DEPARTMENT FOR NANOSTRUCTURED MATERIALS K-7

One of our biggest advantages is our interdisciplinary team. The basic and applied research of the Department for Nanostructured Materials includes metals, intermetallic alloys, engineering and functional ceramics, biomaterials and minerals. Our research encompasses conventional processing as well as the development of new technologies and methods for preparing new materials with advanced properties. It includes experimental and theoretical investigations of structures, analyses of chemical compositions at the atomic level, and measurements and calculations of physical properties, all of which help us to improve the properties of micro- and nanostructured materials.

Head (since 1. 4. 2018):
Prof. Sašo Šturm

Head (until 31. 3. 2018):
Prof. Spomenka Kobe

Magnetic Materials

We employed a "Spark Plasma Sintering" (SPS) approach to prepare a dense, nanostructured, multicomponent magnet containing a high-coercivity region. For this purpose, a nanostructured powder free of heavy rare earth (HRE) was used in combination with a Dy-containing powder. We showed that this type of magnet could be manufactured in a single step by stacking both powders in the desired manner, while avoiding mixing. The short manufacturing time and the low consolidation temperature of the SPS process inhibit the diffusion of the Dy into the Dy-free region of the magnet. SEM and EDX analyses of the interface between both parts of the multicomponent specimen revealed that the microstructural characteristics and chemical compositions of the respective parts were comparable with single-component magnets prepared from the individual powders, which corresponded with the results of the magnetic characterization. In summary, magnets with locally different magnetic properties were prepared from nanostructured melt-spun ribbons using the SPS approach. The work continues with a focus on the processing of anisotropic Nd-Fe-B magnets from jet-milled powders by SPS.

As part of the research work for Slovenian industrial partners we focused on: (i) improving the coercivity of melt-spun powders used for bonded magnets, and (ii) developing a coating procedure and different coating materials to prevent corrosion in aggressive conditions. Already during the first year of the two projects we successfully increased the coercivity by more than 15% and we established the most effective solution so far to protect sensitive Nd-Fe-B powders by using alumina as a thin protective layer. We also used an electroless coating and electrochemical method for coating the basic melt spun powders with a thin Ni layer. The continuation of the work will be in (i) transferring the technology for the coercivity improvement to larger quantities of basic powder, and (ii) to perform a long-term corrosion test on the protected Nd-Fe-B powders in factory conditions. At the laboratory level, we will continue the experimental work by using organic solvents in the electrodeposition of Ni. The following set of research works for the industrial partner relates to the development of a new magnetic material, which will enhance the performance of a magnetic encoder measuring system. In the framework of this project, different magnetic powders will be fabricated and characterized for their magnetic performance.

For the industrial partner ABB (Switzerland) we developed a technology for producing Nd-Fe-B magnets with locally different magnetic properties (multicomponent magnet) that can be used in applications where only certain parts of the magnet experience strong demagnetizing fields and a significant increase in temperature.

In 2018, we started with the new European project **MaXycle**, a transnational collaborative research and innovation project, funded from the ERA-NET Cofund on Raw Materials (ERA-MIN 2) instrument under Horizon 2020. MaXycle is developing and validating a systematic approach to overcome the barriers currently hindering a successful circular economy for Nd-Fe-B-type magnets on an industrial scale. It will provide the tools to identify different quality grades of Nd-Fe-B end-of-life magnets and provide the most suitable methods to upgrade their properties with respect to costs and sustainability for large-scale reprocessing. The project will create a new circular economy around the sustainable supply and (re)use of precious raw materials, with the aim to recycle 15% of all the magnets produced by 2025 and will create eco-innovations, boosting competitiveness and job creation in the EU.

In the frame of the **Marie Skłodowska-Curie European Training Network (DEMETER)** we are focusing on the **recycling of critical raw materials.** We successfully produced novel permanent magnets based on recycled end-of-life Nd-Fe-B and Sm-Co systems. With the implementation of the SPS technique, we produced Nd-Fe-B permanent magnets from recycled powders obtained after HDDR (hydrogenation-disproportionation-decrepitation-recombination) processing. A 30% increase in the initial coercivity (H_{ci} = 1190 kA/m), with a remanent magnetization B_r = 0.82 T, and BH_{max} = 118 kJ/m^3 were achieved (published in the Journal of Alloys and Compounds). Additionally, the recycling scheme of the HDDR route has been established by relating the magnetic properties' variations with the particle size and oxygen content to help industry retain control of the microstructure and quality in recycled Nd-Fe-B powders. Moreover, the SPS method was also successfully used in the compacting of recycled HD (hydrogen-decrepitation) powders based on $SmCo_5$, where we achieved a RT coercivity > 2200 kA/m and at 180 °C an H_{ci} > 1200 kA/m, an improvement over the initial powder properties due to particle size refinement during the HD recycling (reported in a publication in IEEE Transaction on Magnetics). In the frame of the DEMETER project, chemical recycling, i.e., processing of the rare earth, has been investigated. The electrodeposition of the Nd and Fe elements from ionic liquids based on 1-ethyl-3-methylimidazole dicyamide was evaluated. We found that Nd can only be reduced in the presence of Fe, which most probably catalyses the further reduction of Nd, and we also proposed an appropriate mechanism.

FRAME - A novel recycling concept for Nd-Fe-B sintered magnets was developed based on anodic etching (Patent application, European Patent Office, Application EP 18 2018 508.4). By using an organic solvent, the $Nd_2Fe_{14}B$ matrix phase was recovered by preferential anodizing/etching of the grain-boundary phase (Nd-rich phase). Around 70 % of the magnet was recovered directly in the form of $Nd_2Fe_{14}B$ grains, which are suitable for new magnet production. The collected rare-earth oxides and rare-earth-rich leaching solutions can be further treated and used for the production of rare-earth-based products.

In 2018, we started a national project (L2-9213) in collaboration with the company Magneti Ljubljana, d.d. where we are investigating novel ways of recycling magnetic swarfs based on Sm-Co. Novel strategies concerning metallurgical and electrochemical recycling procedures to achieve a circular economy are currently under investigation. We found that by using an organic solvent, a Sm_2Fe_{17} sintered magnet can be selectively etched for further Sm and Co extraction.

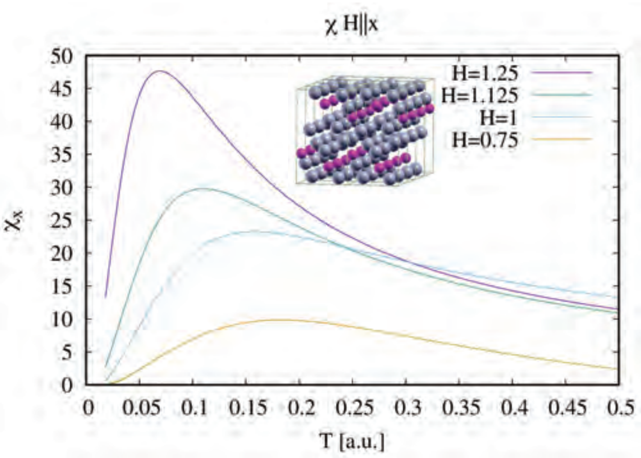

Figure 1: The calculated temperature-dependent magnetic susceptibility for a monatomic nanowire with the help of method the renormalization group of matrix density matrices (TDMRG). The Ce_3Al crystal structure with chains of Ce atoms (magenta balls) as the source of the quasi one-dimensional magnetism is shown in the inset.

