability, etc.) to help to refine the non-contact temperature measurement by thermal imaging cameras or infrared detectors. The result of the development there are two complementary paints to be used in applications from room temperatures up to 1000 ° C. Thanks to the paints, it is now possible to measure materials with glossy surfaces (metals, glass, some plastics) for which the contactless temperature measurement has been problematic so far. Thus, the key obstacle to expand the non-contact temperature measurement into many disciplines is removed.

The interest in these paints has already been shown by research institutes, universities and commercial entities from the USA to Japan. In many cases, they are world leaders in their fields. Research organizations have bought these paints, for example, by Onera, the German Max-Planck Institute or the German Aerospace Center. The interest of industrial companies is for example from ABB, Cognatec or Tatasteel. The application of paints thus moves from the originally planned use in engineering and automotive to electronics, aerospace and many others. Surprising remains the interest of the Spanish National Museum of Natural Sciences.

Approximately one year after reaching the result, it can be said that it has been widely applied to more foreign markets. Due to the limited marketing activities of this product, we attribute this application's success to the fact that it is a result at the world-leading level that was not yet available on the market.

[3] HONNEROVA P., HONNER M., MARTAN J., KUCERA M., SKALA J.: Measurement System

for Analysis of Spectral Normal Emissivity of Materials at High Temperatures, **Functional sample** NTC-FVZ-19-004, Plzen, 2019.

The method enables measurement of temperature dependence of spectral emissivity of coatings up to 1000°C. The device consists of an FTIR spectrometer, high temperature blackbody, infrared camera, high power laser and various optomechanical components. The measured sample is placed in the thermal insulation on a positioning mechanism. The biggest innovations in this device are methods of sample heating and sample surface temperature measurement. Heating of the sample is secured by the laser and it is much faster than other heating methods. The desired sample temperature in the range from 300 to 1000°C is reached by the laser power control. Surface temperature of the sample is measured without contact using the infrared camera and a reference coating (LabIR paint) applied to a part of the analyzed coating. Such an arrangement allows accurate measurement of emissivity of coatings with high thickness and low thermal conductivity. The spectral dependence of the emissivity of coatings is measured by the FTIR spectrometer against a black body placed on the opposite side of the measured sample. Choice between the sample and the black body radiation signal is made by rotating parabolic mirror.

Aim 4: Research programme CT4 – Materials and technologies WP4 (basic research), WP8 (applied research)

Aim WP4:

Performance the high-quality transparent conductive ZnO films, silicon absorption films and completely suppress the light induced degradation in a-Si: H films. Research of dielectric thin films having a perovskite structure ($BaTiO_3$, $SrTiO_3$ etc.) with their potential utilization in photovoltaics, photonics and in micro-system technology. Performance the multi-layered structures with different refractive indices for their utilization in photonics and in photovoltaics.

Description of fulfillment:

In a period of project solution work of the research team was focused on performance and research of high quality transparent non-conductive and conductive ZnO films doped by selected elements (Al, Ga, Co, Cr, Ni, Ti) in order to modify their physical properties proposed especially for certain photonic and micro-system applications. ZnO films having optimized parameters (structure, conductivity, preferred orientation of crystallites) were utilized for piezoelectric generator construction, GaP/ZnO hetero-junction deposited on GaP nano-vires and as an intermediate adhesive film between the glass substrate and Au nano-islets. ZnO films were created by PVD technology (magnetron sputtering and pulsed lased deposition). Research was focused also on improving electrical properties of the films deposited at low temperature (100°C), which can be deposited on temperature sensitive polymer substrates for a flexible electrotechnics. Furthermore, the oxygen content influence on structure and electrical properties of the aluminum doped ZnO films deposited from ceramic targets at temperatures 100°C and 250°C were also probed. In the films doped by a higher level of Ni and Co concentration, ferromagnetic properties have been observed.

In the area of photovoltaic technologies at recent time, more component ferroelectric materials with a perovskite structure (BaTiO3, SrTiO3, etc.) prepared also by a magnetron sputtering technology have been employed. Adding an appropriate element (Co or Ni),

these materials can be transformed from ferroelectric to the ferromagnetic state, but only after the post deposition heat treatment at temperatures 700-900°C, because the ferromagnetic material requires certain degree of crystallinity. As deposited materials had an amorphous structure and no ferromagnetic behavior has been observed. Materials mentioned above can be used as absorption layers in combination with silicon absorption layers to create solar cells. Such solar cells were recently created and for a very short time their efficiency has improved from 2 % in 2009 to 22 % in 2016. Among others, BaTiO3 films in amorphous state exhibited very good antireflective properties, which, when putting them into the solar cell systems, will lead to their higher efficiency.

Apart from the simple absorption layers for tandem solar cells on the silicon basis, especially for the cells with more *p-i-n* structures, multi-layered a-Si:H/a-SiNx:H structures are appropriate too, because where optical band-gap can be tuned by change of a-Si:H sub-layers thickness and their micro-structure. A-Si:H/a-SiNx:H multi-layers were deposited by PECVD technology from silane and nitrogen and subsequently thermally annealed in vacuum at temperatures between 600°C and 1100°C. Sub-layer thicknesses were 5, 10, 15 and 20 nm. Influence of the sub-layers thickness and annealing temperature used on a crystallinity of the a-Si and µc-Si sub-layers were analyzed, because both parameters strongly influence their structure and optical properties. Sub-layers a-SiNx remain amorphous in this process. Hydrogen leaves the multi-layers already at annealing temperature about 500°C. Thinner multi-layers require higher annealing temperatures for crystallization in general (5 nm thick at least 1000°C), and crystallization of more thick multi-layers can be control by annealing temperature level. Generally speaking, structural and optical properties of the multi-layered films are influenced by deposition parameters and by annealing temperature process as well.

Highlights of the WP4:

[1] Siddheswaran, R., Netrvalová, M., Savková, J., Novák P., Očenašek, J., Šutta, P., Kováč, J. Jr., Jayavel, R.:, 636 (**2015**) 85-92, **IF 3.779** Q1 Cit. 22x

Zinc oxide (ZnO) in recent years became interesting for many research institutes. Physical properties (piezoelectric, pyroelectric, photovoltaic, optic and others) of pure and also doped ZnO created by using various technologies predestine it for a broad utilization in microsystem technology, optoelectronics and photovoltaics. This paper deals with the zinc oxide films doped by nickel (ZnO:Ni) deposited by a reactive magnetron sputtering appropriate particularly for optoelectronic applications. Doping levels were 3.5, 4, and 6 atomic % of Ni. Important optical properties are transmittance, optical band-gap and refractive index depending on the microstructure of the films. Doping level of ZnO by nickel has strong influence on refractive index level, which is decreasing when doping level has increased. The same as transmittance of doped films is strongly lower in scale of wavelength between the 400-600 nm against the non-doped ZnO. More significant ferromagnetic effect was observed when the films were doped at doping level 6 at % of Ni. The optical band-gal level has increased to 2.8 eV against 3.34 eV for non-doped ZnO regardless of the dopant amount.

[2] Siddheswaran, R.; Šutta, P.; Novák, P.; Netrvalová, M., Hendrych, A., Životský O.: In-situ X-ray diffraction studies and magneto-optic Kerr effect on RF sputtered thin films of BaTiO3 and Co, Nb co-doped BaTiO3. CERAMICS INTERNATIONAL 42 Issue: 3 (**2016**) 3882-3887, **IF 3.057**, Q1 Cit. 10x

BaTiO3 belongs to the ferroelectric materials, which are significantly applied among others in photovoltaic technologies. If it is prepared by the magnetron sputtering method at low temperatures, material prepared will be in an amorphous state. After a post-deposition thermal annealing process at temperatures from 700°C to 900°C material prepared transforms from the amorphous phase to a polycrystalline phase. Similar situation become also in case of BaTiO3 films doped by cobalt and niobium. In these films their magneto-optic properties were investigated depending on the post-deposition thermal treating of the films. After the heat treatment the BaTiO3 films doped by cobalt transformed from amorphous to polycrystalline phase and very good ferromagnetic properties of the films have been obtained. No ferromagnetic properties have been observed in the amorphous state of the films, because the ferromagnetic material have to be in some polycrystalline state. Films doped by cobalt achieved roughly perfect crystallites about 40 nm in diameter already at 700°C annealing temperature. This effect was more effect when films were annealed at temperature of 900°C. Utilization of the films can be found at amorphous state in area of ferroelectric applications (photovoltaics and photonics) and also at polycrystalline state in areas of ferromagnetic applications.

[3] Tvarožek, V., Szabo, O., Novotný, I., Kováčová, S., Škriniarová, J., Šutta, P.: Plasmonic behavior of sputtered Au nano-island arrays. APPLIED SURFACE SCIENCE 395 (**2017**) 241-247, **IF 4.739**,Q1 Cit. 3x

Nanoparticle areas created from the noble metals (Pd, Ag, Pt, Au) in form of individual islets deposited onto the transparent substrates, for example by a diode sputtering, have a broad employment in utilization of localized surface plasmonic resonances, which are a coherent oscillations of free electrons in metal nano-islets of solid material excited by electromagnetic field namely in an optical scale of spectrum. These phenomena can be used in nano-technology, for example for optical nano-waveguides, excellent optical nano-lenses, or for nano-lithography having distinguishing better than the wavelength used is. Nevertheless, interesting are also applications of these phenomena in area of biological sensors and photovoltaic cells. In this paper, gold islets were deposited on glass substrates and also on zinc oxide films doped by gallium. Effective thickness of the films (height of the Au nano-islets) was 2-8 nm with preferred orientation of (111) lattice plains in direction [111] perpendicular to the substrate. Plasmonic effect of the Au-islets was observed using UV Vis spectrophotometry and was described by modification of a size scaling universal model using the nominal thin film thickness as a technological scaling parameter. Insertion of titanium ultra-thin adhesive inter-layer between the glass and nano-islets substantially improved adhesion of the nano-islets and their forming to the smaller dimension.

Aim WP8:

Investigation of the intrinsic and doped ZnO films for piezoelectric phenomenon utilization as the transparent conductive electrodes. Performance the 2D photonic structures with a forbidden frequency band-gap. Suggest and performance the functional one-dimensional solar cell based on silicon thin films. Suggest and performance the functional tandem solar cell based on silicon thin films (amorphous and micro-crystalline silicon *p-i-n* structures).

Description of fulfillment:

In area of the piezoelectric phenomenon of ZnO films utilization and also as transparent conductive layers their investigation was focused on an optimization of the deposition

technology of undoped ZnO and ZnO doped by aluminum. While non-doped ZnO was utilized for piezoelectric cantilever construction for voltage measurement, ZnO film doped by aluminum was concentrated for technology optimization of thin conductive films as electrode for nano-rods arrays instead of ITO electrode, which was also utilized for construction of piezoelectric generator on a flexible substrate within the Partnership Agreement with Quin Mary University of London UK.

Two-dimensional photonic structures based on a-Si:H/a-SiNx:H were prepared by PECVD technology from silane and nitrogen 500-550 nm in thickness on silicon and on quartz glass substrates. Individual multi-layers were composed from sub-layers with different thickness (5, 10, 15 and 20 nm) and after deposition they were in amorphous state and structural and optical properties of the multi-layers were analyzed at this state. Multi-layers were subsequently thermally treated individually and step by step at temperatures of 600, 700, 800, 1000 and 1100°C in vacuum. Hydrogen at these temperatures has released from the films and silicon nano-crystallites started to form in size depending on temperature level and on a-Si:H sub-layer thickness. At the same time, sub-layers a-SiNx:H transformed to a-SiNx. Microstructure of the films was analyzed by X-ray diffraction, transmission electron microscopy and Raman spectroscopy. All these experimental methods indicated occurrence of silicon nano-crystals in a dielectric matrix. Optical properties of the films were analyzed by UV Vis spectrophotometry and a two-dimensional and three-dimensional quantum effects were in the process observed, demonstrated by absorption edge shifts and by different optical band-gaps found out. Application of these multi-layers can be as in amorphous state with hydrogen (not thermally treated), as in amorphous state without hydrogen (annealed at 600°C) and also in the nano-crystalline state. Very interesting are also values of effective spectral refraction indices of the films, which are different for the individual film thickness of sub-layers and also for the different level of heat treatment.

