DEPARTMENT FOR NANOSTRUCTURED MATERIALS K-7

The R&D at the Department for Nanostructured Materials is focused on the areas of nanotechnology and advanced materials to address the most difficult societal challenges that Europe and the world are currently facing. This includes clean and efficient energy, health, environment remediation and critical-raw-materials resource efficiency. A versatile team with synergies across a variety of complementary basic and applied expertise in combination with state-of-the-art research methods enables us to respond promptly to various emerging societal challenges. The basic and applied research of the Department for Nanostructured Materials includes magnets and intermetallic alloys, engineering and functional ceramics, minerals, sensors, materials for a sustainable and ecologically built environment, biomimetic- and bio-materials.

Head:
Prof. Sašo Šturm

Magnetic Materials

In the frame of H2020 MSCA ITN **Marie Skłodowska-Curie European Training Network (DEMETER)** we are focusing on the **recycling and reprocessing of critical raw materials, i.e., rare-earth-based permanent magnets.** We successfully produced novel permanent magnets based on the recycled end-of-life Nd-Fe-B and Sm-Co systems. With the implementation of the spark plasma sintering (SPS) technique, we produced Nd-Fe-B permanent magnets from recycled powders obtained after HDDR (hydrogenation-disproportionation-decrepitation-recombination) processing. The recycling scheme of the HDDR route has been established by relating the magnetic properties' variations with particle size and oxygen content to help industry retain control of microstructure and quality in the recycled Nd-Fe-B powders (**Published in Journal of Rare Earths**). Likewise, the hot-deformation experiments in the SPS on the recycled HDDR Nd-Fe-B system yielded a 12% improvement in remanence, improving it from 0.9 T in the recycled powder to 1.01 T in the hot-deformed magnet, with the coercivity retained better than the recycled feedstock. SPS was used to consolidate the recycled Nd-Fe-B powder blends containing 1, 2 and 5 wt. % of DyF_3. About ~2 wt. % DyF_3 dopant in the HDDR Nd-Fe-B powder was sufficient to develop a uniform core-shell microstructure, with Dy-rich shells resulting in the coercivity increment. The obtained coercivity values of the blended magnets were 41% higher than the starting recycled HDDR powder and 17.5% higher than the SPS-ed magnet without the Dy addition **(Published in Materials)**.

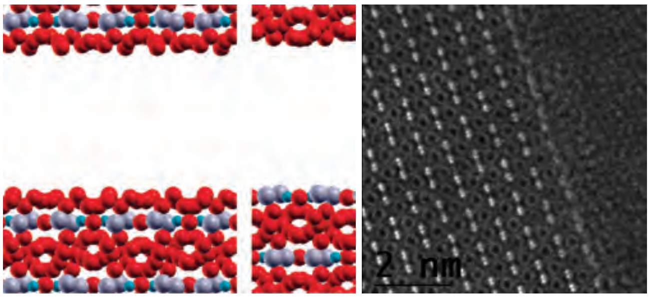


Figure 1: Reconstruction of the Fe- (left) and Nd- (middle) terminated Nd-Fe-B surface, obtained by means of ab-initio calculations, with the corresponding HAADF-STEM image of the Nd-Fe-B grain boundary.

With the aim of understanding the role of the grain boundaries with respect to the properties of Nd-Fe-B-based permanent magnets either from raw materials or from recycled feedstocks, we applied, in addition to various experimental activities, the density-functional theory (DFT). In this manner we performed ab-initio calculations simulating the atomic-scale structural properties at the surface, and at different interfaces of the ideal $Nd_2Fe_{14}B$ crystalline phase, which is the source of the strong ferromagnetism in the magnets (Figure 1). According to extensive experimental evidence the boundary effects prevent us from exploiting the full potential of the material. The DFT simulations, in synergy with the electron-microscopy imaging, will contribute to understanding these effects in detail, and hence to tailoring the respective microstructures, resulting in optimum magnet performance.

In DEMETER we evaluated the electrodeposition of Nd and Fe from ionic liquids based on 1-ethyl-3-methylimidazole dicyamide (Figure 2). We found that Nd can be reduced only in the presence of Fe, which catalyses the further reduction of Nd, and we also proposed an appropriate mechanism (**published in ChemElectroChem**). Furthermore, a novel recycling concept for sintered Nd-Fe-B magnets was developed based on selective anodic etching, where single-crystalline hard magnetic matrix grains of $Nd_2Fe_{14}B$ can be obtained for novel magnet fabrication, thus significantly reducing the energy and environmental impact. (**published in ChemSusChem, IF = 7.804**). The procedure is the subject of a patent application at the European patent office (**Application EP 18 2018 508.4**).

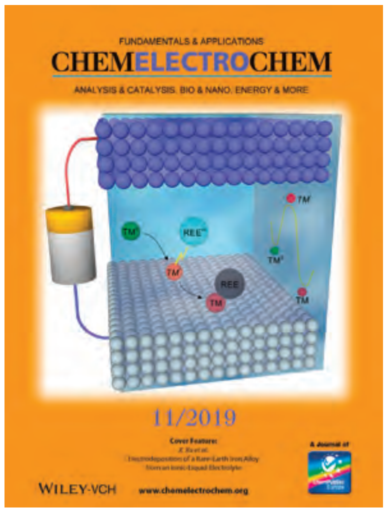


Figure 2: Awarded front cover of the ChemElectroChem journal. Art work illustrating the induced co-deposition mechanism for the rare earth (Nd) and transition metal (Fe).

We continued with the 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. Already, the first results showed that recycling EoL magnets will be a challenging task, as the difference in composition and coatings makes it impossible to develop a uniform recycling route. EoL magnets with no history are the most problematic as they have to be analyzed before recycling. That is why MaXycle is proposing a uniform marking system for magnets for easy recyclability.

By implementing electrochemistry we have developed a facile method for rare-earth elements recovery and Fe deposition from sintered Nd-Fe-B magnets using total magnet oxidation on the anode and Fe deposition on the cathode. The leached rare earths from the magnets are obtained via a precipitation technique (published in Green Chemistry, and patented at the European Patent Office, Application EP 19197716.4). This new, closed-loop technology of continuous magnet leaching and Fe deposition with rare-earth recovery surpasses the current state-of-the-art method of hydrometallurgy in relation to the use of chemicals, the production of waste and the total cost.