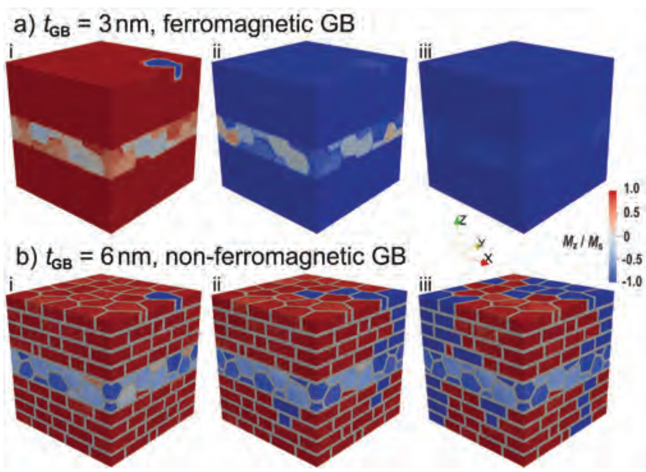

Figure 2: Magnetization reversal in the case of (a) magnet with a ferromagnetic grain-boundary phase and (b) magnet with a non-ferromagnetic grain-boundary phase.

We continued with research in the framework of the European project **AMPHIBIAN** ("AnisoMetric Permanent HybrId magnets Based on Inexpensive And Non-critical materials"). The goal of the project is to prepare hybrid ferrite-based magnets with an energy product, BH_{max}, higher than 50 kJ/m³. The upper limit so far is 45 kJ/m³. The hybrid anisotropic magnets with enhanced magnetic performance prepared in the AMPHIBIAN project will be installed in a flywheel (electric energy storage device). Such an achievement would open up an entirely new field of possible applications. Up till now we systematically studied the influence of various processing methods on the magnetic properties of Sr-hexaferrite and determined the most suitable densification method. In the past year we were also investigating possibilities for an increase in the recycling rate of the scrap material produced during the injection moulding of ferrite magnets.

On the basis of the density-functional theory we investigated the evolution of magnetic Ba-hexaferrite-based nanostructures by predicting the most probable termination planes. In a collaboration with the Department for Solid State Physics we contributed a theoretical description of the quantum-critical point in the magnetically quasi-one-dimensional system Ce_3Al (Figure 1). We applied the transfer-matrix density-matrix-renormalization group (TDMRG) method in order to calculate the temperature-dependent magnetic susceptibility as a function of the external magnetic field H, which gave us the critical point. In addition, we collaborated with the Department for Solid State Physics in the investigation of the Verwey-type charge-ordering transition in a p-shell material, which does not exhibit a complex interplay between various degrees of freedom. The results were published in **Science Advances (IF = 11.5)**.

In the frame of the ARRS postdoc project Z2-7215, we have successfully finalized the study of heavy-rare-earth fluorides' influence on the coercivity of Nd-Fe-B melt-spun ribbons. The excellent results were a starting point for a collaboration with the company Kolektor Group. In this project our mission is to establish a process that would lead to an improvement of the coercivity by 15 %, with the costs not allowed to increase by more than 10 %. With Japanese colleagues at NIMS we performed research in which we correlate the domain movement during magnetization reversal with the microstructural analyses (Figure 2). In two different types of hot-deformed magnets the regions with misaligned grains were compared and their role in magnetization reversal was considered and consequently the coercivity difference was explained.

Complex Intermetallic Alloys

In the frame of the **International Associated Laboratory (LIA) PACS2**, which connects CNRS and JSI, we are studying the crystal structure and chemistry of so-called push-pull complex metallic alloys in relation to their processing routes, final physical properties and potential applications.

We continued our studies of the crystallization mechanisms of a glass prepared by melt-spinning in the Al-RE-Fe-Cu alloys system. Gd, with a much stronger magnetic moment, followed the previous studies when using Ce. The structure of Gd-based alloys manifests a more reduced vitrification ability than that of the Ce-based counterparts, which is consistent with a 300 K higher liquidus line in the Al-Gd diagram. TEM observations of the microstructure at the atomic scale show crystallites within the glassy matrix. The temperatures Tg and Tx are higher compared to a Ce-based system, which coincides with the higher melting point of Gd. The magnetic behaviour of Gd-based glasses at RT changes from paramagnetic (PM) to ferromagnetic (FM) and the magnetization increases from 4 to 16 emu/g. Below the blocking temperature, the PM is replaced by an antiferromagnetic (AFM) state. The evidence of spin-glass behaviour appears as well. The local atomic structure of the glasses imparts a hybridization effect, which couples the adjacent magnetic moments of the constitutive elements. The ribbons of Ce- and Gd-based metallic glasses were successfully consolidated into cylinders in the range between Tg (T of glass transformation) and Tx (T of crystallization), via the SPS technique, while maintaining a glassy structure.

Structural Materials

In the framework of the **EUROfusion** programme, we carried out research devoted to materials for the divertor of the future Demonstration Power Station (DEMO). Namely, the divertor is expected to be exposed to a very severe environment. Currently, no material meets the requirements for use in the DEMO reactor under the proposed operating conditions. Therefore, in the High-Heat-Flux-Materials working group we are working on improving the properties of metallic tungsten, which is, unfortunately, brittle at moderate temperatures, and above approximately 1000 °C its strength is greatly reduced due to recrystallization and the excessive growth of grains. At the Department of Nanostructured Materials we have developed a new W-W_2C composite, which is prepared by adding WC nanoparticles to tungsten powder and by densification using the SPS technique. We examined the material in detail and, with the help of partners in Spain, Romania and Germany, analyzed its properties across a wide range of temperatures up to 1000 °C. Improved properties in comparison to other composites have been confirmed.

In the **Enabling Research project**, we also verified the suitability of low-activation WC-based cemented carbides as a fusion-relevant material. In cooperation with the Institute for Materials and Technology (IMT) we investigated high-entropy alloys and iron triads as a binder phase in the WC-cemented carbide. The samples of WC-Ni are being tested. Both projects were also financially supported by the ARRS.

Sensors

We are developing modified printed electrodes via nanostructuring of the receptor elements based on transition-metal oxides that serve as the base for an autonomic sensor platform suitable for in-situ HCHO analytical studies. We have fabricated modified Ni nanowires for the electro-oxidation of formaldehyde (HCHO), which are promising for use as an effective electrochemical receptor element. An active material (electro-catalyst) for HCHO detection was generated by the template-assisted electrodeposition of Ni into Al_2O_3 membranes, followed by modification in an alkaline solution (KOH), which produced an active amorphous $Ni(OH)_2$ layer on the surface. The proposed electrode shows two wide ranges of linear response and a low detection limit (0.8 μmol L^{-1}). Furthermore, it exhibits a fast response time, a high sensitivity, good reproducibility and selectivity to other similar organic compounds. Furthermore, the Ni nanowires were successfully integrated on paper-based, screen-printed electrodes (SPE) that results in the development of new, low-cost devices for the in-situ analysis of HCHO. Acrylamide is a widely used industrial organic compound. In nature, it can be found as a contaminant originating from polyacrylamide – a polymer that is used in wastewater treatment, the paper and textile industries, and as a monomer in cigarette smoke and in heat-treated food. Due to its neuro and genotoxicity and classification as a potential human carcinogen, it is essential that we are able to detect its presence, especially in food products. We are developing modified screen-printed electrodes via nanostructuring of the receptor elements based on conducting polymers for creating molecular imprinting suitable for acrylamide analytical studies. So far, we have successfully electropolymerized polyaniline onto different gold-based SPE electrodes by using an electrochemical approach. It was prepared in a conductive emelardine form,

With nanostructuring we are developing sensoric receptor elements with enhanced sensitivity for detecting toxic organic compounds, like formaldehyde (HCHO) (national project L2-8182) and acylamide (AA).

which enables further usage in studies for designing molecularly imprinted sensing systems. With the addition of propanamide as a template molecule into the polymerization suspension, polyaniline polymerized around the template, causing its imprint confirmed with FTIR. The obtained systems, after the template molecule removal, present the first stage in the assembly of the acrylamide-sensitive receptor element.