In order to verify functionality of individual *p-i-n* structures in silicon tandem solar cells, a tandem solar cell contained two *p-i-n* structures (a-Si:H/µc-Si:H) was created. Solar cell was prepared by PECVD technology from silane diluted with hydrogen in a standard superstrate configuration on a glass substrate covered by a transparent conductive oxide. Sub-layers *p* and *n* were prepared from silane diluted by diborane (*p*-type sublayer) and by phosphine (*n*-type sublayer). In the first absorption layer (a-Si:H) silane was diluted by hydrogen at level $R = 5$, because according to our previous research it had the lowest micro-voids value in a film volume. The second absorption layer (µc-Si:H) silane was diluted by hydrogen at level $R = 40$, where according to our previous research, nano-dimension silicon crystallites were reliable created and they are surrounded by amorphous Si. The tandem cell has following parameters: Open voltage $V_{OC} = 1.3$ V, short current density $J_{SC} = 12$ mA/cm^2, fill factor $FF = 71$ % and conversion efficiency E_{ff} 11.7 %. In order to increase the solar cell efficiency, antireflection layer, back scattering reflector, or metallic nano-particles (Au) can be implemented to the cell for increasing the non-equilibrium charged carrier concentration.

Highlights of the WP8:

[1] Yilmaz, P., Greenwood, P., Meroni, S., Troughton, J., Novák, P., Li, X., Watson, T., and Briscoe, J.: Self-adhesive electrode applied to ZnO nanorod-based piezoelectric nano-generators. SMART MATER. STRUCT., https://doi.org/10.1088/1361-665X/ab255b in press (2020)

ZnO nanorod-based piezoelectric devices have gained wide attention in energy harvesting systems as they can be processed at low temperatures onto flexible plastic

substrates, giving a good potential for low cost. However, the vacuum-evaporated, precious metal contacts remain a high-cost element of the devices. This paper discusses the use of transparent conductive adhesives (TCAs) as an alternative top contact that is free from both vacuum-evaporation and precious metals. TCA films of various thicknesses were tape-cast onto nickel microgrid on PET substrates and adhered using low-pressure cold-lamination to bond the adhesive component of the TCA to piezoelectric generators with the final device structure of PET/ITO/ZnO-seed/ZnO-nanorods/CuSCN/PEDOT: PSS/TCA. The piezoelectric performances of the devices were compared by measuring output voltage in open-circuit and maximum power output across a range of resistive loads. The voltage output was observed to rise with increasing TCA thickness, reaching a maximum value of 0.72 V generated with 110 µm of TCA as top contact. However, the higher resistance due to increased TCA thickness led to decreased power output; a maximum calculated power of 0.25 µW was obtained from the device with the thinnest TCA layer of 22 µm. Finally, the performance of piezoelectric nanogenerators with TCA contacts were compared to a control device with an evaporated gold contact.

[2] Scholtz, Ľ., Šutta, P., Calta, P., Novák, P., Solanská, M., Müllerová, J.: Investigation of barium titanate thin films as single antireflective coatings for solar cells. APPLIED SURFACE SCIENCE 461 (**2018**) 249-254, **IF 4.739**, Q1 Cit. 2x

Non-doped BaTiO3 (BTO) is a perovskite type material with markedly dielectric and ferroelectric properties. Thin films in an amorphous state are appropriate as antireflective layers for thin films solar cells. For this reason, in this paper, the BTO films were created by a magnetron sputtering without post-deposition heat treatment. Their optical properties have high transparency in a visible scale of spectrum and they have sharp absorption edge at wavelength ~ 300 nm. BTO mono-layers were deposited on a quartz glass and on a silicon wafer covered by a thin film of amorphous silicon (a-Si:H) in order to verify their influence as an anti-reflection layer. BTO films were created in two thicknesses and apart from the experimentally evaluated optical properties, theoretical calculations were also carried out in order to determine optimal thicknesses for antireflective effect. Reflectance

For combinations of a-Si:H/SiO2 with BTO layer and without BTO layer were compared. Reflectance for the combination of a-Si:H/SiO2 with BTO was significantly lower than that without the BTO layer.

[3] Calta, P., Šutta P., Medlín, R., Netrvalová, M.: Impact of sublayer thickness and annealing on silicon nanostructures formation in a-Si:H/a-SiNx:H super-lattices for photovoltaics. VACUUM 153 (**2018**) 154-161, **IF 2.515**, Q2 Cit. 1x

Apart from the simple absorption layers for tandem solar cells based on silicon, especially those, which have more p-i-n structures (more than two p-i-n structures), multi-layered a-Si:H/a-SiN_x:H structures are appropriate. In these multi-layered structures the optical band-gap can be varied by the thickness of the sub-layers, especially by the a-Si:H sub-layer. Multi-layered a-Si:H/a-SiN_x:H structures were created by PECVD technology from silane diluted by nitrogen (as reactive precursors) and after deposition the amorphous multi-layers were thermally treated in vacuum at temperatures from 600°C to 1100°C. The sub-layer thicknesses were fixed as 5, 10, 15 and 20 nm. The aim of this research was to investigate the influence of sub-layers thickness and post-deposition temperature levels on the process of crystallization a-Si:H sub-layers, because the thickness and the temperature

level as well significantly influence their micro-structure and consequently the optical properties. The a-SiN_x:H sub-layers remain amorphous in this process. Sub-layers a-Si:H with smaller thickness require higher annealing temperatures in order to crystalize and crystallinity of more thick sub-layers can be controlled by the post-annealing temperature level. Generally speaking, structural and optical properties of the multi-layered films are influenced by deposition parameters and by annealing temperature process as well.

3. Assessment of achievement of aims and time schedule of the solution

Achievement of all aims within the whole research programme contained within all research packages WP1 to WP8 went as planned and according to the time schedule. No deviations from planned researched occurred. This report and attached enclosures is introducing all achieved results related to solution of this project.

All planned indicators were met and values of their vast majority were significantly exceeded. At the same time were met all requirements on composition and quality of the research team including planned values of FTE titles of all participants (68 FTE) and values of groups D1 and D2 according to the project requirement. Vast international cooperation with top international research institutions was also established including cooperation on solution of the project H2020. Project solution participants thus significantly extended their international cooperation.

As for publications, from the total quantity of impacted outputs published in direct relation to the project solution there were 30,7% of Q1 category and 46,2% of Q2 category. In relation to applied outputs we can among most important mention stend for high-capacity electric energy storage, control system for solar hydrogen cells, emissive colours for thermographic applications, silicon-based tandem solar cell technology, proven technology for preliminary (pilot) analysis of the possibility of recycling nickel-cadmium batteries at high temperatures, international patent, start – up foundation, intention of founding of companies spin-off and achieved participation in the project Horizont 2020. Also objectives set related to number of international and commercial cooperation were met and in majority of cases significantly exceeded, as well as quantity of cooperation with other research and public service organisations including results registered in RIV. Also indicators of number of local and foreign students participating in solution of this project were met and exceeded, including attended internships.

4. Summary of results achieved

Results of type I are results obtained in cooperation with specialists of other research institutions, results of type II are those achieved only by project specialists.

Results of type I:

Articles in impacted magazines of worldwide database ISI (J_{imp})

Applied:

[1] Kovářík, T., Bělský, P., Novotný, P., Říha, J., Savková, J., Medlín, R., Rieger, D., Holba, P.: Structural and physical changes of re-calcined metakaolin regarding its reactivity. Construction and Building Materials, 2015, roč. 80, č. 01. 04. 2015, s. 98-104. ISSN: 0950-0618, **IF 2,421**; Q1, Q1, Q2; DOI: 10.1016/j.conbuildmat.2014.12.062

[2] Smolná K., Gregor T., Buráň Z., Kosek J.: Formation and Distribution of Rubbery Phase in High Impact Poly(propylene) Particles. Macromolecular Materials and Engineering 301, 390-400, 2016. **IF 2,863**; Q2, Q1; DOI: https://doi.org/10.1002/mame.201500277

[3] Dodda, J. M., Bělský, P., Chmelař, J., Remiš, T., Smolná, K., Tomáš, M., Kullová, L., Kadlec, J.: Comparative study of PVA/SiO2 and PVA/SiO2/glutaraldehyde (GA) nanocomposite membranes prepared by single-step solution casting method. Journal of Materials Science, 2015, roč. 50, č. 19, s. 6477-6490. ISSN: 0022-2461, **IF 2,302**; Q2; DOI: 10.1007/s10853-015-9206-7

[4] Očenášek, J., Lu, H., Bark, C., Eom, C., Alcalá, J., Catalan, G., Gruverman, A.: Nanomechanics of flexoelectric switching. Physical Review B, 2015, roč. 92, č. 3, s. 035417-035426. ISSN: 1098-0121, **IF 3,718**; Q2; DOI: http://dx.doi.org/10.1103/PhysRevB.92.035417

[5] Borek, S., Braun, J., Ebert, H., Minár, J.: Multiferroic heterostructures for spin filter applications: An ab initio study. Physical Review B, 2015, roč. 92, č. 17, s. \´174408-1\´-\´174408-5\´. ISSN: 1098-0121, **IF 3,718**; Q2; DOI: 10.1103/PhysRevB.92.17440810.1103/PhysRevB.92.174408

[6] Ullah, H., Inayat, K., Khan, S., Mohammad, S., Ali, A., Alahmed, Z., Al-Jaary, A.: First-principles calculation on dilute magnetic alloys in zinc blend crystal structure. Journal of Magnetism and Magnetic Materials, 2015, roč. 385, č. červenec 2015, s. 27-31. ISSN: 0304-8853, **IF 2,357**; Q2, Q2; DOI: https://doi.org/10.1016/j.jmmm.2015.02.069

[7] Svoboda M., Beneš J., Vobecká L., Slouka Z.: Swelling induced structural changes of a heterogeneous cation-exchange membrane analyzed by micro-computed tomography. Journal of Membrane Science 525, 195-201, 2017. **IF 6,035**; Q1, Q1; DOI: 10.1016/j.memsci.2016.10.046

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195 ID 43922177; WOS: 000419001600017; eid=2-s2.0-85029431754; **IF 2,029**; AIS 0,349; Q2; https://doi.org/10.1007/s11666-017-0637-3

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[158] Properties of nano-structured ZnO thin films synthesized using a modified aqueous chemical growth method. By: Apeh, Oliver O.; Chime, Ugochi K.; Agbo, S.; et al. *Materials Research Express*, Volume: 6 Issue: 5 Article Number: 056406 Published: MAY 2019; **IF 1,449; AIS 0,236; Q3;** https://doi.org/10.1088/2053-1591/aadcd6

[159] Effective Passivation of Black Silicon Surfaces via Plasma-Enhanced Chemical Vapor Deposition Grown Conformal Hydrogenated Amorphous Silicon Layer. By: Ozkol, E.; Procel, P.; Zhao, Y.; et al. Phys. Status Solidi-Rapid Research Letters 2019, 1900087 **IF 3,729;** AIS 0,790; Q2, Q1, Q2**;** https://doi.org/10.1002/pssr.201900087

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Number based on the project plan	Reported since the project begining	Performance (%)
101	163	161

Articles in reviewed non-impacted magazines (J_{neimp}, J_{rec})

Applied:

[1] Pokorná D, Cuřínová P, Šnajdaufová H, Křenek T, Pola M, Novák L, Janeček V, Pola J, Fentonová degradace antibiotik a jiných léčiv v odpadních vodách – vliv železnatých spinelů, Waste forum, č. 3, 2016, 154-165. *https://asep.lib.cas.cz/arl-cav/cs/detail-cav_un_epca-0462839-Fentonova-degradace-antibiotik-a-jinych-leciv-v-odpadnich-vodach-vliv-zeleznatych-spinelu/*