In 2019 we started with the European project **Susmagpro**, which stands for Sustainable Recovery, Reprocessing and Reuse of Rare Earth Magnets in a European Circular Economy. The project aims to develop a recycling supply chain for rare-earth magnets in the European Union and to demonstrate the effective reuse of recycled rare-earth materials within several industries. The multidisciplinary SUSMAGPRO consortium are 20 of Europe's industry and academic leaders in REEs, sustainable processing, reuse, recycling, and recovery schemes, and cover the whole value chain from the collectors of magnet-containing scrap, to the producers of high-tech products.

In work for a Swiss industrial partner we demonstrated that we can design a novel form of permanent magnet, called a multicomponent magnet, where the surface region of the magnet has a high coercivity, while the central part is characterized by high remanence. The magnetic field around the Dy-free inner part is higher than in the Dy-rich surface part of the magnets. The interaction at the interface of two different magnetic phases in such a geometry has been uncovered by theoretical modelling. Our study shows that it is possible to arrange multiple phases of permanent magnets in one magnetic net-shaped body, therefore increasing the overall magnetic performance in spatially confined areas. This new finding opens up possibilities for more complex designs of permanent magnets that are currently gaining momentum related to electric mobility. In addition, such a multicomponent-magnet approach reduces the total cost of the electric motors from two perspectives: it requires a significantly lower amount of expensive Dy, which is also regarded as a critical raw material, and it lowers the amount of other materials used to construct the electric motor, which can now be realized in more compact geometry due to the higher overall remanent magnetization (Br) of the multicomponent magnet. From the economic perspective, we estimated that the increase of the production costs of such a magnet compared to the existing technology is minor. This could enable much faster growth of wind turbine generators' installation, and the use of electrical vehicles that are powered by permanent-magnet motors. The results of this work were published in the **Journal of Magnetism and Magnetic Materials**.

As part of the research work for Slovenian industrial partners, we focused on: (i) the improvement of coercivity of melt-spun powders used for bonded magnets, and (ii) the development of a coating procedure using different coating materials to prevent corrosion in aggressive conditions. Already in the first year of the two projects, we successfully increased the coercivity by more than 15%, and we established the most effective solution to protect sensitive Nd-Fe-B powders by using alumina as a thin protective layer. The improvement of coercivity was achieved by the addition of a Nd-Cu low-melting-point alloy, which was subsequently subjected to the optimized thermal treatment procedure. The next step in this research is to upscale the powder mixtures for the pilot production. The required quantity of the final powder for pilot plant production is 6 kg. In the second project, we established the most effective solution to protect the sensitive Nd-Fe-B powders by using alumina as a thin protective layer and prepared a quantity of 6 kg of coated powder for the pilot production test. The results are excellent and will be further transferred to large-scale production. The final analyses showed that the alumina-coated magnetic powder had almost no loss of magnetic properties after 2 months of a corrosion test. The corrosion resistance in demineralized water at 85 0C of the compressed bonded magnets was significantly improved, and the surface hardness of the alumina-coated magnetic powders is lower than that of the uncoated samples. This implies that the proposed powder-protection technology will not significantly change the existing tool wear used for the fabrication of the final bonded magnets.

We continued with the national project (L2-9213) in collaboration with company Magneti Ljubljana, where we are investigating novel ways of recycling magnetic swarf based on Sm-Co. We found that the magnetic swarf can be partially recycled by a re-melting procedure where the metal part (Co-rich) can be efficiently separated from the slurry (Sm-oxide-rich).

In 2019 we initiated research related to **additive manufacturing**, which is based on a state-of-the-art fused-deposition modeling (FDM) printer from the company Hage and an extruder machine for the production of metal- and ceramic-filed filaments. This technology will facilitate the production of complex net-shaped metallic and ceramic parts for new, emerging technologies. One of the fields where 3D printed parts have a high potential are complex-shaped magnets for new, electric motor design platforms, which theoretically surpass the current motor efficiencies and show great promise in relation to electric mobility and transfer to a carbon-free economy.

The additive-manufacturing technologies make it possible to produce magnets of arbitrary shapes and magnetization distributions. In order to design a magnet as the source of a given magnetic-flux field, expressed in terms of the lines-of-force pattern, it is necessary to solve the so-called magnetostatic inverse problem. This requires solving the respective Maxwell equations. Which we performed in the framework of the finite-element method.

We continued with research in the framework of European project **AMPHIBIAN**, which stands for AnisoMetric Permanent HybrId magnets Based on Inexpensive And Non-critical materials. The goal of the project is to prepare hybrid ferrite-based magnets with energy product, BH_{max}, higher than 50 kJ/m^3. The upper limit so far is 45 kJ/m^3. The hybrid anisotropic magnets with enhanced magnetic performance prepared in the AMPHIBIAN project were installed in a demonstration flywheel (electric energy storage device – Figure 3). Until 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 scrape material produced during the injection moulding of ferrite magnets.

Figure 3: Flywheel prototype in which Nd-Fe-B magnets were replaced by ferrite magnets.

Complex Intermetallic Alloys

We successfully renewed the unique research project **International Associated Laboratory (LIA) PACS2**, which connects CNRS and JSI research teams for the period between 2019-2022. In the frame of joint activities we concluded our studies of the Al–V–Sn ternary system on a new ternary phase with the composition $Al_{1+x}V_2Sn_{2-x}$ (x = 0.19). Single-crystal X-ray diffraction measurements reveal that this ternary phase crystallizes with an orthorhombic structure, isostructural to the GaV_2Sn_2 structure type, showing a layered structure composed of vanadium cluster bands formed with pentagonal faces intercalated by Sn atom layers, which are exchanging with layers composed of Al columns. The time-sequenced atomically resolved HAADF-STEM imaging confirmed the orthorhombic structure and, in addition, the nonperiodic and anomalously large intensity variations at the Al sites (Figure 4). We confirmed that the anomalous image-intensity variations at the Al sites remain constant during the acquisition of the image series, which supports the idea that Al atoms are partially substituted with foreign Ga atoms, introduced during the Ga ion-milling (**published in Inorganic Chemistry**).