Materials for Health and a Clean Environment

The results also showed the high selectivity of the FePt/SiO_2/Au hybrid nanoparticles between the normal and cancerous cell line. Furthermore, the improvement in the contrast and the easier distinction between the healthy and the cancerous tissues were clearly demonstrated with *in vitro* MRI experiments, proving that hybrid NPs have an excellent potential to be used as a contrast agent. The research was published in the scientific journal **Nanoscale** and according to the Slovenian Research Agency's projects "**Excellent in Science**" it was ranked among the best scientific achievements of 2018.

We have prepared an innovative theranostatic material based on FePt/SiO_2/Au hybrid nanoparticles. *In vitro* experiments on normal and cancerous urothelial cells have proven their efficiency for both photo-thermal therapy and magnetic resonance imaging (MRI).

In order to develop the **most effective contrast agent for MRI based on superparamagnetic nanoparticles**, we have investigated the effect of the magnetic interactions acting between the nanoparticles on their magnetic properties, which are crucial for their efficiency. Furthermore, a novel and biocompatible coating on hydrocaffeic acid was used for the first time. *In vitro* testing showed the non-toxicity of as-prepared nanoparticles even at high concentrations and for a longer period of time (1 week). Cellular uptake and the internalization mechanism were studied using ICP-MS and TEM analyses. Moreover, *in vitro* MRI measurements have shown that the exposure of the cells to the lowest used concentration of the HCA-Fe-Pt nanoparticles is already enough to decrease the T_2 signal by 70%. This proves that HCA-Fe-Pt nanoparticles have great potential to be used as safe and very efficient MRI contrast agents. The findings of the study were published in **RSC Advances** (Figure 3).

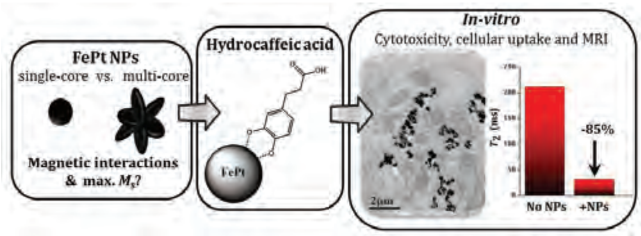

Figure 3: A study of the magnetic interactions revealed the optimal size and morphology of Fe-Pt nanoparticles with the highest saturation magnetization (M_s). A novel biocompatible hydrocaffeic acid coating was used to prepare a highly efficient and safe MRI contrast agent, which was proven by an in vitro study.

Within the framework of the **Isofood** project, we organized a workshop on nanoparticles in food. We demonstrated the various aspects of nanoparticles entering food, either during production, packaging and cooking, or are added to improve taste, colour and consistency. They are difficult to detect in food, because they are very small, so they need specific methods and techniques for their detection and characterization, as well as for analyzing their interactions with cells and the effects on health. In cooperation with the Faculty of Electrical Engineering, the physico-chemical properties of silver and TiO_2 nanoparticles were analysed within the project "Analysis of potential harmful effects of nanoparticles and accompanying mechanisms, from physicochemical and *in vitro* characterization to the activation of the innate immune system". The main aim of the research is to understand the response of the cells to the investigated nanomaterials.

We continued the study of three-dimensional silk fibroin scaffolds for their potential use in tissue engineering, regenerative medicine and pharmacy. In the framework of the project "Role of estrogens and active brain feminisation, and the development of a new hormone implant, mimicking estrous cycle", we focused on the preparation and tailoring of the fibroin scaffolds' degradability and on the controlled release of the estrogen. The results are very promising.

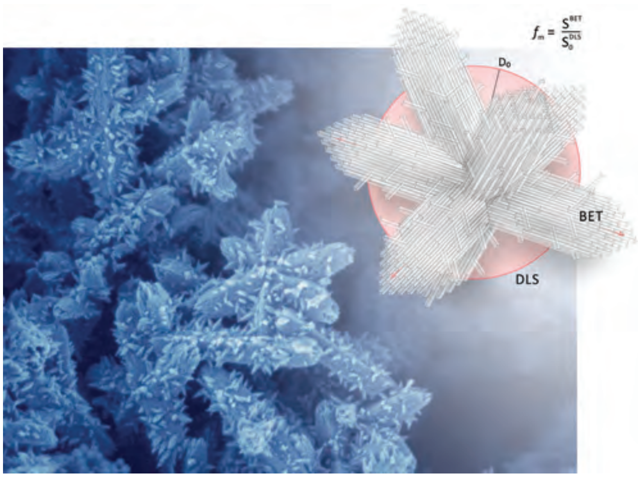

Figure 4: Morphology factor, f_m. A new criterion for the evaluation of nanoparticle branching, allowing a comparison of morphologies regardless of the particle size. It is defined as the ratio of the particle's total surface area vs. the volume of an equivalent sphere that would correspond to the particle's volume.

In the field of the **anodic oxidation** of titanium, the influence of the anodization electrolyte aging and the titanium surface treatment on the photocatalytic properties of the synthesized TiO_2 nanotube films were studied. In these studies caffeine was used as a model organic molecule. In a different study, TiO_2 nanotubes were used as a catalyst for the synthesis of adipic acid from 1,6-hexanediol, which is a very important scientific field still in its development phase. In cooperation with the National Institute of Chemistry, the first immobilized TiON nanotube films were prepared and used for the electrocatalytic degradation of phenol and as a catalyst support for the oxygen-evolution reaction. In the latter case, a high conductivity and specific surface area of the TiON nanotubes served as an efficient and stable substrate for an iridium catalyst. Apart from titanium, many other metals, such as iron, nickel, vanadium, tungsten, zinc and copper, were successfully anodized and their morphologies thoroughly studied. Finally, we continued with the development of innovative reactors for the photoelectrocatalytic purification of water and the photocatalytic purification of air. The active photocatalyst in all the reactors was based on TiO_2 nanotubes.

Our fundamental studies of self-assembly were directed towards studies of how to exploit twinning to achieve the angular branching of rutile TiO_2 mesostructures. We have shown that twin-based oriented attachment (OA) can be realized in a solvothermal process from Ti(IV)-butoxide under mild acidic conditions that favour the precipitation of rutile with a short-prismatic morphology. The aspect ratio of the precipitated nanocrystals decreases linearly with the acidity of the medium, i.e., the lower it is, the higher is the affinity for twin OA. Through the control of lateral {110} and twin {101} OA in rutile we are able to generate diverse fractal-like multiply twinned inorganic mesostructures for nanotechnology applications. To quantify the branching, we defined a morphology factor, f_m, a new generally applicable criterion, which provides a first quantitative measure of the nanoparticle morphology, and can be used to evaluate and compare the relative increase of a specific surface area for any branched materials (Figure 4). The study was published in **Crystal Growth & Design**. The aim of these studies is to explain the mechanism of self-assembly that will allow the production of hierarchic branched multifunctional mesostructures for advanced nanotechnology applications.

The extensive, long-term research work on the exploitation of the naturally self-driven AlN powder hydrolysis that can be used as a powerful tool in advanced materials engineering was summarised in a personalised review article (Personal Accounts) published in *The Chemical Record*.