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[3] Th. Loewenhoff, J. Linke, J. Matějíček, M. Rasinski, M. Vostřák, M. Wirtz, Laser re-melting of tungsten damaged by transient heat loads, Nuclear Materials and Energy, Volume 9, December 2016, Pages 165-170, ISSN 2352-1791. https://doi.org/10.1016/j.nme.2016.04.004,

[4] J. Müllerová, P. Šutta: On some ambiguities of the absorption edge and optical band gaps of amorphous and polycrystalline semiconductors. Communications (3/2017) Volume 19, 9-15.,

[5] R. Pálek, V. Liška, L. Eberlová, H. Mírka, M. Svoboda, S. Haviar, M. Emingr, O. Brzoň, P. Mik, V. Třeška: Experimentální příprava korozivních preparátů orgánů velkého zvířete, Rozhledy v Chirurgii 97, roč. 5 (2018) 222-228;

[6] Mazúr, P.; Mrlík, J.; Charvát, J.; Pocedič, J.; Vrána, J.; Dundálek, J.; Kosek, J.: A complex four-point method for the evaluation of ohmic and faradaic losses within a redox flow battery single-cell, MethodsX 6 (2019) p. 534–539; DOI: 10.1016/j.mex.2019.03.007; CiteScore 1.69
https://doi.org/10.1016/j.mex.2019.03.007

Number based on the project plan	Reported since the project begining	Performance (%)
19	6+5	58

Peer- reviewed books, chapters in peer-reviewed books (B, C)

We planned application of 2 books and 4 chapters in the book. No classification of categories was planned.
In total 1 book and 10 chapters in the book of category I and 4 books and 10 chapters in the book of category II were made up.
Applied:

Books:

[1] Frank, H., Fiala, J., Kraus: Elektronová struktura a reaktivita povrchů a rozhraní. 1. vyd. Praha: Česká technika - nakladatelství ČVUT, 2016, 317 s. ISBN: 978-80-01-05397-3 Původní RIV obor: BM - Fyzika pevných látek a magnetismus, Nový RIV obor: 1. Natural Sciences > 1.3 Physical sciences > Atomic, molecular and chemical physics;
https://vufind.techlib.cz/Record/000949760#description

[0] Kraus, I., Fiala, J.: Elementární fyzika pevných látek. Praha: Česká technika - nakladatelství ČVUT, 2016, 322 s. ISBN: 978-80-01-05942-5. Původní RIV obor: BM - Fyzika pevných látek a magnetismus, Nový RIV obor: 1. Natural Sciences > 1.3 Physical sciences > Atomic, molecular and chemical physics;
https://vufind.mzk.cz/Record/MZK01-001191116/Citation#tabnav

[0] Kraus, I., FIala, J.: Elementární fyzika pevných látek; ISBN: 978-80-01-04391-0; https://www.cupress.cuni.cz/ink2_ext/index.jsp?include=podrobnosti&id=278095

[0] Fiala, J., Kraus, I.: Povrchy a rozhraní; ISBN 978-80-01-04248-9;
https://katalog.vsb.cz/documents/183718?locale=cs

Chapters in the book:

[1] J. Braun, J. Minar and H. Ebert: One Step Model Description of HARPES: Inclusion of Disorder and Temperature Effects; Springer International Publishing Switzerland 2016; Chapter 7, J. C. Woicik (ed.), Hard X-ray Photoelectron Spectroscopy (HAXPES), Springer Series in Surface Sciences 59, ISSN 0931-5195; Library of Congress Control Number: 2015950038, ID 43915058; https://doi.org/10.1007/978-3-319-24043-5_7

[2] Holeček, M., Šesták, J., Mareš, J. J., Hubík, P.: What Is the Physical and Operational Meaning of Temperature and Its Self-Measurability During Unsteady Thermal Processes Within Thermodynamic Concepts; Volume 11 of the series Hot Topics in Thermal Analysis and Calorimetry pp 45-77, 2017. https://doi.org/10.1007/978-3-319-45899-1_3

[3] Šesták, J.; Hubík, P.; Mareš, J.: Self-organized Periodic Processes: From Macro-layers to Micro-world of Diffusion and Down to the Quantum Aspects of Light; Volume 11 of the series Hot Topics in Thermal Analysis and Calorimetry pp 131-157, 2017. https://doi.org/10.1007/978-3-319-45899-1_6

[4] Sedmidubský D., Holba, P.; Nonstoichiometric Phases—Composition, Properties and Phase Transitions; Volume 11 of the series Hot Topics in Thermal Analysis and Calorimetry pp 177-194, 2017. https://doi.org/10.1007/978-3-319-45899-1_8

[5] Holba, P., Sedmidubský, D.; Clapeyron and Ehrenfest Equations and Hyper-free Energy for Partly Open Systemss; Volume 11 of the series Hot Topics in Thermal Analysis and Calorimetry pp 159-175, 2017. https://doi.org/10.1007/978-3-319-45899-1_7

[6] Svoboda, R., Málek, J., Šesták, J.: Thermo-kinetic Phenomena Occurring in Glasses: Their Formalism and Mutual Relationships; Volume 11 of the series Hot Topics in Thermal Analysis and Calorimetry pp 237-256, 2017. https://doi.org/10.1007/978-3-319-45899-1_11

[7] Šesták, J., Avramov, I.; Rationale and Myth of Thermoanalytical Kinetic Patterns: How to Model Reaction Mechanisms by the Euclidean and Fractal Geometry and by Logistic Approach; Volume 11 of the series Hot Topics in Thermal Analysis and Calorimetry pp 295-318, 2017. https://doi.org/10.1007/978-3-319-45899-1_14

[8] Czarnecki, J., Šesták, J.; The Physical Kinetics of Reversible Thermal Decomposition; Volume 11 of the series Hot Topics in Thermal Analysis and Calorimetry pp 363-384, 2017. https://doi.org/10.1007/978-3-319-45899-1_17

[9] Šesták, J., Pavel Hubík, J., Mareš, J.; Thermal Analysis Scheme Anticipated for Better Understanding of the Earth Climate Changes: Impact of Irradiation, Absorbability, Atmosphere, and Nanoparticless; Volume 11 of the series Hot Topics in Thermal Analysis and Calorimetry pp 471-494, 2017. https://link.springer.com/chapter/10.1007/978-3-319-45899-1_22

[10] Chapter 1. Characteristic Temperatures and Their Exploitation: Glass Transition, Glass-Forming Coefficients Analysis and Innovative Concept of Fragility (Jaroslav Šesták and Ana Kozmidis-Petrovič, New Technology Research Center in the Westbohemian Region, West Bohemian University, Pilsen, Czech Republic, and others). 2019. ISBN: 978-1-53615-706-2. https://www.researchgate.net/publication/338209686_Characteristic_Temperatures_and_Their_Exploitation_Glass_Transition_Glass-Forming_Coefficients_Analysis_and_Innovative_Concept_of_Fragility

Number based on the project plan	Reported since the project begining	Performance (%)
B 1	1	100
C 2	10	500

Articles in proceedings (D)

We planned 40 articles in proceedings. No classifiction in categories was planned. In total 32 articles of category I and 37 articles of category II were made up.

Applied:

[1] M. Pecha, J. Vrána, P. Mazúr, J. Pocedič, J. Dundálek, J. Kosek. :CARBON-BASED BIPOLAR PLATES FOR VANADIUM REDOX FLOW BATTERIES. Membrain workshop studentských prací. Stráž pod Ralskem, 21. 10. 201, ISBN 978-80-904517-4-2. https://ntc.zcu.cz/publikace/?id=43913599
https://fpe.zcu.cz/research/publications/?id=43913599

[2] J. Müllerová, P. Šutta, L. Prušáková, M. Netrvalová: On the Puzzle in the Determination of the Optical Gap in Mixed-Phase Hydrogenated Silicon. Advances in Electronic and Photonic Technologies - ADEPT 2015, June 1-4, 2015, Hotel SOREA Trigan in Štrbské Pleso, Slovakia ISBN: 978-80-554-1033-
https://katalog.vsb.cz/documents/182081?back=https%3A%2F%2Fkatalog.vsb.cz%2Fauthorities%2F171976%3Flocale%3Dcs&group=182081

[3] O. Szabó, I. Novotný, V. Tvarožek, P. Šutta, M. Netrvalová, S. Kováčová: The formation of Au nano-structures on ZnO thin films by the sputtering. Progress in Applied Surface, Interface and Thin Film Science - Gold nano-crystals. SURFINT SREN IV, Florence, Italy, Nov 23-26, 2015, pp. 138-138, ISBN 978-80-223-3975-9.
https://doi.org/10.1016/j.apsusc.2016.11.121

[4] R. Medlín, S. Rajendran, P. Swora: Cross section sample TEM preparation by ion slicer compare to PIPs. Mikroskopie 2015, Lednice na Moravě 12.-13. 5.
http://nucleus.img.cas.cz/mikrospol/SBORNIK-2015.pdf

[5] D. Moskal, M. Kučera, E. Smazalová, Š. Houdková, R. Kromer: APPLICATION OF SHIFTED LASER SURFACE TEXTURING, IN: Proceedings of24th International Conference on Metallurgy and Materials; June 3rd - 5th 2015 / Hotel Voronez I, Brno, Czech Republic, EU; http://konsystest.tanger.cz/files/proceedings/21/papers/4103.pdf

[6] Švantner, M., Honnerová, P., Volák, J. ACTIVE THERMOGRAPHY IN MATERIALS FATIGUE TESTING. In METAL 2015 - 24th International Conference on Metallurgy and Materials. Ostrava: Tanger Ltd., 2015. http://konsys2.tanger.cz/files/proceedings/21/papers/3884.pdf
[7] P.Šutta, R. Medlín, P. Novák, M. Netrvalová, M. Kolega, J. Müllerová, L. Vančo, P. Vogrinčič, M. Veselý: Zn-Ti-O thin films (Fabrication-structure-phase-transformation-properties). In 19. Škola vákuovej techniky (vákuum a nové materiály), 9-12 Nov, 2016, Štrbské Pleso, Slovensko. ISBN 978-80-971179-7-9; http://svs.stuba.sk/svt19/

[8] J. Müllerová, P. Šutta, R. Medlín, M. Netrvalová, P. Novák: Optical properties of zinc titanate perovskite prepared by reactive rf sputtering. Proceedings of 9th solid state surfaces and interfaces. Nov, 21-24, 2016 Piešťany, Slovakia. ISBN 978-80-223-4203-2, https://doi.org/10.1515/jee-2017-0049

[9] Š. Houdková, P. Šperka, M. Repka, J. Martan and D. Moskal: Shifted laser surface texturing for bearings applications,Journal of Physics: Conf. Series 843 (2017) 012076 doi:10.1088/1742-6596/843/1/012076, https://iopscience.iop.org/article/10.1088/1742-6596/843/1/012076

[10] Müllerová, J., Šutta, P.: On the Parametric Modeling of Optical Functions of Amorphous /Polycrystalline Semiconductors. Applied Physics of Condensed Matter (APCOM), June 12-14, 2017 Štrbské pleso, Slovakia.
http://kf.elf.stuba.sk/~apcom/apcom17/proceedings2017/pdf/232%20mullerova.pdf

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Number based on the project plan	Reported since the project begining	Performance (%)
40	32+37	172

Results of type II:

Articles in impacted articles of worldwide database ISI (J_{imp})

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Number based on the project plan	Reported since the project begining	Performance (%)
71	95	134

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Number based on the project plan	Reported since the project begining	Performance (%)
19	6+5	58

Peer-reviewed books, chapters in peer-reviewed books (B, C)

Books:

Applied:

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Number based on the project plan	Reported since the project begining	Performance (%)
B 1	4	400
C 2	10	500

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Number based on the project plan	Reported since the project begining	Performance (%)
40	32+37	172

Other results:

Patents, semi industrial installations, verified technologies or other results protected in accordance with special legal regulations, certified methodology, healing and cultural heritage procedures, specialised maps (P, Z, N)