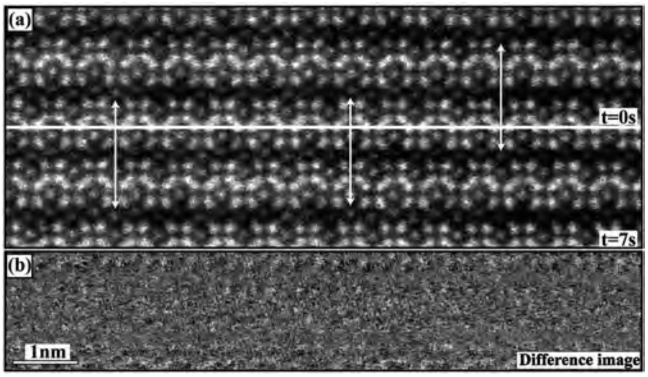


Figure 4. (a) Series of drift-corrected subsequently acquired images (Δt = 7 s) with the indicated equivalent atomic column positions (arrow marks). (b) Difference image confirming the minimized drift image region.

Sensors

We have fabricated KOH-modified Ni-nanowire-based electrodes (i.e., catalysts) for formaldehyde (HCHO) electro-oxidation in alkaline media. The catalysts based on Ni nanowires were synthesised via template-assisted electrodeposition, followed by a modification process in an alkaline solution (potential cycling in KOH), which produced a catalytically active $NiOOH/Ni(OH)_2$ redox couple on the surface. We demonstrated that the morphological and chemical changes introduced in the KOH-modification process play a crucial role in the electrocatalysis of the HCHO oxidation in alkaline media. We have been able to produce the catalyst, which is not only fundamentally interesting, but also very much applicable for the catalysis industry, as it ranged among the best catalytic performance (i.e. low overpotential of 0.4V) in comparison with the Ni-based catalysts disclosed in the literature. It also exhibits excellent sensor properties: a low detection limit of (0.8 μmol L^{-1}), a fast response time, a high sensitivity, good reproducibility and selectivity to other organic compounds (**published in Electrochimica Acta**). Furthermore, the Ni nanowires were successfully integrated into commercially screen-printed electrodes (SPE) that results in the development of new low-cost devices for the in-situ analysis of HCHO that are currently being developed together with the Institute for Pulp and Paper and Faculty of Electrical Engineering and Computer Science University Maribor (FERI UM).

We are developing modified printed electrodes via the nanostructuring of the receptor elements based on transition metal (oxide)hydroxides and conductive polymers that serve as the base for an autonomic sensor platform for toxic organic compounds such as formaldehyde (national project L2-8182) and acrylamide (national project J2-1739) suitable for an in-situ detection system.

In the frame of developing a sensory platform for the acrylamide we investigated the use of polymers. Polyaniline is a conductive polymer with chemi-resistive properties, which makes it a widely used material for sensors. We are

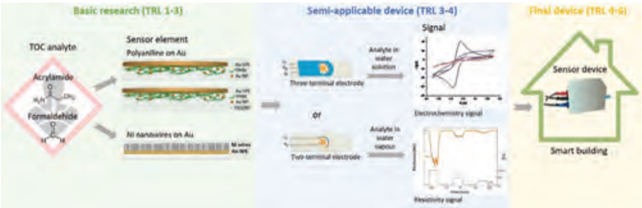


Figure 5: Research scheme towards the commercialization of TOC sensors.

preparing polyaniline via electrochemical synthesis on commercial screen-printed electrodes. Polyaniline is studied for the potential resistivity sensing of gases (ammonia) or liquids, and as a polymer for molecular imprinting (acrylamide sensing). We supplemented our fundamental electrochemical deposition studies by in-situ dynamic correlative approaches combining UV-vis spectroscopy and electrochemistry (spectro-electrochemistry) to understand the polymerisation mechanism in details. The acquired knowledge presents the base for an efficient realization of polyaniline as a material for the sensing of toxic organic compounds, such as acrylamide. In collaboration with FERI UM we are developing a sensory platform, designed as a two-terminal electrode device sensitive to ammonia in gas and acrylamide in water vapour (Figure 5).

Materials for a Clean Environment and Health

In the field of **photo-electro-catalytic decomposition of organic substances**, we were engaged in the degradation of volatile organic compounds (VOCs) in air and persistent organic pollutants in water. Air purification was focused on the design and assembly of a photocatalytic reactor and the preparation of an active photocatalyst by the anodic oxidation of titanium foil. We were able to eliminate key problems associated with the anodization of a flexible titanium foil. The prepared TiO_2 nanotube catalyst is strongly attached to the substrate, which is important for the safe operation of the cleaning system, without polluting the environment with detached nanoparticles. The designed air reactor was mainly used for the decomposition of formaldehyde, which is one of the main indoor VOC pollutants. Photocatalytic degradation has proven to be a very effective and promising approach for technology transfer to a larger scale. In the field of water purification, we investigated the suitability of substrates in the form of immobilized 2D nanostructures for the immobilization of metal catalysts. TiO_2 nanotubes were enhanced by annealing them in an ammonia atmosphere. The prepared TiOxNy films were tested for electrochemical, morphological and structural properties. Degradation studies were performed on phenol and textile dye. We elucidated the kinetics and the mechanism of phenol degradation. The results of this study were published in a highly ranked journal ***Applied catalysis B, Environmental*** (IF = 14.229). In addition, the TiO_2 photocatalyst was used for the photocatalytic degradation of microplastics, which has proved to be successful, but the studies are still in the first phase of research. (Figure 6)

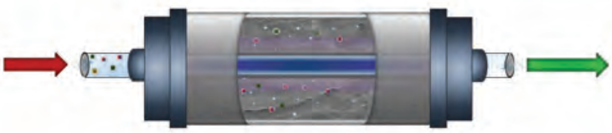


Figure 6: Schematic presentation of VOC air purification filter based on nanostructured TiO_2.

Biomaterials

In collaboration with the Queen's University Belfast, United Kingdom, and the Faculty of Medicine, University of Ljubljana, we have developed **pH-sensitive liposomes** with encapsulated anticancer drug doxorubicin conjugated to a prostate-specific antigen (PSA)-cleavable peptide that can be selectively activated by secreted PSA at the tumour site. Our results demonstrated the superior activity of Dox-PSA loaded pH-responsive liposomes in tumour spheroids, due to deeper penetration, compared to a free drug. Moreover, such a system enables enhanced safety due to a dual safety mechanism, i.e., the pH-sensitivity of liposomes that release prodrug only in the acidic tumour micro-environment and the enzymatic cleavage of a prodrug that occurs only inside of the PSA-expressing cancer cells. This study was published in **Molecular Pharmaceutics**.