Engineering Ceramics

In collaboration with Madrid's CSIC (Instituto de Ciencia de Materiales de Madrid), we have developed **cellulose, nanofiber-reinforced, engineering electro-conductive ceramics** and filed a Great Britain patent application. Imparting the electrical conductivity to a dielectric ceramic with conducting nano-carbons (nanotubes or graphene) is challenging. The invention relates to an alternative, sustainable way with a small addition of cellulose nanofibers, which render highly homogeneous ceramic dispersions due to the increased hydrophilicity character and facilitates green machining of the consolidated green bodies. During sintering, the nanofibers are in-situ transformed to a 3D, percolative, few-layered-graphene network within a dense and refined ceramic matrix inducing a high electrical conductivity (Figure 5). The work was published in **Nanoscale.**

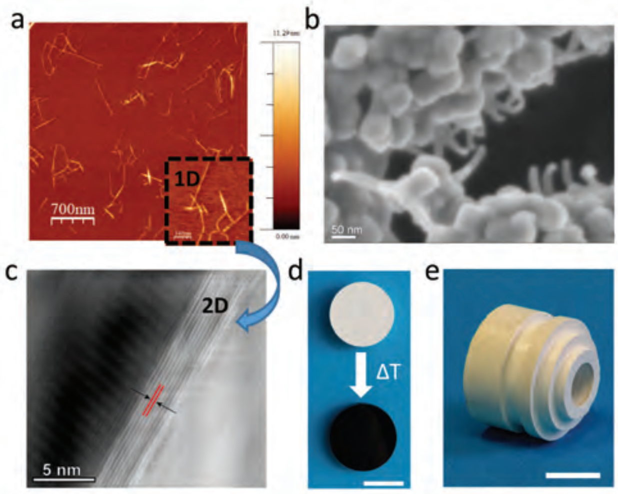

Figure 5: (a) Atomic force microscopy (AFM) micrograph of individual cellulose nanofibres (CNF) deposited on a mica substrate. The magnified inset image underlines the 1D morphology of the CNF, which is transformed into a 2D carbon phase during SPS sintering, as observable in d. (b) SEM micrograph of freeze-dried 2%CNF-zirconia powder. (c) Photograph of a machined 2% CNF-zirconia green body. (d) BF STEM image of a few-layered graphene (FLG) film between alumina grains in 3%CNF-alumina. (e) Photograph of 3%CNF-alumina before and after SPS sintering, showing a white-to-black colour change. Copyright (2018) The Royal Society of Chemistry.

In collaboration with the distinguished Israeli Ben-Gurion University and Max Planck Institute, we have characterized the pore evolution and thermal properties of newly developed foam-based materials (C-N-P) targeted for fire-retardant applications. The work was accepted for publication in the renowned journal of **Angewandte Chemie International Edition.**

In the field of **dental ceramics**, we have traditionally been involved in the research on zirconia (3Y-TZP) as well as other dental materials conducted in collaboration with the Department for Prosthetic Dentistry, Medical Faculty, University of Ljubljana. In 2018 a basic research ARRS project was obtained entitled "Towards reliable implementation of monolithic zirconia dental restorations." In **Journal of Prosthodontic Research**, we have published a study on the influence of thermo-mechanical cycling on porcelain bonding to Co-Cr and Ti alloys fabricated by casting, milling, and selective laser melting. The investigation of the fracture resistance of endodontically treated maxillary incisors restored with zirconia posts, where we have studied the effect of the internal plateau preparation, was published in **Advances in Applied Ceramics**. Juliane Moritz from the Technical University of Dresden conducted experimental work for her diploma thesis, where she modified the surface topography of zirconia ceramics for the improved biocompatibility of dental implant surfaces. The work was recognised by Deutsche Keramische Gesellschaft and awarded Juliane with prestigious Hans-Walter Hennicke lecture prize for the best lecture given by young ceramists during the annual 2018 DKG conference that was held in Munich in April. In collaboration with Ustna Medicina d.o.o. we have developed a next-generation bioactive sealer for the endodontic treatment of teeth with improved bioactive, rheological (handling) and chemical properties, described in a technical innovation.

A spin-out company, Genuine Technologies d.o.o., was founded that will use the JSI`s licensed knowledge and provide more successful treatments for patients.

Functional Ceramics

In the field of **oxide thermoelectric materials** of the n-type, we proceeded with the development of **ZnO ceramics**. In cooperation with Laboratoire CRISMAT from Caen (France) we studied the structural characteristics and thermoelectric properties of ZnO ceramics doped with extremely low quantities of In. ZnO(In) ceramics were synthesized using a simple solid-state process. The structural features and thermoelectric properties of the $Zn_{1-x}In_xO$ series with an ultra-low indium content ($0.00 \leq x \leq 0.02$) were assessed. HAADF–STEM analyses indicate that indium has the ability to create multiple basal plane (*b*–IB) and pyramidal (*p*–IB) defects that produce domains with inverted polarity, starting from dopant concentrations as low as 0.25 atom % (Figure 6). Interestingly, the formation of IBs causes increased phonon scattering, while increasing the electrical conductivity, and thereby enhancing the overall thermoelectric properties. This is a completely new finding for ZnO ceramics with such low additions of In, showing that we do not have classic solid solubility of In in ZnO, but the inverse boundaries (IBs) are immediately formed. The study is a result of a continued collaboration with the French group and was published in **ACS applied materials & interfaces** (IF=8.456).

This study is a step forward to the design of other thermoelectric materials where dopant-induced planar defects in bulk transition-metal compounds have the potential to enhance both phonon scattering and electronic conductivity.

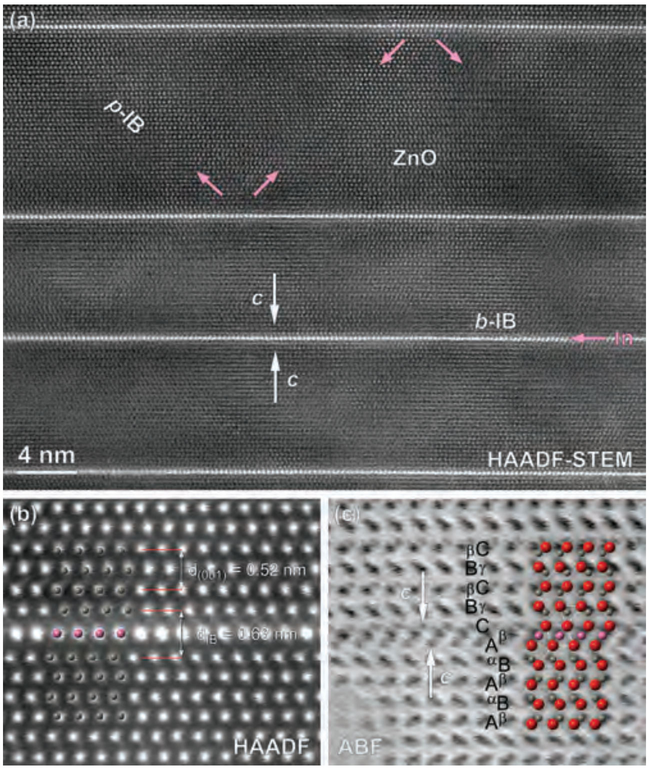

Figure 6: High-resolution STEM images of the $Zn_{1-x}In_xO$ (x = 0.02) sample viewed along the [100]ZnO zone axis. (a) HAADF-STEM overview with parallel b-IBs composed of strong white dots, corresponding to In-atomic column positions, interconnected by dark diffuse p-IB defects (marked by pink arrows at about 45°). (b) HAADF-STEM image close-up of b-IB section with overlaid cationic column positions and (c) corresponding ABF-STEM image with O-columns that allow determining the atom layer stacking and polarity (inverted c-axis) (red, O; gray, Zn; pink, In). From an article published in ACS Appl. Mater. Interfaces, 10, (2018), 6415-6423.

According to recent findings that magnetic semiconductors have better thermoelectric properties than expected, we began to study the effects of magnetic dopants on the thermoelectric properties of ZnO ceramics. The first analysis of the samples with the composition $Zn_{0.98-x}Al_{0.02}Co_xO$ (x = 0, 0.001, 0.0025, 0.005, 0.01, 0.05, 0.10) showed that the ceramics sintered at 1400°C became paramagnetic when doped with Co. Further research will focus on studying the possible effects of Co and magnetism on the density and mobility of charge carriers, the Seebeck coefficient and the electrical conductivity.