Number based on the project plan	Reported since the project begining	Performance (%)
P 5 Z 2 N 0	6 13	120 650

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Název: Směs pro přípravu termocitlivého hydrogelového materiálu s velkou změnou objemu v úzkém teplotním intervalu, číslo zápisu 28 757, Autoři: Dodda, Novotný, NTC – UVZ – 15 – 002, CENTEM+
Datum zápisu (udělení): 4. 11. 2015

[3] Užitný vzor – ČR: PUV 2016 – 32519
Název: Thermographic camera for quantitative temperature fields measurement (CZ: Termovizní kamera pro kvantitativní měření teplotních polí). Utility model (PUV) pending - national; reg.date 29.06.2016; Owner: Západočeská univerzita, Plzeň, CZ; Authors: Milan Honner, Michal Švantner,
NTC – UVZ – 16 – 001, CENTEM+
Datum zápisu (udělení): 31. 10. 2016

[4] Užitný vzor – ČR: PUV 2016 – 31204Název: Stimulátor pro nevidomé. Praha, 2016, Západočeská univerzita, Plzeň. Číslo listiny: 29218, Autor: Moskal D., NTC – UVZ – 16 – 002, TG02010011
Datum zápisu (udělení): 8. 3. 2016

[5] Užitný vzor – ČR: PUV 2017 – 34050
Název: Vodivé spojení grafitové plsti a kompozitní desky (TA04011373-V11). Praha, 2017. Autoři: J. Kosek a kol., NTC – UVZ – 17 – 001, TA04011373. Číslo listiny: 31309.
Datum zápisu (udělení): 18. 12. 2017

Authorised software:

Reference to website: https://ntc.zcu.cz/vysledky/sw/

[1] Holeček, M., Novotný Pavel.: Optimalizace funkce obnovitelných zdrojů elektrické energie na bázi palivových článků, akumulátorů a FV panelů pro malé výkony. ZČU v Plzni 2015. Autorizovaný software. NTC-ASW-15-003, CENTEM+

[2] Jiří Skála, Michal Švantner: HDM Eval, ZČU v Plzni 2017. Autorizovaný software. NTC-ASW-17-005, CENTEM+

[3] Tomáš Chmelík, Michal Švantner, Jiří Skála: Software LabIR ThermoStitch. ZČU v Plzni 2017. Autorizovaný software. NTC-ASW-17-006, CENTEM+

[4] Tomáš Chmelík, Michal Švantner, Lukáš Muzika: Software LabIR NDT. ZČU v Plzni 2017. Autorizovaný software. NTC-ASW-17-007, CENTEM+

[5] Jiří Skála, Tomáš Chmelík, Jiří Tesař, Michal Švantner, Milan Honner: Software LabIR Technology. ZČU v Plzni 2017. Autorizovaný software. NTC-ASW-17-008,CENTEM+

[6] Jiří Skála, Jiří Martan, Martin Kučera: Software LabIR Control. ZČU v Plzni 2017. Autorizovaný software. NTC-ASW-17-009, CENTEM+

[7] Voldřich J.: Autorizovaný software OSLOC_V5. ZČU v Plzni 2017. Autorizovaný software. NTC-ASW-17-012, CENTEM+

[8] Tuček O., Tomáš M.: Application for optimization and control of fuel cells – v1.0.0. ZČU v Plzni 2018. Autorizovaný software. NTC-ASW-18-001, CENTEM+

[9] Veselý Z., Lang V.: Pokročilý software pro měření s moduly ADAM. ZČU v Plzni 2018. Autorizovaný software. NTC-ASW-18-002, CZ.01.1.02/0.0/0.0/15_019/0004671

Results of following types:

Applied:

Number based on the project plan	Reported since the project begining	Performance (%)
G 15 F 0 R 0 Z 2	37 5 9 13	246 - - 650

Most significant results:

Introduce 3 most significant results of the project solution for the whole project period.

[1] Pocedič, J., Mazúr, P., Dundálek, J., Vrána, J.: **Svazek vanadové průtokové baterie**, Plzeň 2019, NTC-PRT-19-003,CENTEM+, https://ntc.zcu.cz/vysledky/pr/

The result is pack of vanadium flow battery with 20 cells and active surface >350 cm2. Vanadium battery is using an anion exchange membrane and graphite felt optimized for long stack life. The stack was characterized by a charging and discharging cycle, and the results of the characterization are stated in an internal document from Pinow Energy Storage, s.r.o. "Stack verification report.pdf". The result was verified for putting into production.

Subject of industrial property rights relates to power core of technology of vanadium redox flow battery, one of solutions of stationary elektricity storage. Vanadium redox flow battery seems to be advantageous for elektricity storing for a short time period (max. 2 weeks) in outputs heading up to tenths of MW. Its advantage is high scalability. The output is classified with use of battery packs, capacity is determined independently on the electrolyte volume..

Subject of the license represents good foundation for further development of redox flow batteries technology, thus can be attractive for companies dealing with development of stationary storage based on redox flow batteries. The solution can serve as initial point for development of the vanadium redox flow battery pack based on good production practice. The technology obtained was licensed on 12. 10. 2018. Pinflow energy storage, s.r.o. http://www.pinflowes.com/, as a developer of redox flow batteries technology is planning to produce and sell vanadium flow batteries based on this license from 2020 with assumed financial volume over 10 million of CZK. The license agreement is attached.

[2] **International USA patent:** KUČERA, M., MOSKAL, D., MARTAN, J.: Method of laser beam writing with shifted laser surface texturing. Alexandria, 2018. Číslo patentu US10160229 (B2). NTC-PAT-18-001,
https://ntc.zcu.cz/vysledky/pat/NTC-PAT-18-001.html
https://worldwide.espacenet.com/publicationDetails/biblio?FT=D&date=20181225&B=EPODOC&locale=en_EP&CC=US&NR=10160229B2&KC=B2&ND=5

Method of shifted laser surface texturing (shifted Laser Surface Texturing, sLST) was awarded the **American patent US 10160229, 2018**. It is result of a long-term cooperation on development of new laser surface texturing methods using pulsed lasers. Method is determined for effective industrial formation of functional surfaces (for example hydrophobic, reducing friction, anti-bacterial, light-absorbing and improving adhesion) having texture with repeated up to millions of micro objects. Main advantage of the shifted laser surface texturing method compared to conventional methods is acceleration of the process in orders as well as elimination of adverse impacts as are thermal accumulation and plasma shielding during laser processing. Application of results was proved by the established international cooperation with both, research centres and production companies, for example Trumpf Praha spol. s r.o., GF Machining Solutions, Hofmaister s.r.o.
The result has a world level excellence from the view of its originality, importance and difficulty of its obtaining. The result has been applied since 2019.
Among users are companies dealing with production of material surface laser processing machines. The result is offered in the form of a licence to companies dealing with technologies of laser texturing of material surface.

[3] **Švantner, M.:** A water-washable emissive paint for non-contact temperature measurement of objects by infrared detection and a method of using this paint. **Praha, 2017. Číslo patentu: 307047. NTC-PAT-15-001**. https://ntc.zcu.cz/vysledky/pat/NTC-PAT-15-001.html https://isdv.upv.cz/webapp/resdb.print_detail.det?pspis=PT/2015-661&plang=CS

A water-washable emissive paint for non-contact temperature measurement of objects by infrared detection with an emissivity value in the range of 0.93 to 0.98. Due to these paints we can now measure materials with glossy surfaces (metals, glass, and some plastics) which have been so far difficult to measure by non-contact temperature measurement. It´s thus a setback of extension of accurate quantitative non-contact measurement in many fields. Compared to other thermography reference paints however this paint can be easily washed off from the surface. This significantly extends its application field.

In cooperation with an industrial producer of paints and sprays the theoretical result was transformed into the product (Honnerová P., Honner M., Švantner M., Šroub J., Veselý Z., Angelovová M.: **Prototype** NTC-PRT-17-003 of water-washable reference thermography paint HEWP-LT-MWIR-BK-21. 2017, ID 43921333), which is currently offered by our research centre under the brand LabIR Paints and distributed to its potential users. More details on https://paints.labir.eu/homepage/thermographic-washable-paintD

Prototype of reference thermographic paint is significantly affecting also the development activity of application sphere: Thermographic paints are used for example in the field of automotive, aviation and space applications, solar energy, electronics, construction industry, machinery, health technologies, maintenance, university research and development centres. Among its users are important research institutions and companies, as for example Fraunhoffer, Max-Planck Institute, Onera, DLR, ABB, HP, Cognatec, Valeo Siemens, etc. Important cooperation based on distribution contract was started with Belgian partners, due to which is our software for thermographic applications used by the application sphere, for example in food industry. Potential users expressed their interests, as are research centres, universities and commercial subjects. Sales have been so far made to USA, France, Spain, Belgium, Sweden, Poland, Slovenia and Czech Republic. The results are being used by subjects as are for example ONERA, German Aerospace Center, ABB. We can state after about year since the result was obtained that it has been applied in foreign markets. Such result has been missing as from the aspect of its originality, importance and impact on a world-leading level.

5. Benefit of achieved results

Results achived by project solution can be classified in three categories. These results represent achievement of planned aims of the project. Benefits of published results are listed in chapter 2 by citation of published articles and comments at selected publications listed in the implementation plan. Then other results results, which can be after putting into operation used in practice and results, which were already used in practice and had specific economic impact. The exact financial benefit is very difficult or almost impossible to estimate as even in case of commercial contracts the paid price does not really reflect the real contribution. We believe that majority of results can be assessed on national level and many of results can be assessed on international level. Contributions of some selected results are mentioned hereinafter.

[1] Honner M., Veselý Z.: Method of measuring total emissivity of material surfaces. **Patent.** Patent No. 306316, University of West Bohemia in Plzen 2016, NTC-PAT-16-001.
https://ntc.zcu.cz/vysledky/pat/NTC-PAT-16-001.html
https://isdv.upv.cz/webapp/resdb.print_detail.det?pspis=PT/2012-175&plang=CS

Knowledge of emissivity of processed material surface is very important for efficient design of structure and smooth operation of for example thermally processed components and other devices. Designed method of emissivity measurement significantly clarifies information on behaviour of material surface under high temperatures necessary mainly in the field of mechanical engineering and energy. Results should be applied in 2021 and are focused on producers of laboratory measuring instruments. We expect building of FVZ where will be measured samples supplied by potential users based on the service contract of work. Licensor of the result would request license fee in some cases.

Invention relates to measuring of total emissivity of surface materials in relation to temperature and aiming to obtain knowledge about behaviour of material surface under high temperatures as well as possibilities of modification of these surfaces. Current methods were inaccurate and did not provide correct and useful information on real values necessary for further application.

[2] Kučera, M., Moskal, D., Martan, J.: Method of laser beam writing with shifted laser surface texturing. Alexandria, 2018. **Patent.** Číslo patentu US10160229 (B2), NTC-PAT-18-001.
https://ntc.zcu.cz/vysledky/pat/NTC-PAT-18-001.html
https://worldwide.espacenet.com/publicationDetails/biblio?FT=D&date=20181225&DB=EPODOC&locale=en_EP&CC=US&NR=10160229B2&KC=B2&ND=5

Method of shifted laser surface texturing (shifted Laser Surface Texturing, sLST) was awarded the American patent US 10160229, 2018. It is result of a long-term cooperation on development of new laser surface texturing methods using pulsed lasers. Method is determined for effective industrial formation of functional surfaces (for example hydrophobic, reducing friction, anti-bacterial, light-absorbing and improving adhesion) having texture with repeated up to millions of micro objects. Main advantage of the shifted laser surface texturing method compared to conventional methods is acceleration of the process in orders as well as elimination of adverse impacts as are thermal accumulation and plasma shielding during laser processing. Application of results was proved by the established international cooperation with both, research centres and production companies. The result has a world-leading level from the view of its originality, importance and difficulty of its obtaining. Among users are companies dealing with production of material surface laser processing machines.