We are developing theranostic nanosystems based on liposomes that are assumed to be one of the safest drug-delivery systems developed so far.

Important results were also achieved in diagnostics. The majority of the clinically approved iron oxide nanoparticles (IO NPs) used as contrast agents for **magnetic resonance imaging (MRI)** have been withdrawn from the market, either due to safety concerns or lack of profits. Therefore, there is a need for novel IO NPs-based imaging agents with a high safety margin and superior MRI properties. Thus, we investigated magnetic-liposomes with different formulations and tested their contrast performance for MRI. We found that the encapsulation of NPs into liposomes dramatically improves their contrast performance (up to 42-fold) due to the favourable interactions between water visualized in MRI and the lipid coating. Importantly, an in vitro study showed improved the selectivity of the magnetic-liposomes compared to the free nanoparticles. The cancer cells

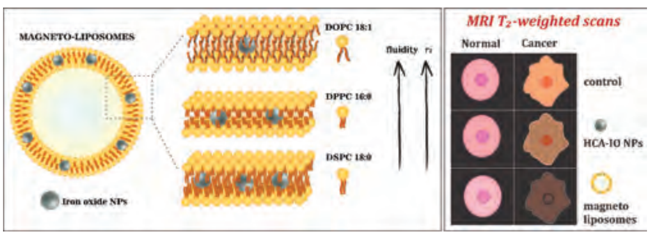


Figure 7: Left: Graphical representation of the structure of magnetic liposomes with different lipid bilayer compositions, which affects the fluidity of the bilayer and, consequently, the relaxivity, which is a measure of the effectiveness of the contrast agent for MRI. Right: In-vitro results have shown that due to the preferential internalization of magnetic liposomes into cancer cells, these in the MRI image have a much darker contrast than those exposed to free nanoparticles or as untreated. Therefore, they can be clearly distinguished from healthy cells that maintain a brighter contrast in the image.

internalized a high concentration of liposomes, while their content was minimal in the normal cells, which led to an improvement in the contrast and an easier distinction between the healthy and the cancerous cells (Figure 7). In the case of free nanoparticles, the rate of internalization in both types of cell lines is similar and thus the diagnostics is limited.

As part of the project, which is being carried out in collaboration with the Faculty of Veterinary Medicine, UL, we continued our research on the silk fibroin carrier for pharmaceutical ingredients. We successfully incorporated estradiol into the fibroin film, and by using a surfactant we also achieved a significant increase in the release of estradiol over a longer period of time. The results of fibroin degradation studies have shown that controlling the rate of crystallization can affect the rate of estradiol release from the fibroin carrier.

In 2019, a patent (US 10,322,001) was granted to protect the process of preparing a multilayer bioactive coating in porous surface of Ti-based bone implants. The main component of the multilayer coating is nanoparticulate bioactive glass, introduced in the implant surface layer. In a biological environment, bioactive glass dissolves and helps to form bone, thereby improving the osteointegration of a titanium-based implant.

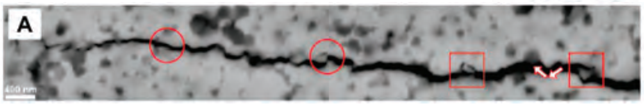


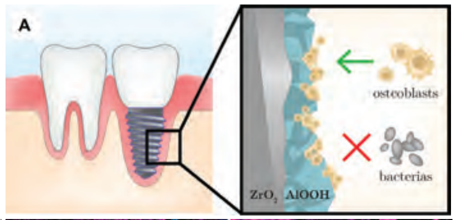
Figure 8: (a) SEM micrograph showing an arrested crack propagated from a Vickers indent. Circles, squares, and arrows indicate the crack branching, crack bridging, and crack deflection mechanisms, respectively, all contributing to a tougher ceramic nanocomposite. (b) Different sphere ratios between larger non-conducting matrix particles and the surrounding smaller, electrically conductive ones.

Asst. Prof. Andraž Kocjan has received the prestigious, early career "Young Scientist Award" given by the European Ceramic Society (ECerS) for outstanding contributions to the ceramic sciences given at the biannual 16th ECerS Conference held in Turin, Italy.

Engineering Ceramics

A fabrication route for the processing of tough and electrically conductive ZrO_2–TiN ceramic nanocomposite was established (Figure 8), enabling its electro-discharge machining (EDM) in a fully densified state. The TiN nanoparticles were incorporated into the zirconia matrix by admixing nanopowders or via the wet-synthesis approach. The powder precursors were rapidly sintered in a spark plasma sintering (SPS) furnace. We showed that the addition of 15 vol.% of TiN nanoparticles was already a sufficient amount to provide electrical percolation. These findings were coupled with theoretical simulations made using the Metropolis method for electrical conductivity of a binary system of electrically insulating and conducting spheres showing the influence of the ratio between bigger non-conducting matrix particles and the surrounding smaller, electrically conductive ones (Figure 8), yielding a roadmap for electrically conductive ceramic composites. The works were published in **Materials** and **Journal of the European Ceramic Society**.

In the field of dental ceramics, we have been traditionally involved in the research on zirconia (3Y-TZP). In an interdisciplinary study, we have demonstrated a simple, viable, and effective solution for the modification of the 3Y-TZP dental implant surfaces by a combination of micro- and nano-roughening. To achieve both roughening types, gentle sandblasting was followed by nanostructured alumina coating deposition, improving 3Y-TZP`s osseointegration and antibacterial properties (Figure 9). Such an approach was successful for the adhesion and differentiation of human osteoblasts, while also minimising the attachment of Staphylococcus aureus bacteria. The work was published in the **Journal of the European Ceramic Society**. The same nanostructured coating can be used in an everyday dental laboratory procedure of 3Y-TZP surface preparation for improving the bonding of dental cements to 3Y-TZP. In collaboration with the Department for Prosthetic Dentistry, Medical Faculty, University of Ljubljana, an in-vitro study evaluating different laboratory firing protocols affecting the bond strength to 3Y-TZP was performed. The work was published in **Advances in Applied Ceramics**.