In the field of varistor ceramics, in cooperation with the "Shanghai Institute of Ceramics, the Chinese Academy of Science - SICCAS" we continued with the research and development of a new type of varistor ceramics that do not contain standard dopants for current-voltage (IU) nonlinearity, such as oxides of Bi, Ba, V and Pr. They are distinguished by high I-U nonlinearity and a very low addition of dopant, none of them melting or having high vapour pressure at the sintering temperature, which means great advantages in comparison with the classic varistor ceramic containing Bi_2O_3. For the development of high-voltage varistor ceramics and multilayer chip varistors, our investigations about the influence of the composition and the sintering regime on the microstructure development and I-U characteristics of ZnO-Bi_2O_3 varistor ceramics at temperatures below 1000 °C are important. We have developed varistor ceramics that have excellent I-U characteristics for applications after sintering at temperatures between 800 and 950°C. The results are reported in the journal **Ceramics-Silikaty**.

We investigated the effects of the dual doping of SnO_2 varistor ceramics with CoO and Nb_2O_5 on the formation of twin boundaries, microstructure development and electrical properties by electron microscopy methods. With the addition of Nb_2O_5, densification is shifted to higher temperatures (1430°C), producing a coarse-grained microstructure composed of twinned SnO_2 grains. Already a small addition of Nb_2O_5 (0.1 mol%) triggers a three-fold increase in growth rate via the diffusion-induced grain-boundary mobility (DIGM) due to the formation of oxygen vacancies in the grain-boundary region. At 0.5 mol % of Nb_2O_5 chemical equilibrium is achieved and the SnO_2 grains undergo normal grain growth. Electron back-scatter diffraction (EBSD) has shown that the prevailing type of twins is {101}. Cyclic twins are common. HAADF-STEM analysis revealed a nonuniform segregation of Nb along the twin boundaries, indicating that they are not directly triggered by the addition of the dopant, but are most probably a result of a yet unexplained sequence of topotaxial replacement reactions. Using energy-dispersive spectroscopy (EDS) we have shown that by the dual doping of SnO_2 with CoO and Nb_2O_5 the amount of Co dissolved in the SnO_2 grains is ~4× lower compared to the amount of Nb. We proposed the following charge-compensation mechanism: 6 Sn(IV)Sn × (IV) ⇋ Sn(II)Sn "(IV) + Co(II)Sn "(IV) + 4 Nb(V) ˙ Sn(IV) where oxygen vacancies, generated by the acceptor dopants Sn^{2+} and Co^{2+}, are compensated by one vacancy on the tin lattice site. The optimal electrical properties were achieved for the SnO_2–1 mol% CoO–1 mol% Nb_2O_5 sample displaying the highest nonlinear coefficient (α=50), matching those of ZnO-based varistors, while higher additions of Nb_2O_5 (>1.0 mol%) result in a collapse of the nonlinearity and a sudden increase in the leakage current. The study was published in **Ceramics International**.

Minerals

In collaboration with the Department for Litospheric Research of Vienna University we contributed to their study of spinel ($MgAl_2O_4$) formation during a replacement reaction between corundum (Al_2O_3) and periclase (MgO), involving the reorganization of Al atoms in octahedral interstices, the incorporation of Mg atoms into tetrahedral sites and a transition from the hexagonal close-packed (*hcp*) to the cubic close-packed (*ccp*) oxygen (O) sublattice. For the first time we show this type of transformation as a progressive diffusion-controlled process at the atomic scale using quantitative HAADF–STEM. Spinel forms in a progressive zipper-like interface motion, in which $MgAl_2O_4$ adopts two crystallographic orientations related by the 180° rotation in the $(111)_{SP} || (0001)_{COR}$ interface. Intergrowth of these domains generates a new type of coherent (111) twin boundaries in spinel that have previously not been reported. This is a case study of topotaxial replacement reactions involving the *hcp*/*ccp* transition in general. It was published in **Acta Crystallographica A** (IF=7.93). Further research subjects are in progress, including a study of Fe- Ti micro- inclusions as carriers of rock magnetism from the Mid- Atlantic ridge (starts in March 2019) and the study of garnet inclusions.

Analytical Electron Microscopy

For the characterization of materials on the micro- and submicrometer scales we use the advanced analytical methods of high-resolution scanning electron microscopy (FEGSEM), qualitative and quantitative elemental analysis by electron-probe microanalysis (EPMA) using energy-dispersive and wavelength-dispersive X-ray spectroscopy (EDS, WDS), electron-backscatter diffraction (EBSD) and complementary atomic force microscopy (AFM).

With the implementation of correlative microscopy, i.e., by using an optimum combination of FEGSEM, EDS, WDS, EBSD and AFM methods and taking into account the characteristics of the individual materials, we achieved reliable, precise and accurate analytical results. We studied various materials such as ceramic thermoelectrics, complex metallic and quasicrystalline alloys, magnetic materials based on Nd-Fe-B and Sm-Co, abrasives, piezoelectric perovskite ceramics. Among other things, we examined the influence of heat treatment on the microstructure and phase composition in Al-Cr-Sc alloys. By performing the expert-level quantitative WDS microanalysis we have accurately measured trace concentrations of the dopants Eu and Dy in phosphorescent ceramics based on $Sr_4Al_{14}O_{25}$; we have determined the exact chemical composition of submicrometric ceramic thin films that were made from 67PMN33PT complex perovskite. Using micro-crystallographic EBSD analyses, we directly confirmed the presence of icosahedral and decagonal quasicrystals in complex alloys based on Al-Mn (Figure 7), we investigated and determined the type of twins in cassiterite SnO_2 ceramics, and we studied the texture in $Nd_2Fe_{14}B$ magnetic materials.

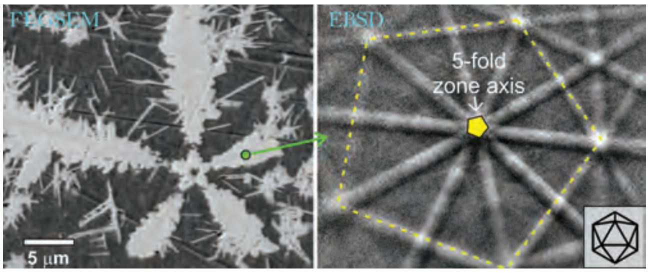

Figure 7: FEGSEM micrograph of dendritic quasicrystals in Al-Mn alloy and the corresponding EBSD pattern, which directly confirms the 5-fold symmetry of the icosahedral quasicrystal.

The ESTEEM consortium (Enabling Science and Technology through European Electron Microscopy) continued its activities in the field of materials characterization using state-of-the-art techniques of transmission electron microscopy, such as electron energy-loss spectroscopy (EELS), high-resolution scanning transmission electron microscopy (STEM, HAADF-STEM) and the mechanical preparation of the TEM samples.

The ESTEEM consortium has the status of an EU Advanced Community, and a lot of effort was focused on the preparation of a new project proposal for ESTEEM3, which was successfully granted in 2019. A member of our department is the scientific coordinator of the consortium.

The research group of the Department for Nanostructured Materials is very strongly connected with the activities within the **Center for Electron Microscopy and Microanalysis (CEMM)**, mainly through the implementation of various electron microscopy analytical techniques and the possibility for the researchers to access the research infrastructure for electron microscopy.

Industrial partners

We have conducted analyses of innovative composite abrasives for the industrial partner **Weiler Abrasives - SwatyComet** within the project "Microstructural investigations of abrasive materials", which are intended to develop and manufacture improved cutting and grinding tools with a prolonged lifetime.

Education and outreach activities.