[3] MOSKAL, D.: Stimulátor pro nevidomé. Praha, 2018. **Patent.** Číslo patentu: 307507. NTC-PAT-18-002.
https://ntc.zcu.cz/vysledky/pat/NTC-PAT-18-002.html
https://isdv.upv.cz/webapp/resdb.print_detail.det?pspis=PT/2015-392&plang=CS

Visually handicapped persons are usually facing the difficulty to find so called high obstacles, i.e. dangerous objects located from the waist line up. Then there is a problem to find uneven terrain, various terrain drops or stairs. A stimulator for visually handicapped is

aspiring on partial ability to detect the so called high obstacle. If the obstacle is located on the head level, stimulator shall warn its holder by vibrations. It is and ideal accessory to the white cane. The Stimulator is able detect the obstacle up to the distance of 2m, when the sensation is weak and gradually intensifies with the object approaching. Based on assessment of visually handicapped the tool has a potential which would appreciate further development and improvement. Mainly rapid response of the system is appreciated allowing timely reaction to unexpected obstacle. In order to reach full commercial success some functions based on visually handicapped should be completed. We assume potential users from among producers of ophthalmic optics. Licensors shall request a license fee for the product.

[4] ŠVANTNER, M.: ŠVANTNER, M.: Vodou smyvatelná vysoce-emisivní barva pro termovizní a termografické aplikace. Praha, 2017. **Patent.** Číslo patentu: 307047. NTC-PAT-15-001.
https://ntc.zcu.cz/vysledky/pat/NTC-PAT-15-001.html
https://isdv.upv.cz/webapp/resdb.print_detail.det?pspis=PT/2015-661&plang=CS

A water-washable emissive paint for non-contact temperature measurement of objects by infrared detection with an emissivity value in the range of 0.93 to 0.98. Due to these paints we can now measure materials with glossy surfaces (metals, glass, and some plastics) which have been so far difficult to measure by non-contact temperature measurement. It´s thus a setback of extension of accurate quantitative non-contact measurement in many fields. Compared to other thermography reference paints however this paint can be easily washed from the surface. This significantly extends its application field.

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Potential users expressed their interests, as are research centres, universities and commercial subjects. Sales have been so far made to USA, France, Spain, Belgium, Sweden, Poland, Slovenia and Czech Republic. The results are being used by subjects as are for example ONERA, German Aerospace Center, ABB. We can state after about year since the result was obtained that it has been applied in foreign markets. Such result has been missing as from the aspect of its originality, importance and impact on a world-leading level.

The result will be further provided to potential users in the form of license, we assume transfer to spin-off, will be established in 2020.

[5] ŠVANTNER, M., HONNER, M., VOSTŘÁK, M., HRUŠKA, M.: Způsob a zařízení pro vytváření povrchů o vysoké drsnosti a specifických mechanických vlastnostech. Praha, 2018. **Patent.** Číslo patentu: 307120. NTC-PAT-18-003.
https://ntc.zcu.cz/vysledky/pat/NTC-PAT-18-003.html
https://isdv.upv.cz/webapp/resdb.print_detail.det?pspis=PT/2013-108&plang=CS

For some applications must be prepared surfaces with very high roughness and specific

mechanical properties. This relates for example to some moulding forms, grinding tools, tribological applications and other devices. Requested roughness can be reached mechanically with high difficulties. This problem is solved by the method of surface modification with implantation of abrasive particles in the thermally softened or melted surface of basic mateial. Principle of the solution is that surface of the basic material is thermally soften or melted by laser or other thermal source. On softened or melted surface layer are suitably with corresponding energy imported grains of abrasive or roughening material of required size.

Formation of surfaces with high roughness and specific mechanical properties based on the invention can be successfully used in all field where is a need of local preparation of rough surface which cannot be prepared by conventional methods, for example by high-pressure pressing or by high-temperature heating of the whole piece in the furnace. Once the technical realisation of solved this method will be offered on the basis of license to potential users (assumption in 2022) mainly from the field of mechanical engineering and automotive industry.

OTHER APPLICATION OUTPUTS:

[7] Dodda J. M., Novotný P.: „Směs pro přípravu termocitlivého hydrogelového materiálu s velkou změnou objemu v úzkém teplotním intervalu“ a „Směs pro přípravu termocitlivého hydrogelového materiálu s plynulým řízením změny objemu“ Západočeská univerzita v Plzni 2015, **Užitné vzory ČR**, NTC – UVZ – 15 – 002, PUV 2015 – 31535, NTC – UVZ – 15 – 001, PUV 2015 – 31536.

Technical solution concerns thermalsensitive hydrogel material with continuous control of volume change within the range of temperatures 0 - 80 °C, used in sensors or micro-actuators in aquatic environment. These materials are used based on relation of hydrogel volume on change of external conditions (change of pressure, temperature, concentration of ions and other substances in water etc.). Currently used methods of preparation are sensitive to presence of air oxygen, which is complicating their practical application due to unsuitable mechanical properties. The hydrogel prepared from the mixture based on technical solution is eliminating problems related to effect of air oxygen on hydrogel preparation thus satisfying requirements on increased strength. The result is currently used by the recipient for solution of project of purpose funding, contract research and additional activities.

[8] Group of results
a) J. Kosek a kol.: „Vodivé spojení grafitové plsti a kompozitní desky“, 2017. Číslo listiny: 31309, NTC – UVZ – 17 – 001, TA04011373,
b) Mazur P.: „Vícevrstvé trubky pro snížení výskytu statického náboje“, Vícevrstvé trubky pro snížení výskytu statického náboje. ZČU v Plzni, 2015. Functional sample, NTC-FVZ-2015-003,TA04011373,

c) Mazůr P.: Granulát pro výrobu vodivých kompozitních desek. ZČU v Plzni, 2015. Functional smaple, NTC-FVZ-2015-004,TA04011373,

d) Mazúr P., Dundálek J.: Funkční vzorek kompozitní desky. ZČU v Plzni 2016. Funkční vzorek,

NTC-FVZ-2016-003,TA04011373,,

e) J. Vrána, J. Dundálek, P. Mazúr: Způsob vodivého spojení grafitové plsti a kompozitní desky. Functional sample, ZČU v Plzni, 2017. NTC-FVZ-17-009, TA04011373-V10,

f) Mazúr P.: Verified technology of composite plate production, ZČU in Plzen, **Verified technology**, NTC-OTE-17-004. TA04011373, prepared conditions for formation of the following prototype:
Pocedič, J., Mazúr, P., Dundálek, J., Vrána, J.: Pack of vanadium flow battery, Plzeň 2019, prototype, NTC-PRT-19-003,CENTEM+

The result is pack of vanadium flow battery with 20 cells and active surface >350 cm2. Vanadium battery is using an anion exchange membrane and graphite felt optimized for long stack life. The stack was characterized by a charging and discharging cycle, and the results of the characterization are stated in an internal document from Pinow Energy Storage, s.r.o. "Stack verification report.pdf". The result was verified for putting into production.

Subject of industrial property rights relates to power core of technology of vanadium redox flow battery, one of solutions of stationary elektricity storage. Vanadium redox flow battery seems to be advantageous for elektricity storing for a short time period (max. 2 weeks) in outputs heading up to tenths of MW. Its advantage is high scalability. The output is classified with use of battery packs, capacity is determined independently from the electrolyte volume.

Subject of the license represents good foundation for further development of redox flow batteries technology, thus can be attractive for companies dealing with development of stationary storage based on redox flow batteries. The solution can serve as initial point for development of the vanadium redox flow battery pack based on good production practice. The know-how obtained license on 12. 10. 2018. Pinflow energy storage, s.r.o. http://www.pinflowes.com/, as a developer of redox flow batteries technology is planning production and sale of vanadium flow batteries from 2020 based on the license with assumed financial volume more than ten millions of CZK.

[9] Šnita, D.: Pocedič, J.: Ověřená technologie pro předběžnou (pilotní) analýzu možností recyklace nikl-kadmiových akumulátorů žárovou cestou, ZČU v Plzni 2019. **Verified technology**, NTC-OTE-19-003, CENTEM+

The technology lies in high temperature processing of the cadmium plates (chemical decomposition of cadmium oxide and distillation of the metal cadmium in reduction environment). Detail technical parameters of the technology are described in the classified report.

Recycling of NiCD accumulators has a limited capacity in Europe and out of Europe it is facing economical, legislative and environmental problems. Quantity of processed NiCd batteries does not drop as limiting of its use does not related to many fields, as it is for example its use for standby source for railways in a global scale. Presented technology allows its owner to secure its own recycling of NiCd batteries in CR, meaning savings of transportation costs to current processing factories (which are often overseas) and mainly allows continuous nickel recycling.

Proven technology for pilot analysis of cadmium recycling will be, in cooperation with Nimetal s.r.o., extended to design and build technology of the high temperature recycling of

nickel-cadmium batteries with a batch of 200-500 kg / day.

[10] Tuček O., Tomáš M.: Application for optimization and control of fuel cells – v1.0.0. ZČU v Plzni 2018. **Authorized software**. NTC-ASW-18-001, CENTEM+

Software for optimisation and control of hydrogen fuel cell has been developed in cooperation with development of the pack of fuel cells with polymeric membrane. Development of the pack has not been yet fully finished, it was fitted with peripheral system providing supply of the fuel and maintenance of working temperature, pressure and humidity of gasses in anodic and catodic branch. Peripheral system is controlled by the software automatically reacting to change of working conditions or demanded power output.

This system is suitable for applications requiring constant supply of power energy. Fuel cell works as a standby source. Specific application may by the standby source for vanadium flow battery of higher output, when the fuel cell keeps constant battery charge. Another example may be a standby source in the building where we want to reach the island system in case of sudden distribution network failure. For this purpose, is the given device ordered by Jablotron company. With respect possibility of scaling of power output, the fuel cell tailored to the given application can be made. The system is therefore attractive also for mobile applications as are trailers (caravans) where the power supply is needed for a longer time. System seems to be attractive also for the army, ordering power source without need of long-time charging characteristics for currently used batteries. Least but not last the system can be used for passive building, where in connection with photovoltaic panels and electrolyser forms the circuit, allowing disconnection of the building from distribution grid. System is forming compact unit demanded by companies from telecommunication or security field. Individual components are attractive for large companies, as are Unipetrol or ČEZ. Mainly the designed modification of working gas compared to the actual fuel cell is interesting for the type of companies, as it can be used for further development of electro mobility.

Further results with possible specific impact are listed in the implementation plan table.

6. Other benefits of the project solution

The project allowed to complete and stabilise research teams and develop activities within all research programmes CT1 – CT4.

Due to the possibility to work on CENTEM+ project, researchers participating in the project obtained a project from the programme „Excellent research centres“ called „Computational and experimental design of advanced materials with new functionalities“ CZ.02.1.01/0.0/0.0/15_003/0000358 (EVT) in financial amount of about 161 milions CZK, within which was published in the **NATURE** magazine the article Rienks E.D.L., Wimmer J., Sánchez-Bariga J., Caha O., Mandal P.S., Růžička J., Ney A., Steiner H., Volobuev V.V., Grois H., Albu M., Kothleitner G., Michalička J., Khan S.A. Minár J., Ebert H., Bauer G., Freyse F., Varykhalov A., Rader O., Springholz G.: Large magnetic gap at the Dirac point in Bi2Te3/MnBi2Te4 heterostructures, Nature 576, (2019) 423-428; ISSN:0028-0836, **IF= 43,07;**

D1, https://doi.org/10.1038/s41586-019-1826-7, describing with use of quantum mechanical calculations properties of material system directed to superconducting condition, properties necessary of quantum computers. These obtained theoretical properties would further allow predicting the properties of other new materials. These researchers have further published about 75 publications in leading impacted journals, see the enclosure „Results of EVT project". Further was obtained the project LabiR-PAV / Pre-application research of infrared technologies, No. CZ.02.1.01/0.0/0.0/18_069/0010018 in the financial amount of about 102 milions CZK.