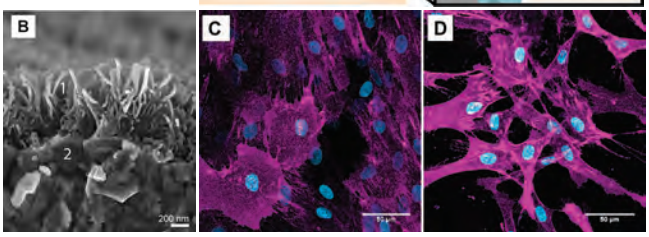


Figure 9: (a) Schematic representation of the surface-modification concept of a dental implant using nanostructured coating making a dental implant osseoconductive while repelling bacterial adhesion. (b) Nanostructured alumina coating residing on 3Y-TZP surface. Fluorescence micrographs of 3Y-TZP surfaces with adhered osteoblasts after 9 days in culture: (c) on sandblasted and (d) coated 3Y-TZP surface.

Genuine Technologies d.o.o., a start-up company, co-founded by dr. Nataša Drnovšek and Asst. prof. Andraž Kocjan, is using JSI`s licensed knowledge for the manufacture of Ca-silicate-based cement for endodontic treatment of teeth. The company has received a **CE mark** for its product RS+™ – a medical device (Figure 10), and has acquired an **ISO 13485** standard, which specifies requirements for a quality-management system, where an organization needs to demonstrate its ability to provide medical devices and related services that consistently meet customer and applicable regulatory requirements.

Figure 10: Glass vials containing RS+™ powder cement.

Structural Materials

As part of EUROfusion's European fusion program, we continued our research on W-W_2C composites for the DEMO demonstration fusion power plant, while expanding our research to include binder-less tungsten carbide (WC), based on the encouraging results of the completed Enabling research project. In the first part, the composition and the process of the preparation of the W-W_2C composites were optimized based on a study of the relationship between the initial and final compositions of the material and the mechanical and thermal properties in the temperature range from room temperature to 1000 °C. The main criterion for selecting the optimal composition was the resistance of the material to thermal shocks during laser testing in high heat fluxes. The composite with 11% W_2C showed the best performance. In a similar way, the analysis of WC samples was carried out. The results revealed that the particle size had a crucial influence on the thermal conductivity and thus the resistance to thermal shocks. We therefore focused primarily on increasing the thermal conductivity.

Functional ceramics: semiconducting ZnO-based ceramics (varistors, thermoelectrics)

In the field of oxide thermoelectric materials of the n-type, our results obtained in cooperation with the "Shanghai Institute of Ceramics, the Chinese Academy of Science - SICCAS" showed that classic sintering in a reducing atmosphere and also spark plasma sintering (SPS) in a vacuum strongly enhance the thermoelectric characteristics of ZnO-based ceramics by increasing the electrical conductivity (σ) for several orders of magnitude in comparison to sintering in air due to strongly increased charge carrier concentration and mobility. We found that such sintering conditions increase the otherwise limited solid solubility of the donor dopants in ZnO and also prevent the formation of the intrinsic acceptor states (zinc vacancies, V_{Zn}, and oxygen interstitials, Oi) and hence electrostatic Schottky barriers at the grain boundaries. However, for the application of such thermoelectric ZnO-based ceramics their stability under oxidising atmosphere (i.e., air) is questionable. Therefore, we studied the effect of annealing in air on the thermoelectric characteristics of the ZnO-based ceramics prepared by sintering in at reducing atmosphere. It showed that annealing in air strongly reduced thw electrical conductivity and hence the power factor, PF ($PF = \sigma S^2$; S = Seebeck coefficient) of ceramics in comparison to the original one, nevertheless their PF is still 8-times higher than in ceramics prepared by sintering in air. Results indicate that despite property degradation in air the preparation of thermoelectric ZnO-based ceramics by sintering in a reducing atmosphere or vacuum has advantages for their applications.

Recently it was discovered that some magnetic semiconductors have better thermoelectric properties than expected and that also the incorporation of a magnetic element in some otherwise nonmagnetic semiconducting compounds enhances their thermoelectric characteristics due to coupling between the magnetic moment and the charge carriers. Hence, we study in collaboration with National Institute for Materials Science – NIMS (Tsukuba, Japan) the influence of Co on the structural, microstructural and thermoelectric properties of the Al-doped ZnO ceramics with the compositions $Zn_{0.98-x}Al_{0.02}Co_xO$ (x = 0; 0.001; 0.0025; 0.005; 0.01; 0.05; 0.10). We analyse the possible effects of adding Co on the magnetism of ceramics and consequently the density and the mobility of the charge carriers, the electrical conductivity and the Seebeck coefficient. In collaboration with NIMS we also studied the influence of using fine nano-powders of ZnO prepared by the double-emulsion method on the microstructure development and the thermoelectric characteristics of undoped and Al-doped ZnO ceramics processed by the SPS method.

In the field of ZnO-based varistor ceramics we continued our research, in collaboration with the Shanghai Institute of Ceramics, the Chinese Academy of Science – SICCAS, on the development of a novel type of varistor ceramics. Standard ZnO-based varistor ceramics, which strongly dominate in the field of overvoltage protection applications, have a complex chemical composition with typically about 7 to 10 wt.% of oxides of Bi, Sb, Co, Mn, Ni and Cr added to ZnO and hence the microstructure. Because Bi_2O_3 results in the formation of a liquid phase during sintering and also evaporates, this causes various difficulties and higher costs in the mass production of varistors. The new type of ZnO-based varistor ceramics has an excellent current-voltage (I-U) nonlinearity, despite a very simple chemical composition with only three easily available dopants added to ZnO in amount of about 3.5 wt.%, none of them forming a liquid phase or being volatile during the sintering. Our research was focused on the mechanism of the formation of the Schottky barriers to explain the nature of the I-U nonlinearity in this new type of varistor ceramic in the absence of standard dopants inducing nonlinearity, like oxides of Bi and Pr.