For the sixth year, the members of the department participated in science-promotion activities within the framework of the Science on the Street (ZnC) project. In 2018 there were 18 popular science lectures, a scientific slam, and a round table. On the ZnC website we have published 19 blogs of researchers and 2 contests. In cooperation with the Slovenian Fusion Association, IJS, we co-organized a professional excursion to the ITER fusion reactor that is under construction.

Awards and appointments

1. **Department for Nanostructured Materials**, the European project REProMag, German Prize for Efficient Use of Raw Materials 2017 (Deutscher Rohstoffeffizienz-Preis 2017, given in January 2018. Prestigious Award received by EU research project REProMag where the Department for Nanostructured Materials was one of the 14 partners from 5 countries, which successfully developed the technological process of re-use of recycled rare-earth magnets, which enables economically efficient production of magnetic parts with complex structures and geometry and 100% free of waste material along the entire production chain (http://www.repromag-project.eu/).
2. **Benjamin Podmiljšak**, Award for the best poster at the 2nd IEEE Conference on Advances in Magnetics; AIM2018, La Thuile, Italy, 3–10 February 2018. Title of the awarded contribution: "Tailored metal injection moulding of isotropic NdFeB hard magnets based on recycled powders with and without Nd-additions".
3. **Matej Kocen**, Award for the best poster and oral presentation at the 26th International Conference on Materials and Technology, 26 ICM&T, Portorož, Slovenia, 3–5 October 2018. Title of the awarded contribution: "Capturing the Sun in a tungsten 'box'" (co-authors: Petra Jenuš, Saša Novak Krmpotič, Andreja Šestan)
4. **Nina Kostevšek**, Candidate for "Excellent in Science 2018", given by members of the Scientific Research Council of Technology, Slovenian Research Agency (ARRS). Selected Achievement: "Hybrid nanoparticles for cancer treatment and diagnostics". Ljubljana, Slovenia, 23 October 2018.

Organization of conferences, congresses and meetings

1. The 26th International Conference on Materials and Technology – 26. ICM&T, 3–5 October 2018, Portorož, Slovenia (co-organisers)
2. Annual meeting of LIA PACS2: International Associated Laboratory; Push-Pull Alloys and Complex Compounds: from bulk properties to surface functions, 17–20 December 2018, Ljubljana, Slovenia
3. ISO-FOOD Spring School & Workshop on Nanoparticles and Food, 9–13 April 2018, Ljubljana, Slovenia (organisers)
4. Kick-off meeting of Maxycle project: A novel Circular Economy for Sustainable RE-Based Magnets (ERA.MIN2), Goriška Brda, Slovenia, 6–8 May 2018
5. Annual Meeting of Slovenian Fusion Association - SFA, Podgorica, Slovenia, 20 December 2018 (co-organisers)
6. Workshop on "Opportunities of cooperation in the field of complex metallic alloys";
7. 2nd phase SRIP ToP, "New materials" value chains and the horizontal network "Modern Production Technology for Materials", Ljubljana, Slovenia, 19 December 2018 (organisers)
8. Expert meeting on the topic of the project application under Horizon 2020; Building a water-smart economy and society ter Microorganism communities for plastics bio-degradation (RIA), Ljubljana, Slovenia, 7 December 2018

INTERNATIONAL PROJECTS

1. K7, CTT - ID Creations; Rights and Obligations regarding the Development, Use and Commercialization of Hydrothermally Synthetized TiO2 Coatings in Metal Orthopaedic and Dental Implants
   Prof. Saša Novak Krmpotič
   Id Creations Oy
2. Spark Plasma Sintering (SPS) of Cost Effective and High Performance Rare-Earth Based Permanent Magnets for Electrical Machines
   Prof. Spomenka Kobe
   ABB Switzerland Ltd
3. 7 FP; ERA CHAIR ISO-FOOD - Era Chairs for Isotope Techniques in Food Quality, Safety and Traceability
   Prof. Saša Novak Krmpotič
   European Commission
4. COST MP1407 - e-MINDS; Electrochemical Processing Methodologies and Corrosion Protection for Device and Systems Miniaturization
   Prof. Kristina Žužek Rožman
   Cost Office
5. COST CA17140 - Nano2Clinic; Cancer Nanomedicine - From the Bench to the Bedside
   Dr. Nina Kostevšek
   Cost Association Aisbl
6. H2020 - DEMETER; Training Network for the Design and Recycling of Rare-Earth Permanent Magnet Motors and Generators in Hybrid and Full Electric Vehicles
   Prof. Kristina Žužek Rožman
   European Commission
7. H2020 - STEM4youth; Promotion of STEM Education by Key Scientific Challenges and their Impact on Our Life and Career Perspectives
   Dr. Luka Suhadolnik
   European Commission
8. H2020 - AMPHIBIAN; Antisometric Permanent Hybrid Magnets based on Inexpensive and Non-Critical Materials
   Dr. Petra Jenuš
   European Commission
9. H2020-EUROfusion-Plasma Facing Components-1-IPH-FU, EUROFUSION

Prof. Saša Novak Krmpotič
European Commission
10. H2020 EUROfusion - Materials-PPPT-FU
Prof. Saša Novak Krmpotič
European Commission
11. H2020 EUROfusion - Education-ED-FU
Prof. Saša Novak Krmpotič
European Commission
12. H2020 EUROfusion - ER-4-FU; Enabling Research
Prof. Saša Novak Krmpotič
European Commission
13. Synthesis of Core/Shell MgAl2O4 Spinel Powders for Transparent Armor and IR Applications – CSMASP
Prof. Slavko Bernik
Slovenian Research Agency
14. Crystal and Electronic Structure of NbS3 Phases
Prof. Sašo Šturm
Slovenian Research Agency
15. Crystallography, Twinning and Phase Transformations in Minerals with Aragonite-Type Structure (CaCO3, SrCO3, BaCO3, PbCO3)
Prof. Aleksander Rečnik
Slovenian Research Agency
16. Characterization of Structural Defects in Semiconductor ZnO Films Grown by Atomic Layer Deposition (ALD)
Prof. Aleksander Rečnik
Slovenian Research Agency
17. Advanced Electronic Ceramics for the Sustainable, Efficient and Safe Use of Energy
Prof. Slavko Bernik
Slovenian Research Agency
18. Hydrous Defects and Twinning in Silicates
Asst. Prof. Nina Daneu
Slovenian Research Agency
19. Tungsten-Based Composite for Fusion Applications
Prof. Saša Novak Krmpotič
Slovenian Research Agency
20. Atomic-Scale Investigations of Twinning and Polytypism in Natural Diamonds
Prof. Aleksander Rečnik
Slovenian Research Agency
21. Properties of Monolithic and Composite Advanced Ceramics obtained by Conventional and Non-Conventional Sintering Methods
Dr. Petra Jenuš
Slovenian Research Agency
22. Functionalized TiO2 Nanostructures for Application in Photo-Catalysis and Sensors
Prof. Miran Čeh
Slovenian Research Agency
23. Stability via Doping: Experimental and Theoretical Design of Functional Oxide Ceramics
Prof. Aleksander Rečnik
Slovenian Research Agency
24. Micro-to Nanoscale Textures of Ore Minerals: Methods of Study and Significance
Dr. Janez Zavašnik
Slovenian Research Agency

RESEARCH PROGRAMS

1. Nanostructured Materials
Prof. Spomenka Kobe
2. Ceramics and complementary materials for advanced engineering and biomedical applications
Asst. Prof. Andraž Kocjan