A contact was obtained to international project SFERA III, based on the sale of reference thermographic coating in the field of space application, allowing use of infrastructure of leading European workplaces. We expect from the project possible improvement of knowledge about other properties of thermographic coatings, so far impossible for us due to the limits of our infrastructure, as well as new contacts of international excellent workplaces.

Project solution allowed not only development of knowledge in all studied fields but also possibility of new cooperation with other local and foreign workplaces. Large amount of publications was prepared in cooperation with colleagues from Institute of chemical engineering of VŠCHT Praha. Publications from the field of research of morphology of automotive catalysts were prepared in cooperation with research centre of one of largest world producers of automotive catalysts – company Johnson Matthey from Great Britain.

GAČR project was also solved in cooperation with VŠCHT Praha (Agglomeration of polyolefin particles investigated at meso-scale) as well as TAČR project (Advanced conductive composite materials and products). Within the enhanced cross-border Czech-Bavarian cooperation was solved with Technological centre for energy (TZE – part of University of Applied Sciences in Landshut) the project FSTORE – cross-border platform of research of future energy storages and their integration.

CENTEM+ project allowed participation of many researchers on many prestigious foreign conferences, presentation of our results and support of networking with other foreign workplaces and specialists. Results of new cooperation's made full use in 2019, when NTC was invited to joint consortium of **HORIZONT 2020** project specialists in the call LC-BAT-04-2019. HIGREEW project (Affordable High-performance Green REdox floW batteries) was supported starting in November 2019. Another supported project related to previous results of CENTEM+ project is project TAČR THÉTA (Research and development of advanced flow energy storage technologies) starting in August 2019. Above project guarantee to our workplace research continuity even after the CENTEM+ project termination.

Research programme in the field of fuel cells helped us to initiate contact with the group of Prof. Alex Schechter, University Ariel, Israel (https://www.ariel.ac.il/wp/alex-schechter/). International cooperation is leading to significant development of the topic related to efficiency of new type of membranes for fuel cells.

Remarkable achievement in the field of research of inorganic materials and nano-alloys is new cooperation with the group of Prof. Dr. Denitsa Docheva UKR, Germany (https://www.ukr.de/kliniken-institute/unfallchirurgie/Forschung/Labor-experimentelle-Unfallchirurgie/Team/index.php). Cooperation with this group led to the submission and obtaining of an international project dealing with issues in NTC workplace. Another international cooperation (Institute of physics of solids, Bulgarian Academy of Sciences and Institute of advanced ceramics, University in Bremen, Germany) led to publication output in the form of Jimp publications. We expect further cooperation in the field of functionalised

biocompatible carries and development in the field of responsive hydrogels for medical applications.

Further perspective related to Thermographic reference coating and software of brand LabIR is connecting our research activities with educational ones. We work on activities for students of grammar and secondary schools in the area of popularisation of science and modern technologies. We developed an infrared camera for educational purposes. Modern educational tool can be used for various subjects as it is helping to understand the world in bigger picture. This is entirely fulfilling the Strategy of Innovation of the Czech Republic 2019 – 2030. We work also in professional education – as we obtained certification for approved training centre in the field of thermography diagnostics.

Publications prepared by members of the project team of CENTEM+ within the project of Ministry of education and youth and sports „Excellent research centres“

2017

[1] **KHAN, S. A., MINÁR**, J., EBERT, H., BLAHA, P., ŠIPR, O. Local environment effects in the magnetic properties and electronic structure of disordered FePt. *Physical Review B*, 2017, roč. 95, č. 1, s. 1-9. ISSN: 2469-9950.

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[75] **PRUŠÁKOVÁ, L., ŠUTTA, P., MEDLÍN, R**., VINCZE, A. Structural analysis of silicon nanostructures obtained from thermal annealing of PVD deposited SRO/SiO2 multilayers. *Vacuum*, 2019, roč. 166, č. August 2019, s. 32-36. ISSN: 0042-207X.

7. Implementation of indicators of results and fulfilling of aims of NPU I program projects

a) No.of new unique results of type I. according to art. 8. 2. Specification

Threshold	Produced since project commencement	Implementation (%)
25	163	652

b) No. of new unique results of type II. according to art. 8. 2. Specification

Threshold	Produced since project commencement	Implementation (%)
71	95	134

c) Patents, semi-industrial installations, verified technologies or other results protected according to special legal regulations, certified methodology, heald and heritace protection procedures, specialised maps (P, Z, N)

Threshold	Produced since project commencement	Implementation (%)
5	6+13	360

d) No.of project of international cooperation of the Center

Threshold	Produced since project commencement	Implementation (%)
1	10	1000

e) List of project of the international cooperation

Project: [1]
HIGREEW: AFFORDABLE HIGH-PERFORMANCE GREEN REDOX FLOW BATTERIES (**HORIZONT 2020, LC-BAT-4-2019**)
Result: Work on the project started on 01.11.2019

Project: [2]
Cost Action 1306, SML/6100/0020/15 ,(Doba řešení 2015-2017), „Teoretická spektroskopie nových materiálů založená na kooperativním využití více programů“.
Author: Ing. Rostislav Medlín Ph.D.
Coauthor:
Mumich University, Prof. Hubert Ebert
Results:
https://www.rvvi.cz/riv?s=jednoduche-vyhledavani&ss=detail&n=0&h=RIV%2F49777513%3A23640%2F16%3A43928684%21RIV17-MSM-23640
https://www.rvvi.cz/riv?s=jednoduche-vyhledavani&ss=detail&n=0&h=RIV%2F49777513%3A23640%2F15%3A43927478%21RIV16-MSM-23640

[1] Khan, W. and Goumri-Said, S. (2015), Engel–Vosko generalized gradient approximation within DFT investigations of optoelectronic and thermoelectric properties of copper thioantimonates(III) and thioarsenate(III) for solar-energy conversion; Phys. Status Solidi B, 1521-3951, doi: 10.1002/pssb.201552435, https://doi.org/10.1002/pssb.201552435

[2] Wilayat Khan, Sophia B. Betzler, Ondrej Šipr, Jim Ciston, Peter Blaha, Christina Scheu, and Jan Minar, J.: Theoretical and Experimental Study on the Optoelectronic Properties of Nb3O7(OH) and Nb2O5 Photoelectrodes; Phys. Chem. C, 2016, 120 (41), pp 23329–23338 https://www.osti.gov/biblio/1506260

[3]Saleem Ayaz Khan, Peter Blaha, Hubert Ebert, Jan Minár, and Ondřej Šipr: Magnetocrystalline anisotropy of FePt: A detailed view; PHYSICAL REVIEW B 94, 144436 (2016), 10.1103/PhysRevB.94.144436

[4] J. Krempaský, H. Volfová, S. Muff, N. Pilet, G. Landolt, M. Radović, M. Shi, D. Kriegner, V. Holý, J. Braun, H. Ebert, F. Bisti, V. A. Rogalev, V. N. Strocov, G. Springholz, J. Minár, and J. H. Dil: Disentangling bulk and surface Rashba effects in ferroelectric α-GeTe; PHYSICAL REVIEW B 94, 205111 (2016), 10.1103/PhysRevB.94.205111

[5] Saleem Ayaz Khan, Ján Minár, Hubert Ebert, Peter Blaha, and Ondřej Šipr: Local environment effects in the magnetic properties and electronic structure of disordered FePt; Phys. Rev. B, (2017) 95, 014408. https://doi.org/10.1103/PhysRevB.95.014408

[6] Myrtille O. J. Y. Hunaul , Wilayat Khan, Jan Minár, Thomas Kroll, Dimosthenis Sokaras, Patric Zimmermann, Mario U. Delgado-Jaime, and Frank M. F. de Groot: Local vs Nonlocal States in FeTiO3 Probed with 1s2pRIXS: Implications for Photochemistry; Inorg. Chem, (2017) 56, 10882–10892, DOI: 10.1021/acs.inorgchem.7b00938

[7] Medlin R., Minar J., Sutta P., Khan W., Sipr O., Novak P., Netrvalova M: Structural and Electronic Properties of Ti Doped ZnO: XRD, TEM, EELS and Ab-initio Simulations; Microscopy and Microanalysis, 23(S1), 1686-1687. (2017) doi:10.1017/S1431927617009096, https://doi.org/10.1017/S1431927617009096

Project: [3]
Framework contract for cooperation, SML/6100/0027/15, (Solution period 2015-2024),
Author: Ing. Jan Očenášek Ph.D.
Partner: Technical University Catalanya
Results:

[1] Varillas, J; Ocenasek, J; Torner, J; Alcala, J; Unraveling deformation mechanisms around FCC and BCC nanocontacts through slip trace and pileup topography analyses, ACTA MATERIALIA Volume: 125 Pages: 431-441 DOI: 10.1016/j.actamat.2016.11.067 Published: FEB 15 2017 ISSN: 1359-6454, IF 7.293, https://doi.org/10.1016/j.actamat.2016.11.067

[2] Ocenasek, J; Lu, H; Bark, CW; Eom, CB; Alcala, J; Catalan, G; Gruverman, A; Nanomechanics of flexoelectric switching. PHYSICAL REVIEW B Volume: 92 Issue: 3 Article Number: 035417 DOI: 10.1103/PhysRevB.92.035417 Published: JUL 14 2015 ISSN: 2469-9950, IF 3.736, https://doi.org/10.1103/PhysRevB.92.035417

[3] Alcala, J; Ocenasek, J; Nowag, K; Esque-de los Ojos, D; Ghisleni, R; Michler, J; ACTA MATERIALIA Volume: 91 Pages: 255-266 DOI: 10.1016/j.actamat.2015.02.027 Published: JUN 1 2015 ISSN: 1359-6454, IF 7.293https://doi.org/10.1016/j.actamat.2015.02.027

[4] Alcala, J; Esque-de los Ojos, D; Ocenasek, J; Extracting uniaxial responses of single crystals from sharp and spherical hardness measurements, MECHANICS OF MATERIALS Volume: 84 Pages: 100-113 DOI: 10.1016/j.mechmat.2015.01.008 Published: MAY 2015 ISSN: 0167-6636 Impact Factor: 2.958,https://doi.org/10.1016/j.mechmat.2015.01.008

Project: [4]
Framework contract for cooperation, SML/6100/008/16, (solution period 2016-),
Author: Doc. RNDr. Pavol Šutta Ph.D.
Partner: International Laser Centre Bratislava

Result:
[1] J. Bruncko, P. Šutta, M. Netrvalová, M. Michalka, A. Vincze: Pulsed laser deposition of Ga doped ZnO films - influence of deposition temperature and growth rate on structural, optical and electrical properties. Vacuum (2018); https://doi.org/10.1016/j.vacuum.2018.10.031

Project: [5]
Framework contract for cooperation, SML/6100/0011/16, (Solution period 2016-),
Author: Doc. RNDr. Pavol Šutta Ph.D.
Partner: University of Žilina

Result:
[1] Ľ. Scholtz, P. Šutta, P. Calta, P. Novák, M. Solanská, J. Müllerová: Investigation of barium titanate thin films as single antireflective coatings for solar cells. Appl. Surface Science, (2018); ID 43924125; WOS: 000450528100042; eid=2-s2.0-85049357183
https://doi.org/10.1016/j.apsusc.2018.06.226

Project: [6]
Framework contract for cooperation, SML/6100/0021/16, (Solution period 2016-2019),
Author: Doc. Ing. Milan Honner Ph.D.
Partner: OstbayerischeTechnische Hochschule Regensburg

Result:
[1] Schmailzl, J. Käsbauer, J. Martan, P. Honnerová, F. Schäfer, M. Fichtl, T. Lehrer, J. Tesař, M. Honner, S. Hierl „Measurement of Core Temperature through Semi-Transparent Polyamide 6 using Scanner-Integrated Pyrometer in Laser Welding“, Int. J. Heat Mass Transf. 146, https://doi.org/10.1016/j.ijheatmasstransfer.2019.118814

Project: [7]
Contract for cooperation, SML/6100/0033/16, (Solutio period 2016-),
Author: Doc. RNDr. Pavol Šutta Ph.D.
Partner: Slovak Univerzity of Technology in Bratislava