We continued on the microstructure evolution and electrical properties of SnO_2-based varistor ceramics. Promising dielectric and varistor properties were obtained by the dual doping of SnO_2 with CoO and Ta_2O_5. Unlike in the SnO_2–CoO–Nb_2O_5 system, we find that more CoO is needed to obtain fully dense microstructures with optimal electrical properties. **This is due to the difference in the charge-compensation mechanism where no Sn^{2+} is incorporated into the structure and Co^{2+} takes the role of the acceptor**. Already, 0.05 mol% Ta_2O_5 effectively reduces the porosity, improves densification and dielectric permittivity and triggers a 3-fold increase in the SnO_2 growth rate. With larger additions, however, Ta_2O_5 segregates to the grain boundaries and hinders SnO_2 grain growth, which in turn improves the electrical properties. The **non-linear coefficient α reaches a value of 40** and a threshold voltage of 272 ± 2 V/mm at a low leakage current I_L = 1.2 μA with the addition of 1 mol% Ta_2O_5. The lowest content of Ta_2O_5 results in a **high dielectric permittivity, reaching 6525** for a doping level of 0.10 mol%. The study was published in ***J Eur Ceram Soc*** .

Mineralogy

In collaboration with the Department for Litospheric Research of Vienna University we started two research projects that involve the **atomic-resolution electron microscopy of petrological samples**. The first is FWF-ARRS International Project GInA: 'Mineral inclusions in garnets from macroscopic to atomic scale – opening the petrogenetic archive'. Another project that we take part is FWF-RFBR International Joint Project MiMa: 'Fe-Ti oxide inclusions and magnetism of oceanic gabbro'. Within the project we receive one PhD student and one post-doc for specialization in atomic-scale electron microscopy methods. From our collaboration with the University in Novosibirsk and Tairus we published atomic-scale studies of the internal structure of leucosapphire, and high-temperature in-situ transmission electron microscopy and an X-ray study of twinning in natural aragonite (Figure 11). The work was published in **CrysEngComm.**

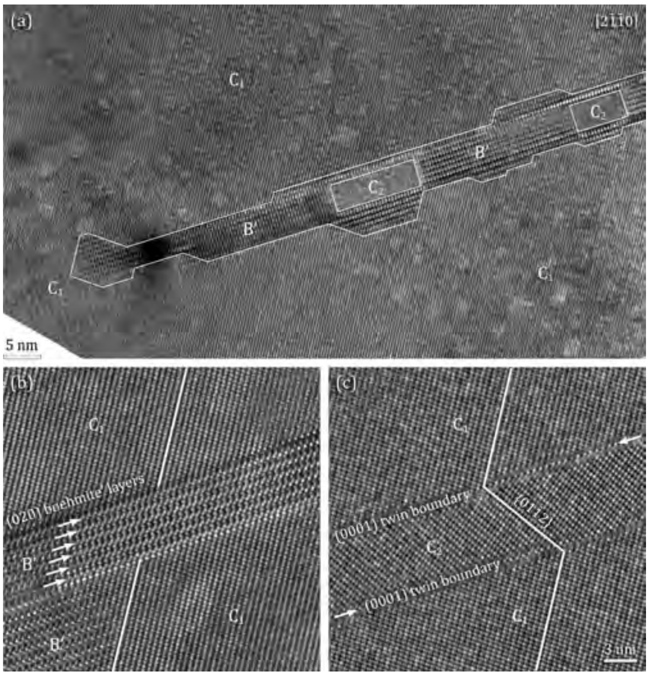


Figure 11: High-resolution TEM of Al–O–H lamellae in leucosapphire. (a) Segment of the lamella embedded in the corundum (C1) matrix. Boehmite-like layers (B') are faceted towards the host corundum matrix (C1). Within B' layers domains of corundum are in a twin (C2) orientation with respect to the host (C1). (b) Close-up of the boehmite-like layer (B') within the host corundum (C1). (c) Segment of the lamella with corundum in a twin orientation (C2). [Thomas et al. CrystEngComm 2019]

Self-assembly: We continued fundamental studies on the self-assembly TiO2 rutile mesostructures. Grown on a single-crystal substrate, rutile fibres show unusual displacements that could not be explained by simple epitaxial growth. The shifts between the fibres are systematic and show the presence of some strong, yet unknown, ligand interaction that compresses the adjacent rutile structure. Ab-initio theoretical calculations of the TiO_2-water-TiO_2 interface result in increased acidity when the interface includes the observed shift, and neutral in the absence of the shift. **This is the first theoretical proof that acidic conditions directly control the translation state between the rutile fibers**. Rutile crystals decorated with mesostructured rutile fibres show enhanced photocatalytic properties. To extend our studies of self-assembly we submitted an FET-open project in collaboration with University of Barcelona and Fraunhofer Institute in Freiburg as of September 2019.

In collaboration with the Institute for Multidisciplinary Research in Belgrade we selected inversion boundaries (IBs) in **ZnO as a model system for quantum chemical investigation of the stability and formation of chemically induced planar defects in crystals**. Our studies are based on modeling IB structures and involve atomic-scale investigations of IBs with selected dopants, and experimental in-situ studies of their formation mechanisms. Five possible IB structures were addressed, out of which three were already experimentally confirmed. The theoretical part of the investigations was made in collaboration with the Department of Physical and Organic Chemistry of the JSI. The main goal of these fundamental studies is to obtain an understanding of the formation and stability of chemically induced defects in crystals and to predict how they modify the material's physical properties.

Advanced Electron Microscopy

For the microscopic examinations of materials, we use advanced **correlative microstructural characterization**, for a combined and optimal use of several analytical microscopic methods including: 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**).

We have successfully demonstrated how Liquid-Cell Transmission Electron Microscopy can be implemented for the in-situ dynamic observation of nucleation and growth processes taking place in nanoscale materials that are in a solvated environment.