R & D GRANTS AND CONTRACTS

1. High-Performance Nanostructured Coatings - breakthrough in concentrated solar power
Asst. Prof. Andraž Kocjan
2. Evaluation of possible harmful effects of nanoparticles and underlying mechanisms – from physico-chemical and in vitro toxicity characterisation to innate immune system activation
Prof. Saša Novak Krmpotič
3. Role of estrogens in active brain feminisation? and development of a novel hormone implant, mimicking estrous cycle
Prof. Saša Novak Krmpotič
4. Characterization of fractal structures and scale-up parameters in their synthesis
Dr. Matejka Podlogar
5. W- and WC-based composites for high thermally loaded parts in the fusion demonstration power plant DEMO
Prof. Saša Novak Krmpotič
6. Catalytically-assisted high efficiency and low-cost nanostructured sensors based on modified screen printed electrodes for analytical chemistry
Prof. Kristina Žužek Rožman
7. Nanoscale investigations of diffusion controlled topotaxial phase transformations in rutile-corundum host systems
Prof. Aleksander Rečnik
8. Towards reliable implementation of monolithic zirconia dental restorations
Dr. Andraž Kocjan
9. UV sensors nanoparticles embedded into PA fibres
Prof. Spomenka Kobe
10. Effective recycling of abrasive sludge in the production of Sm2Co17 magnets for a waste-free economy
Prof. Kristina Žužek Rožman
11. Developement of multifunctional hybrid liposomes for active cancer treatment and multimodal diagnostics
Dr. Nina Kostevšek
12. Strategic Research & Innovation Partnership Factories of the Future (SRIP FoF)
Prof. Sašo Šturm
Ministry of Economic Development and Technology
13. A novel ciruclar economy for sustainable RE-based magnets
Prof. Spomenka Kobe
Ministry of Education, Science and Sport
14. Services for the Exports
Dr. Zoran Samardžija
15. Advanced Methods and Technologies for Processing of a New Generation of ZnO-based Varistor Ceramics
Prof. Slavko Bernik
Chinese Academy of Sciences
16. External Services
Asst. Prof. Andraž Kocjan

NEW CONTRACTS

1. Corrosion protection of magnetic powders to improve their resistivity to liquids at higher temperatures
Prof. Spomenka Kobe
Kolektor Group d. o. o.
2. Implementation of surface modification of Nd-Fe-B powders to increase the coercivity of bonded magnets
Prof. Spomenka Kobe
Kolektor Group d. o. o.
3. The corrosion resistivity of Nd-Fe-B powders in an aggressive environment
Prof. Spomenka Kobe
Sieva d. o. o.
4. Effective recycling of abrasive sludge in the production of Sm2Co17 magnets for a waste-free economy
Prof. Kristina Žužek Rožman
Magneti Ljubljana, d. d.
5. EPP - enhanced powder properties
Prof. Sašo Šturm
RLS Merilna tehnika d. o. o.
6. NexGenHVEC: Advanced materials, technologies and prototypes for cost effective hybrid varistor electronic components with improved thermal stability
Prof. Sašo Šturm
Kekon d. o. o.
7. Coating of Nd-Fe-B powders for corrosion protection - transfer to pilot production
Prof. Spomenka Kobe
Sieva d. o. o.

VISITORS FROM ABROAD

1. Philipp Stass, Gymnasium Borbeck, Essen, Germany, 28 January – 10 February 2018
2. Dr. Pavel Gavryushkin, Sobolev Institute of geology and mineralogy SB RAS, Novosibirsk, Russia, 1–10 February 2018
3. Dr. Lavinia Scherf, ABB Schweiz AG, Baden-Dättwil, Switzerland, 20–21 February 2018
4. Prof. Cleva W. Ow-Yang, Sabanci University, Faculty of Engineering & Natural Science, Istanbul, Turkey, 22 March 2018
5. Prof. Mehmet Ali Gülgün, FENS, Sabanci University, Istanbul, Turkey, 4 April 2018
6. Dr. Martina Lorenzetti, GE Healthcare Life Sciences, Cardiff, Great Britain, 12–15 April 2018
7. Dr. Blaž Belec, University of Novi Gorici, Nova Gorica, Slovenia, 16 April 2018
8. Dr. Ismail Ozgur Ozer, Anadolu University, Eskişehir, Turkey, 17–22 April 2018

9. Nicolas Cinq, Ecole des Mines Nancy- University of Lorraine, Nancy, France, 16 April – 1 September 2018
10. Prof. Michel Hehn, Institut Jean Lamour, University of Lorraine, Nancy, France and Dr. Jaćim Jaćimović, ABB Switzerland Ltd., Baden-Dättwil, Switzerland, 3–4 May 2018
11. Matej Baláž, Institute of Geotechnics, Slovak Academy of Sciences, Košice, Slovakia, 5–13 May 2018
12. Doris Meertens, Forschungszentrum Jülich GmbH, Jülich, Germany, 13–18 May 2018
13. Dr. Vanni Lughi, dr. Stefano Fornasaro, dr. Valter Sergo and dr. Alois Bonifacio, University of Trieste, Department of Engineering and Architecture, Trieste, Italy, 21 May 2018
14. Dr. Jianding Yu, Shanghai Institute of Ceramics, Chinese Academy of Science, Shanghai, China, 21–22 May 2018
15. Asst. Prof. Gülten Sadullahoğlu, Bülent Ecevit University, Zonguldak, Turkey, 20 June – 15 September 2019
16. Dr. Julian Ledieu and Dr. Vincent Fournee, Institut Jean Lamour, Nancy, France, 26– 29 June 2018
17. Dr. Bernd Wicklein, Materials Science Institute of Madrid-CSIC, Madrid, Spain, 29 June – 9 July 2018
18. Muhammad Awais, University of Birmingham, Birmingham, Great Britain, 15 July – 8 September 2018
19. Dr. Aleksandra Dapčević, Vesna Ribić, Dr. Goran Branković, Dr. Jelena Rogan, University of Belgrade, Belgrade, Serbia, 6–17 August 2018
20. Prof. Takao Mori, National Institute for Materials Science (NIMS), Tsukuba, Japan, 12–14 August 2018
21. Cesare Ormelli, Politecnico di Torino, Torino, Italy, 1 October 2018 – 31 January 2019
22. Prof. Guorong Li, Prof. Zhenyong Man and Prof. Xiangyan Kong, Chinese Academy of Science and Shanghai Jiao Tong University, Shanghai, China, 2–7 October 2018
23. Dr. Aleksandar Pačevski, Faculty of Mining and Geology, University of Belgrade, Belgrade, Serbia, 10–12 October 2018
24. Dr. Mikolaj Owsianiak and dr. Christine Molin, Technical University of Denmark, Kgs. Lyngby, Denmark, 17 October 2018
25. Dr. Lidija Ćurković and Dr. Irena Žmak, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Zagreb, Croatia, 18–20 October 2018
26. Dr. Zsolt Foragassy and Dr. Ildiko Cora, Hungarian Academy of Sciences, Institute of Technical Physics and Materials Science, Budapest, Hungary, 19 November – 18 December 2018
27. Prof. Rafal E. Dunin-Borkowski, Institute for Microstructure, Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Jülich, Germany, 21–23 November 2018
28. Dr. Mihály Pósfai, Department of Earth and Environmental Sciences, University of Pannonia, Veszprem, Hungary, 21–23 November 2018
29. Ljiljana Matovic, Radojka Vujasinin and Aleksander Devečerski, Laboratory for Materials, Vinča Institute of Nuclear Science, University of Belgrade, Belgrade, Serbia, 28 November 2018
30. Dr. Andreja Gajović, Ruđer Bošković Institute, Zagreb, Croatia, 3–5 December 2018
31. Dr. Goran Branković, Institute for Multidisciplinary Research, University of Belgrade, Belgrade, Serbia, 3–7 December 2018
32. Prof. Michael Coey, School of Physics, Trinity College Dublin, Ireland, 7 December 2018
33. Zrinka Švagelj and Milan Vukšić, Faculty of Mechanical Engineering and Naval Architecture (FSB), University of Zagreb, Zagreb, Croatia, 9–14 December 2018
34. Aleksandar Luković, Faculty of Mining and Geology, University of Belgrade, Belgrade, Serbia, 19–21 December 2018