Result:
[1] V. Tvarožek, O. Szabo, I. Novotný, S. Kováčová, J. Škriniarová, P. Šutta: Plasmonic behaviour of sputtered Au nano-island arrays. Applied Surface Science 395 (2017) 241-247 ; https://doi.org/10.1016/j.apsusc.2016.04.183

Project: [8]
Contract for cooperation, SML/6100/0007/17, (Solution period 2017-),
Author: Ing. Petr Novák Ph.D.
Partner: Queen Mary University of London

Result:
[1] P. Novák; J. Briscoe; T. Kozák; M. Kormunda; M. Netrvalová; Š. Bachratá: Optimization of sputtered ZnO transparent conductive seed layer for flexible ZnO-nanorods-based devices, Thin Solid Films 634 (2017) 169–174; DOI:10.1016/j.tsf.2017.02.017

Project: [9]
Contract for cooperation, SML/6100/0048/18, (solution period 2018-2019),
Author: Prof. Ing. František Maršík, DrSc
Partner:
Institute of Aerospace Thermodynamics, University og Stutgart

Results:
[1] P Novotný, B Weigand, F Maršík, C Biegger and M. Tomáš: Flow structures in a swirl flow - vortex breakdown condition, 2018 J. Phys.: Conf. Ser. 1045 012031, doi https://iopscience.iop.org/article/10.1088/1742-6596/1045/1/012031

[2] František Maršík, Bernhard Weigand, Martin Tomáš, Ondřej Tuček, Pavel Novotný: On the efficiency of electrochemical devices by perspectives of endoreversible thermodynamics, Submitted to the Journal of Non-Equilibrium Thermodynamics, https://doi.org/10.1515/jnet-2018-0076

Project: [10]
Contract for cooperation, SML/6100/0002/16, (solution period 2016-),
Author: Ing. Lucie Prušáková Ph.D.
Partner: Uppsala University, Švédsko

Result:
[1] Prušáková L., Hubík P., Aijaz a., Nyberg T., Kubart T: Room temperature reactive depozition of InGaZnO and amorphous oxide semiconductors for flexible electronics, Coatings, in pres. https://doi.org/10.3390/coatings10010002

f) No. of cooperation projects in VaVaI with companies

Threshold	Produced since project commencement	Implementation (%)
1	12	1200

g) List of new results created by members of the tea m within cooperaton in VaVaI with companies:

Project: [1]
Contract for cooperation, SML/6100/0007/16, (Solution period 2016-2018),
Author: Ing. Zdeněk Veselý, Ph.D.

Partner: Eurometalgroup s.r.o.

Result:
[1] Veselý Z., Lang V., Honner M., Langer T. (Eurometalgroup s.r.o.), Fišerová S. (Eurometalgroup s.r.o.). Funkční vzorek testovacího stendu pro měření provozních vlastností krbových kamen. ZČU v Plzni, 2017. Functional sample, NTC-FVZ-17-001, MPO-EMG-17-001, https://ntc.zcu.cz/vysledky/fv/

Projekt: [2]
Contract for cooperation, SML/6100/0065/17, (Solution period 2017-2018),
Author: Ing. Petr Bělský, Ph.D.
Partner: Contipro a.s.

Result:
[1] Chmelař J., Bělský P., Mrázek J., Švadlák D., Hermannová M., Šlouf M., Krakovský I., : Nanostructure of hyaluronan acyl-derivatives in the solid state; Carbohydrate Polymers, Volume 195, 1/9/2018, Pages 468- 475, https://doi.org/10.1016/j.carbpol.2018.04.111

Project: [3]
Contract for cooperation, SML/6100/0011/18, (Solution period 2018-),
Author: Prof. Ing. Dalimil Šnita, CSc.
Partner: Nimetal spol. s r.o.
Result:
[1] Šnita, D., Pocedič, J.: Ověřená technologie pro předběžnou (pilotní) analýzu možností recyklace nikl-kadmiových akumulátorů žárovou cestou, ZČU v Plzni 2019. Proven Technology, NTC-OTE-19-003, CENTEM+, https://ntc.zcu.cz/vysledky/ot/

Project: [4]
Contract for cooperation, SML/6100/0023/18, (Solution period 2018-2022),
Author: Ing. Jiří Martan, Ph.D.
Partner: SHM s.r.o.

Result:
[1] D. Moskal, J. Martan, M. Kučera, A. Franc, M. Honner, Funkční vzorek ocelového dílu JFS-18 s funkční povrchovou úpravou pro zvýšení životnosti provedenou pikosekundovým

laserem, ZČU v Plzni, 2018. Functional sample, NTC-FVZ-18-008,CENTEM+, https://ntc.zcu.cz/vysledky/fv/

Project: [5]
Contract for cooperation, SML/2100/0082/18, (Solution period 2016-),
Author: Ing. Jiří Martan, Ph.D.
Partner: MANN+HUMMEL Service s.r.o.

Result:
[1] Martan J., KUČERA M., Skala J., Tesař J., Honner M.,: Functional sample laserem svařeného dílu KMH-30 z plastového kompozitu, ZČU v Plzni, 2018. Functional sample, NTC-FVZ-18-007, CZ-BY 103 TheCoS. https://ntc.zcu.cz/vysledky/fv/

Project: [6]
Contract for cooperation, SML/6100/0046/15, (Solution period 2018-2019),
Author: Ing. Jan Šroub, Ph.D.
Partner: PILSEN TOOLS s.r.o.
Result:
[1] Šroub J., Tolar D.,Kohlschutter T., Lang V.,: Prototyp elektronické části modernizovaného tvrdoměru ŠKODA RB-3000, ZČU v Plzni, 2019. Prototype, NTC-PRT-19-001, CZ.01.1.02/0.0/0.0/17_205/0014329, https://ntc.zcu.cz/vysledky/pr/

Project: [7]
Contract for cooperation, SML/6100/0038/15, (Solution period 2018-2019),
Author: Ing. Jan Šroub, Ph.D.
Partner: TESLA Electrotubes s.r.o.

Result:
[1] Šroub J., Kučera M.,: Prototyp laserově řezané mřížky z pyrolitického grafitu, ZČU v Plzni, 2019. Prototype, NTC-PRT-19-002, CZ.01.1.02/0.0/0.0/17_205/0013075, https://ntc.zcu.cz/vysledky/pr/

Project: [8]
Contract for cooperation, SML/6100/0019/18, (Solution period 2018-2019),
Author: Ing. Jaromír Pocedič, Ph.D.
Partner: PinFlow Energy Storage s.r.o.

Result:
[1] Pocedič, J., Mazúr, P., Dundálek, J., Vrána, J.: Prototype - Svazek vanadové průtokové baterie, Plzeň 2019, NTC-PRT-19-003,CENTEM+, https://ntc.zcu.cz/vysledky/pr/

Project: [9]
Contract for cooperation, SML/6100/0022/18, (Solution period2018-2019),
Author: Ing. Petr Novák, Ph.D.
Partner: KRYSTALY Hradec Králové a.s.

Result:
[1] Novák P.: FBAR zařízení z transparentních vrstev využívající piezoelektrických vlastností ZNO. ZČU v Plzni, 2019. Functional sample, NTC-FVZ-19-005, CENTEM+, https://ntc.zcu.cz/vysledky/fv/

Project: [10]
Contract for cooperation, SML/6100/0013/17, (Solution period 2017-2018),
Author: Doc. RNDr. Šutta P., Ph.D.
Partner: UJP Praha a.s.

Result: [1] Jandová, D.: Sample preparation and quantitative evaluation of secondary phases in steel, pp. 51 – 54. ISSN 1213-9289, https://doi.org/10.4028/www.scientific.net/MSF.782.311

Project: [11]
Contract for cooperation, SML/6100/0001/17, (Solution period2017-2018),
Author: Muzika L.
Partner: Lintech s.r.o.

Result:
[1] Muzika L., Kučera M. Ph.D.: Funkční vzorek laserového systému pro IRNDT, ZČU v Plzni, 2019, Functional sample, NTC-FVZ-19-002,CENTEM+, https://ntc.zcu.cz/vysledky/fv/

h) No. of project of cooperation in VaVaI with public application sector

Threshold	Produced since project commencement	Implementation (%)
1	2	200

i) List of new results prepared by members of the team of authors within cooperation in VaVaI with public application sector

Project: [1]
Contract for cooperation, SML/6100/0058/17, (Solution period 2017-2018),
Author: Ing. Miloš Svoboda, Ph.D.
Partner: Pilsen – faculty hospital, Clinic of Surgery

Result:
[1] https://www.sciencedirect.com/science/article/pii/S0940960217300699
[2] https://www.prolekare.cz/casopisy/rozhledy-v-chirurgii/2018-5-experimentalni-priprava-korozivnich-preparatu-organu-velkeho-zvirete-63664

Project: [2]
Contract for cooperation, SML/6100/0047/18, (Solution period2018-2019),
Author: Prof. Ing. Josef Rosenberg, DrSc
Partner: Charles University – Faculty of Medicine in Pilsen

Result:
[1] E. Vavrinský, H. Svobodová, M. Mikolášek, V.Tvarožek, J.Kováč jr., P.Šutta, M.Matějovic, S.Sedlák, M.Kopani, T.Závodník, M.Donoval: Electro – optical monitoring of trisodium citrate applicable in haemodialysis. ASDAM 2018 October 21-24,2018, Smolenice Castle, Slovakia, DOI: 10.1109/asdam.2018.8544574

j) No. of project of cooperation in VaVaI with other reserach institutions

Threshold	Produced since project commencement	Implementation (%)
1	4	400

k) List of new results prepared by members of the team of authors in cooperation in VaVaI with other reserach institutions[9]

Project: [1]
Contract for cooperation, SML/5200/0014/116, (Solution period 2016-2018),
Author: Ing. Robert Cimrman, Ph.D.
Partner: Institute of Thermomechanics AVČR v.v.i.

Result:
[1] Cimrman, Robert; Novák, Matyáš; Kolman, Radek; Tůma, Miroslav; Plešek, Jiří; Vackář, Jiří. Convergence study of isogeometric analysis based on Bézier extraction in electronic structure calculations. Applied Mathematics and Computation, Available online 6 March 2017, ISSN 0096-3003, http://dx.doi.org/10.1016/j.amc.2017.02.023. http://www.sciencedirect.com/science/article/pii/S0096300317301273 ID 43921055; WOS: 000415906200013; eid=2-s2.0-85014468888

Project: [2]
Contract for cooperation, SML/6100/0020/16, (Solution period 2016-),
Author: Prof. Ing. Juraj Kosek, Ph.D.
Partner: VŠCHT in Prague.

Result:
[1] Mazúr P., Mrlík J., Beneš J., Pocedič J., Vrána J., Dundálek J., Kosek J.: Performance evaluation of thermally treated graphite felt electrodes for vanadium redox flow battery and their four-point single cell characterization, Journal of Power Sources 380 (2018) 105–114

Project: [3]
GAČR 17-14840S, SML/6100/0010/17, (Solution period 2017-2019),
Author: Doc. Ing. Ján Minár Ph.D.
Partner: Institute of Physics AVČR

Result:
[1] Šipr, O., Vackář, J., Minár, J.: Finite lifetime broadening of calculated X-ray absorption spectra: possible artefacts close to the edge. Journal Synchrotron Rad., vol. 25, p.523–528, 2018.

[2] Häusler J.; Niklaus, R.n; Minár J.; Schnick W.: Ammonothermal Synthesis and Optical Properties of Ternary Nitride Semiconductors Mg-IV-N2, Mn-IV-N2 and Li-IV2-N3 (IV=Si, Ge). Chem. Eur. J. vol. 24, p. 1686-1693, 2018.

[3] Azam, S.; Irfan, M.; Khan, S.A.; Ali, Z.; Kityk, I.V.; Muhammad, S.; Al-Sehemi, A. G.: Doping induced effect on optical and band structure properties of Sr2Si5N8 based phosphors: DFT approach. Journal of Alloys and Compounds vol. 771, p. 1072-1079, 2019.