By using **optimized correlative microanalysis**, we have studied various materials such as: thermoelectric ceramics, complex metallic alloys, magnetic materials based on Nd-Fe-B and Sm-Fe-Co, abrasives, piezoelectric perovskite ceramics. 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. With the micro-crystallographic **EBSD** analyses we investigated and directly determined the **crystallographic twin**

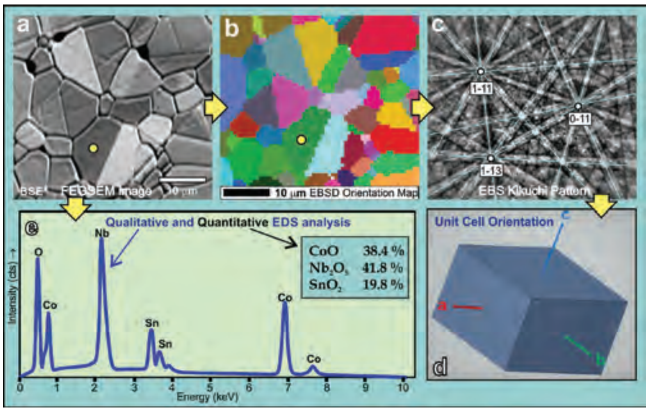


*Figure 12: **Correlative microstructural characterization of SnO_2-CoO-Nb_2O_5 ceramics**: (a) FEGSEM micrograph of the microstructure; (b) EBSD orientation map revealing the random crystallographic orientations of the grains; (c) individual Kikuchi EBSD pattern from a selected grain; (d) reconstruction of the orientation of the tetragonal unit cell in a selected grain; (e) qualitative and quantitative EDS analysis of chemical composition of the material.*

ESTEEM3 consortium, which was successfully granted in 2019, has a status of EU Advanced Community. A member of our department is the scientific coordinator of the consortium.

types in **cassiterite** SnO_2 ceramics (Figure 12), we studied the texture in conventionally and SPS sintered $Nd_2Fe_{14}B$ magnets.

To bridge the gap between conventional (high-vacuum) and in-situ liquid TEM we have recently implemented an interdisciplinary research platform for dynamic TEM studies in liquid environments, Liquid-Cell Transmission Electron Microscopy (LCTEM), that are overcoming the static limitations of conventional analysis techniques. This ground-breaking approach opens up a wide range of possibilities in high-resolution in-situ dynamic studies where case-by-case specialized experiments can be performed by the proper redesign of liquid chambers, allowing us to perform direct nucleation and growth studies of nanoparticles either from solutions or during the electrodeposition, at the nanoscale and in real time. However, the beam-driven solvent radiolysis, which results from the microscope's high-energy electron beam, can dramatically influence the dynamics of the system (Figure 13). Recent research suggests that radical-induced redox chemistry can be used to investigate the various redox-driven dynamics for a wide range of functional nanomaterials. We proposed a holistic approach to the processes in the radical-induced redox chemistry in LCTEM, including the complex kinetics of the radiolysis species and their influence on the redox chemistry of the materials under investigation. The results of this study were published in a highly ranked journal ***Chemical Science*** (IF = 9.5).

The ESTEEM3 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), in situ TEM and mechanical preparation of the TEM samples.

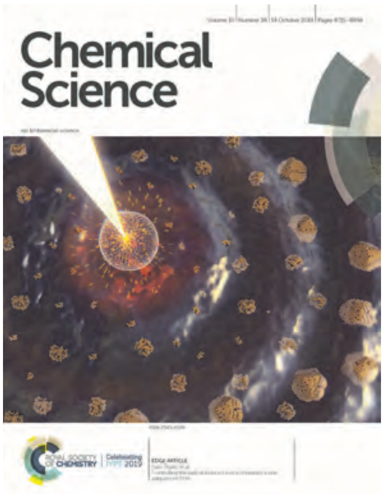


Figure 13 Awarded front cover of Chemical Science journal. Art work representing the radical-induced redox chemistry inside the LCTEM.

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 research infrastructure for electron microscopy.

Industrial partners

Within the project "Microstructural investigations of abrasive materials" with industrial partner Weiler Abrasives (SwatyComet) we have investigated innovative composite abrasives, intended to develop and manufacture improved cutting and grinding tools with a prolonged lifetime.

Education and outreach activities

For the seventh year, the members of the department participated in science promotion activities within the framework of the Science on the Street project. In 2019 there were 16 popular science lectures. The Scientific slam was organized in collaboration with the Cutting Edge conference, which is organized by FKKT-UL. On the ZnC website we have published 13 blogs of researchers and 3 contests. At the invitation of the EIT "Raw Materials" and JA Slovenia (Institute for the Promotion of Youth Entrepreneurship), we co-organised the Innovation Camp 2019 in Zreče. 100 students from 20 high schools from all over Slovenia participated in the Innovation Camp.

SRIP ToP activities, vertical value chain (VVV) New materials

Within the SRIP ToP VVV New Materials activities, we prepared new action plan for the III. phase of SRIP ToP for the period 2020-2023, which is following the successful ending of II. phase. We participated in the preparation of the brochure, which will represent the main focus areas of SRIP ToP. In collaboration with the Horizontal network (HOM) of Modern technology for materials, we organized two workshops, namely, "Modern characterization techniques" and "Chemical and structural analysis of materials". They were intended to educate and connect industry with research organizations in research and development fields. Further, we have prepared a brochure "Examples of good practice", which presents application topics, services and examples of collaboration with industry.