STAFF

Researchers
1. Prof. Slavko Bernik
2. Prof. Miran Čeh
3. *Asst. Prof. Nina Daneu, 01.05.18, transferred to Department K9*
4. Prof. Jean Marie Dubois
5. Prof. Spomenka Kobe, Head, until 31.03.18
6. Asst. Prof. Andraž Kocjan
7. Asst. Prof. Matej Andrej Komelj
8. Prof. Saša Novak Krmpotič
9. Dr. Matejka Podlogar
10. Dr. Benjamin Podmiljšak
11. Prof. Aleksander Rečnik
12. Dr. Zoran Samardžija
13. **Prof. Sašo Šturm, Head, since 01.04.18**
14. Dr. Kristina Žagar Soderžnik
15. Prof. Kristina Žužek Rožman

Postdoctoral associates
16. Dr. Anže Abram
17. Dr. Nataša Drnovšek*
18. *Dr. Ana Gantar, left 11.04.18*
19. *Dr. Aljaž Iveković, on leave 01.03.16*
20. Dr. Petra Jenuš
21. Dr. Nina Kostevšek
22. Dr. Marko Soderžnik
23. Dr. Luka Suhadolnik
24. Dr. Tomaž Tomše
25. Dr. Janez Zavašnik

Postgraduates
26. Bojan Ambrožič, B. Sc.
27. Anja Drame, B. Sc.
28. *Dijana Đeorđić, B. Sc., left 01.12.18*
29. Hermina Hudelja, B. Sc.
30. Awais Ikram, B. Sc.
31. Vanja Jordan, B. Sc.
32. *Luka Kelhar, B. Sc., left 26.10.18*
33. Matej Kocen, B. Sc.
34. Matic Korent, B. Sc.
35. Monika Kušter, B. Sc.
36. Ana Lazar, B. Sc.
37. Živa Marinko, B. Sc.
38. Muhammad Farhan Mehmood, B. Sc.
39. Ipeknaz Özden, B. Sc.
40. Sara Tominc, B. Sc.
41. Špela Trafela, B. Sc.
42. Xuan Xu, B. Sc.

Technical officer
43. Sanja Fidler, B. Sc.

Technical and administrative staff
44. Sabina Cintauer, B. Sc.
45. Darko Eterović
46. Tomislav Pustotnik

Note:
* part-time JSI member

BIBLIOGRAPHY

Original Article

1. Jean-Baptiste Labégorre, Oleg Igorevich Lebedev, Cédric Bourgès, Aleksander Rečnik, Mateja Košir, Slavko Bernik, Antoine Maignan, Thierry Le Mercier, Lauriane Pautrot-d'Alençon, Emmanuel Guilmeau, "Phonon scattering and electron doping by 2D structural defects in In:ZnO", *ACS applied materials & interfaces*, 2018, **10**, 7, 6415-6423.
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3. Mariola Brycht, Andrzej Leniar, Janez Zavašnik, Agnieszka Nosal-Wiercińska, Krzysztof Wasiński, Paulina Półrolniczak, Sławomira Skrzypek, Kurt Kalcher, "Synthesis and characterization of the thermally reduced graphene oxide in argon atmosphere, and its application to construct graphene paste electrode as a naptalam electrochemical sensor", *Analytica chimica acta*, 2018, **1035**, 22-31.
4. Wenyao Zhang, Jesús Barrio, Christel Gervais, Andraž Kocjan, Yu Aiping, Xin Wang, Menny Shalom, "Synthesis of carbon-nitrogen-phosphorous materials with unprecedented high phosphorous amount toward an efficient fire retardant material", *Angewandte Chemie*, 2018, **57**, 31, 9764-9769.

5. Janvit Teržan, Petar Djinović, Janez Zavašnik, Iztok Arčon, Gregor Žerjav, Matjaž Spreitzer, Albin Pintar, "Alkali and earth alkali modified CuO_x/SiO_2 catalysts for propylene partial oxidation: what determines the selectivity?", *Applied catalysis. B, Environmental*, 2018, **237**, 214-227.
6. Ana Bjelić, Miha Grilc, Sašo Gyergyek, Andraž Kocjan, Darko Makovec, Blaž Likozar, "Catalytic hydrogenation, hydrodeoxygenation, and hydrocracking processes of a lignin monomer model compound eugenol over magnetic $Ru/C-Fe_2O_3$ and mechanistic reaction microkinetics", *Catalysts*, 2018, **8**, 10, 425.
7. Sara Tominc, Aleksander Rečnik, Zoran Samardžija, Goran Dražič, Matejka Podlogar, Slavko Bernik, Nina Daneu, "Twinning and charge compensation in Nb_2O_5-doped SnO_2-CoO ceramics exhibiting promising varistor characteristics", *Ceramics international*, 2018, **44**, 2, 1603-1613.
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9. Andraž Kocjan, "The hydrolysis of AlN powder: a powerful tool in advanced materials engineering", *The chemical record*, 2018, **18**, 7-8, 1232-1246.
10. Vanja Jordan, Venkata D. B. C. Dasireddy, Blaž Likozar, Aleš Podgornik, Aleksander Rečnik, "Material's design beyond lateral attachment: Twin-controlled spatial branching of rutile TiO_2", *Crystal growth & design*, 2018, **18**, 8, 4484-4494.
11. I. Buljan Meić *et al.* (12 authors), "How similar are amorphous calcium carbonate and calcium phosphate?: a comparative study of amorphous phase formation conditions", *CrystEngComm*, 2018, **20**, 1, 35-50.
12. Mariola Brycht, Andrzej Leniar, Janez Zavašnik, Agnieszka Nosal-Wiercińska, Krzysztof Wasiński, Paulina Półrolniczak, Sławomira Skrzypek, Kurt Kalcher, "Paste electrode based on the thermally reduced graphene oxide in ambient air: its characterization and analytical application for analysis of 4-chloro-3,5-dimethylphenol", *Electrochimica Acta*, 2018, **282**, 233-241.
13. Aravinthan Gopanna, Selvin P. Thomas Thomas, Krishna Prasad Rajan, Rathish Rajan, Egidija Rainosalo, Janez Zavašnik, Murthy Chavali, "Investigation of mechanical, dynamic mechanical, rheological and morphological properties of blends based on polypropylene (PP) and cyclic olefin copolymer (COC)", *European Polymer Journal*, 2018, **108**, 439-451.
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16. Branko Pivac, Pavo Dubček, Jasna Dasović, Jasminka Popović, Nikola Radić, Sigrid Bernstorff, Janez Zavašnik, Branislav Vlahović, "Stress evolution during Ge nanoparticles growth in a SiO_2 matrix", *Inorganic chemistry*, 2018, **57**, 23, 14939-14952.
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1. Eva Pellicer, Martina Lorenzetti, Jordina Fornell, Maria D. Baró, Saša Novak, Jordi Sort, "Progress Beyond the State-of-the-Art in the Field of Metallic Materials for bioimplant applications", In: Fatima Živić (ed.), *Biomaterials in clinical practice: advances in clinical research and medical devices*, 2018, 25-46.

Mentoring

1. Vanja Jordan, *Mesocrystal self-assembly of hierarchic rutile-type TiO_2 structures:* doctoral dissertation, Ljubljana, 2018 (mentor Aleksander Rečnik).
2. Luka Suhadolnik, *Titania nanostructures based photocatalytic and photoelectrocatalytic reactors:* doctoral dissertation, Ljubljana, 2018 (mentor Miran Čeh).
3. Tomaž Tomše, *Novel multicomponent Nd-Fe-B permanent magnets:* doctoral dissertation, Ljubljana, 2018 (mentor Spomenka Kobe; co-mentor Jean-Marie Dubois).