Project: [4]
Contract for cooperation, SML/6100/0039/18, (Solution period 2016-),
Author: Ing. Tomáš Křenek Ph.D.
Partner: Institute of Chemical Process Fundamentals AVČR

Result:
[1] V. Jandová, D. Pokorná, J. Kupčík, P. Bezdička, T. Křenek, M. Netrvalová, P. Cuřínová, J. Pola Thermal reactions in mixtures of micron-sized silicon monoxide and titanium monoxide: redox paths overcoming passivation shells, Research on Chemical Intermediates, 2018, 44(1), pp 503-516.
https://doi.org/10.1007/s11164-017-3116-z

l) Summary of research and development specialists and academics who are employees of other research institution with registered office in the Czech Republic and who provably actively participated on research activities on the Center premises, among which are guest professors.

Juraj Kosek (VŠCHT Praha, 5* 0,1875), Miloš Marek (VŠCHT Praha, 5*0,125), Michal Přibyl (VŠCHT Praha, 4*0,1875), Dalimil Šnita (VŠCHT Praha, 5*0,125), Petr Kočí (VŠCHT Praha, 5*0,1875), Zdeněk Slouka (VŠCHT Praha, 5*0,1875)
Total for 5 let: 5*1*12-0.1875=**59,8125 FTE man/month**
4 professors

m) Summary of research and development specialists and adacemics who are foreign residents and/or employees of foreign research institution with registered seat in abroad, who provably actively participated on research activities on Center premises.

Doc. Dr. Ján Minár Ludwig-Maxmilians-Universität München (LMU), (2015-2016,); 0,2149 FTE/měs.
Prof. Ing. Ali H. Reshak Ph.D. Univerzita Basra-Irák pracoval v rámci NPUI v letech 2015-2018. Úvazek = 3,5*1*12=42 FTE/měs.
Ing. Gmitra Martin, Univerzita Košice, 12*0,25 months.
Total: **45,2149 FTE man/month**

n) Summary of local students in master or doctoral study programs who provably actively participated on research activities on Center premises.

Martina Podivinská (VŠCHT Praha, 3*12), Andra Nistor (VŠCHT Praha, 3*12), Jan Dundálek (VŠCHT Praha, 5*12), Jiří Vrána (VŠCHT Praha, 4,5*12),
Tomáš Remiš (ZČU Plzeň, 4*12), David Rieger (ZČU Plzeň, 4*12),
Ing. Matěj Hruška, (ZČU v Plzni, 4*12), Ing. Marek Vostřák, (ZČU v Plzni, 3,5*12),
Ing. Martin Kučera, (ZČU v Plzni, 3*12), Mgr. Denys Moskal, (ZČU v Plzni, 4*12),
Ing. Eva Smazalová, (ZČU v Plzni, 3*12), Jan Kubant, (FJFI Praha, 1*12), Petr Vágner, (Matematicko fyzikální fakulta, 1*12), Lukáš Vála, (ZČU v Plzni, 3*1), Mina Zafouri, (ZČU v Plzni, 0*12), Jan Jansa (ZČU v Plzni, 5*1).
Total: **612 man/month**

o) Summary of students of foreign universities in master or doctoral study program or their equivalent, who provably actively participated on research activities on Canter premises.

Tiago Motta Novaes Lopes, Universidade Federal (Rio de Janeiro, Brazílie, 2 měsíce),
Ricardo Felipe S.C. Ouvinã, Universidade Federal (Rio de Janeiro, Brazílie, 3 měsíce),
Shaikh Asad Ali Dilawary, (Istanbul Technical University, Turecko, 3 měsíce)
Khan Wilayat (Quaid Azam Univerzity Pakistan, 36 měsíců)

Saleem Ayaz Khan (Hazara univerzity Pakistan, 48 Měsíců)
Sikander (Quaid Azam Univerzity Pakistan, 36 měsíců)
Javier Varilas Delgado, Univerzita v Barceloně, 24 měsíců),
Alexey Moskovchenko, Tomsk Polytechnic University, Russia, 4 měsíce
Total: **156 člověk/months.**

p) Summary of research and development specialists and academics employed by other legal entity acting in applciation field wcho participated on research and development activities of the Center and on its premises.

Marek Bobák (Membrain s.r.o, 5*0,0625, 2015-2019),
Tomáš Gregor (Valeo Výměníky tepla, k.s., 4*0,125, 2015-2018),
Ing. Jan Klepáček, Ph.D., (LaserTherm, s.r.o., 5*0,5; 2015-2019).
Total: **39,75 man/month**

q) Summary of members of team of authors who are employees of subsidy recipient (or other project participant) and who provably actively participated on research and research and educational activities in other foreign research institution in the function of research and development specialist or academic (classified as Bc./Mgr./Ph.D.).

Bc:
J. Kubant - Německo 24. 2. 2015 - 24. 4. 2015, 2 měsíce

Mgr.:
L. Loukotová - Srí Lanka 26. 4. 2015 - 22. 6. 2015, 2 měsíce
P. Novotný - Stuttgart Německo - 2. 5. 2016 - 30. 6. 2016, 2 měsíce
P. Novotný - SRN, 31. 7.2017 – 1. 9. 2017, Stuttgart, 1 měsíc
Jan Dundálek Hochschule Landshut, D, 3 měsíce
J. Dundálek - SRN, 3. 10. 2017 – 16. 12. 2017, Ruhstorf an der Rott, 2 měsíce
T. Remiš - Dánsko, 6. 11. 2017 – 7. 12. 2017, 1 měsíc

Ph.D.:
L. Prušáková - Uppsala Švédsko 1. 1. 2015 - 30. 4. 2015, 3 měsíce
M. Netrvalová - Německo Berlín 18. 1. 2015 - 21. 3. 2015, 3 měsíce
P. Calta – Delft, Holandsko, 2015, 2 měsíce
R. Medlín – SRN, 31. 10. 2016 – 02. 12. 2016, Mnichov 2 měsíce
P. Novák – Švédsko, Uppsala 31. 10. 2016 - 1. 12. 2016, 2 měsíce
Saleem Khan - Hazara Univerzity Mansehra Pakistán, 1 měsíc
Rajedran - Indie 1. 3. 2015 – 30. 4. 2015, 2 měsíce
J. Očenášek - Španělsko, Univerzita v Barceloně 1. 6. 2017 – 30. 6. 2017, 1 měsíc
J. Očenášek - Španělsko, Univerzita v Barceloně 4. 6. 2018 – 5. 7. 2018, 1 měsíc
J.Pocedič -Technische Universität Braunschweig, Institute of Energy and Process Systems Engineering, 2 měsíce

Threshold	Produced since project commencement	Implementation (%)

15	17	113

r) Summary of members of team of authors who are employees of subsidy recipient (or other project participant) and who provably actively participated on research and research and educational activities in other local research center in the function of research and development specialist or academic (classified as Bc./Mgr./Ph.D.).

Ing. Miloš Svoboda, Ph.D. VŠCHT Praha, (2015-2019)
Ing Jaromír Pocedič, Ph.D. VŠCHT Praha, (2015-2019)
Ing. Jiří Vrána, Ph.D. VŠCHT Praha, (2015-2019)
Prof. Ing. J. Šesták DrSc (FU AVČR, 24 měsíců)
Ing. Pavel Holba, CSc (FU AVČR, 12 měsíců)

s) Summary of members of team of authors who are employees of subsidy recipient (or other project participant) and who provably actively participated on research and research and educational activities in application field of private sector - constantly for at least one month and maximum six calendar months.

Ing. Miloš Svoboda, Ph.D. Pin- Flow Energy s.r.o, 3 měsíce

8. Summary of changes

Some minor personnel changes occurred due to retirement or change to other workplace during the project, having no impact on predicted number of specialists in categories D1 and D2.

During the project another software system had to be leased with specialised modules for characteristics of chemical reactions and modelling of processes created during formation of thin layers, and service works had to be paid, which exceeded the estimated value. For these reasons was during the first year of the project proposed the following:

a) Transfer of funds of total UN from chapter FX (operational costs) in amount of 1.230.000 CZK to the item F4. Costs of supplier´s services.

b) Transfer of funds of total UN from chapter F.3.5 (travel costs) in amount of 750.000 CZK in the item F4. Costs of supplier´s services.

Item F4 Costs of supplier´s services were increased by 1.980.000 CZK from overall deductible costs. ŘO met in 2015 our above requirements related to change of the budget structure.

During further work on the CENTEM+ project some minor changes occurred in the structure of planned costs however the total annual spending did not exceed the allowed 20% of planned amount of possible item changes. In accordance with these changes all subsidies annually spent (every project year) were in amount of 26 863 000 CZK and the project was refinanced up to the planned amount with further public and non-public funds based on the plan.

All planned activities were accomplished according to plan.

9. Consumption of recognized cost and public financial support

Total cost: (CZK thousand)	Recognized costs – plan under the contract	Recognized costs – actually consumed cost	Financial support – plan under the contract	Financial support – actually consumed cost
Personal cost	196 040	196 040	88 220	88 220
Cost of puchase assets	0	0	0	0
Operating cost	19 900	20 051	8 455	8 889
Travel expenses	6 690	6 957	3 010	3 010
Costs of publication of results and industrial rights of results	1 200	1 200	540	540
Cost of external contractors services	16 130	15 712	7 105	6 671
Additional (overhead) costs	59 990	59 990	26 985	26 985
Total cost	299 950	299 950	134 315	134 315

Public financial support	134 315
Total additional financing – public sources	115 173
Total additional financing – non public sources	50 462
Total anused support	0
Total	299 950

Comment

Necessary transfers financial of funds were commented in the Chapter 8 Summary of changes. During realization of the project CENTEM+ were minor changes occurred in the structure of the planned cost according the contract, but the total recognized costs in the each year does not exceed the permitted 20% of the planned amounts possible changes to the items.

Total additional financing from non public sources according plan under the contract	Produced since project commencement	Implementation (%)
45 010	50 462	112

10. Press release

10.1. Press release in Czech

Program NPUI MŠMT umožnil zcela ojedinělou podporu výzkumných Center zaručující efektivní využití investic SFEU ve spojení s evaluací. V případě projektu CENTEM+ jehož řešitelem bylo NTC (Nové technologie – výzkumné centrun, ZČU), se jednalo o rozvoj materiálového výzkumu. V rámci projektu bylo publikováno 253 vědeckých článků v impaktovaných časopisech (dle Article Influence Score bylo 30,7% Q1 a 46,2% Q2). Vzniklo 6 udělených patentů; 7 prototypů; 9 SW a dalších 35 aplikovaných výsledků vč. star-up. NPUI umožnil rozvinout potenciál NTC, navázat další mezinárodní spolupráce, rozvoj kolaborativního výzkumu s firmami a dosažení unikátních výsledků. Mezi nejvýznamnější výsledky, které snesou celosvětové srovnání patří stend na velkokapacitní úložiště elektrické energie, emisivní barvy pro termografické aplikace, technologie přípravy tandemového solárního článku na bázi křemíku, ověřená technologie pro předběžnou analýzu možností recyklace nikl-kadmiových akumulátorů žárovou cestou a.j.

10.2. Press release in English

The NPUI program of the MSMT enabled very unique support of research centers guaranteeing effective use of the EU sturctural investments in conjunction with evaluation. In the case of the project CENTEM +, where the investigator was NTC (New Technologies - Research Centre, UWB), was the focus on the development of research of materials. Within the project 253 scientific articles were published in impacted journals (according to the Article Influence Score 30.7% Q1 and 46.2% Q2). There were 6 granted patents; 7 prototypes; 9 SW and other 35 applied results incl. start-up. The NPUI has enabled to develop the potential of NTC, establish further international cooperation, develop collaborative research with companies and achievement of unique results. Among the most significant results that can withstand comparable comparisons is the large-scale electrical energy storage, special emission paints for thermographic applications, technology of preparation of tandem silicon based solar cells, proven technology for preliminary analyses of the recyclation of nickel-cadmium accumulators by heat treatment etc.