Awards and appointments

1. In April 2019 **Dr Nina Kostevšek** received a Best poster award at the H2020 COST Action training school in Trieste (CA17140 "Cancer nanomedicine - from bench to the bedside") for the presentation of her results on the development of multi-functional nanoparticles for medical applications. Dr Kostevšek is also a management committee member and representative for Slovenia in this COST Action.
2. The 27th International Conference on Materials and Technology (27th ICM&T) took place in Portorož from 16 to 18 October 2019. In the scope of the conference Young researchers' competition was organized. The six-member international committee awarded **Hermina Hudelja** with the second place for her talk "Feather-light, cellulose-nanofiber-reinforced γ–Al_2O_3 foams".
3. At the 6th European Conference on Environmental Applications of Advanced Oxidation Processes which was held from 26 to 30 June 2019 in Portorož, Slovenia, **Živa Marinko** presented a poster with the title "Connecting Metal Titanium Surface Properties and TiO_2 Nanotube Photocatalytic Activity: Top-Down Approach" and was awarded 3rd place at the Student Paper Contest as well as Environmental Science: Water Research & Technology Poster Prize.
4. **Asst. Prof. Andraž Kocjan**, a senior research fellow at the Department for Nanostructured Materials of Jožef Stefan Institute, has received prestigious, early career award "Young Scientist Award" given by the European Ceramic Society (ECerS) for outstanding contributions to the ceramic sciences. Dr Kocjan has published 44 scientific papers (~1000 citations), 2 professional papers and 3 non-technical articles (and held 7 invited talks and 7 interviews). He is an author of an EU and Slovenian patent, GB patent application, technical invention and has co-founded a spin-out company based on JSI's licensed knowledge (producing bioactive fillers for endodontic treatment of teeth receiving ISO 13485 and CE mark for manufacturing and marketing of medical devices). The award was given at the biannual 16th ECerS Conference held in Turin, Italy. At the ceremony Dr Kocjan gave a talk entitled "From unusual to innovative and sustainable processing of ceramics.
5. Tajda Koblar, a Poljane High School student, designed a research study entitled "Comparison of laser and water bath-based thawing process of frozen red blood cells" under the mentorship of **Dr Nina Kostevšek** (JSI, K7) and Dr Ruka Rudež (Poljane High School). Her work was selected for this year's Krka Prize.
6. Laura Drasler and Ula Dragman, Vič High School students, created a research study entitled "Coloidal silver in dental products" under the mentorship of **Anja Korent** (Drame at the time, JSI, K7), and Dr Alenka Mozer (Vič High School). Their work was selected for this year's Krka Prize.
7. **Dr Nina Kostevšek** was awarded the Wüthrich International Young Star Award for the outstanding performance during the early career stages at Sustainable Industrial Processing Summit (SIPS 2019) which was in Cyprus from 23 to 26 October 2019. This award has been established in honour of the distinguished work and lifetime achievements of 2002 Nobel Laureate in Chemistry, Prof. Kurt Wüthrich, who is known for developing the NMR method for studying macrobiological molecules. Dr Nina Kostevšek presented work on the development of new nanoparticle-based contrast agents for magnetic resonance imaging.
8. **Prof. Spomenka Kobe** is the recipient of the prestigious "Frey Award for Leadership in development new technologies that contribute to global sustainable development in the environment, economy, and social points of view." The summit honoured the 2019 STARS of sustainable science, technology, and innovation and was divided into ten parallel Symposia devoted to the awardees. One of them was the "Kobe International Symposium on Science of Innovative and Sustainable Alloys and Magnets (SISAM)," Paphos, Cyprus, where the world-leading scientists from the field of magnets and complex alloys presented their latest achievements in the field. Frey Award is granted to scientists, economists, and politicians. So far, the only awarded Slovenian was Dr Janez Potočnik, European Commissioner for Science and later for Environment.

Organization of conferences, congresses and meetings

1. The 27th International Conference on Materials and Technology – 27. ICM&T, 16–18 October 2019, 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, 16–19 December 2018, Nancy, France
3. The 11th Jožef Stefan International Postgraduate School Students' Conference and 13th CMBE day, 15–16 April 2019, Rateče, Slovenia (co-organisers)
4. Workshop on "Chemical and structural analysis of materials"; SRIP ToP, "New materials" value chains and the horizontal network "Modern Production Technology for Materials", Podgorica, Slovenia, 28 November (co-organisers)
5. Workshop "EIT Raw materials", 23–24 September 2019, Zreče, Slovenia (co-organisers)
6. Midterm meeting of the H2020 project AMPHIBIAN: AnisoMetric Permanent HybrId magnets Based on Inexpensive And Non-critical materials, 10–12 June 2019, Ljubljana, Slovenia

Patent granted

1. Saša Novak, Nataša Drnovšek, Gregor Murn
   Implant having a multilayered coating and a process for preparing thereof
   US10322001 (B2), US Patent Office, 18. 06. 2019.

INTERNATIONAL PROJECTS

1. Spark Plasma Sintering (SPS) of Cost Effective and High Performance Rare-Earth Based Permanent Magnets for Electrical Machines
   Prof. Spomenka Kobe
   Abb Switzerland Ltd
2. 7 FP; ERA CHAIR ISO-FOOD - Era Chairs for Isotope Techniques in Food Quality, Safety and Traceability
   Prof. Saša Novak Krmpotič
   European Commission
3. COST MP1407 - e-MINDS; Electrochemical Processing Methodologies and Corrosion Protection for Device and Systems Miniaturization
   Prof. Kristina Žužek Rožman
   Cost Office
4. COST CA17140 - Nano2Clinic; Cancer Nanomedicine - From the Bench to the Bedside
   Dr. Nina Kostevšek
   Cost Association Aisbl
5. A novel ciruclar economy for sustainable RE-based magnets
   Prof. Spomenka Kobe
   Ministry of Education, Science and Sport
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 - AMPHIBIAN; Antisometric Permanent Hybrid Magnets based on Inexpensive and Non-Critical Materials
   Dr. Petra Jenuš
   European Commission
8. H2020 - ESTEEM3; Enabling Science and Technology through European Electron Microscopy
   Prof. Miran Čeh
   European Commission
9. H2020 - SUSMAGPRO; Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy
   Prof. Spomenka Kobe
   Sennheiser Electronic Gmbh & Co Kg
10. H2020-EUROfusion-Plasma Facing Components-1-IPH-FU, EUROFUSION
    Prof. Saša Novak Krmpotič
    European Commission
11. H2020 EUROfusion - Materials-PPPT-FU
    Prof. Saša Novak Krmpotič
    European Commission
12. H2020 EUROfusion - Education-ED-FU
    Prof. Saša Novak Krmpotič
    European Commission
13. RECEMENT: Re-generating (raw) materials and end-of-life products for re-use in Cement/Concrete, ERA.MIN2
    Prof. Sašo Šturm
    University of Ljubljana (UNI-LJ), University POLITEHNICA of Bucharest (UPB), Sabanci University (SU)
14. Atomic-Scale Investigations of Twinning and Polytypism in Natural Diamonds
    Prof. Aleksander Rečnik
    Slovenian Research Agency
15. Properties of Monolithic and Composite Advanced Ceramics obtained by Conventional and Non-Conventional Sintering Methods
    Dr. Petra Jenuš
    Slovenian Research Agency
16. Functionalized TiO2 Nanostructures for Application in Photo-Catalysis and Sensors
    Prof. Miran Čeh
    Slovenian Research Agency
17. Stability via Doping: Experimental and Theoretical Design of Functional Oxide Ceramics
    Prof. Aleksander Rečnik
    Slovenian Research Agency
18. Micro-to Nanoscale Textures of Ore Minerals: Methods of Study and Significance
    Dr. Janez Zavašnik
    Slovenian Research Agency
19. Investigation of Helium Retention in Plasma Facing Materials Using Advanced Analytical Methods
    Dr. Janez Zavašnik
    Slovenian Research Agency

RESEARCH PROGRAMMES

1. Nanostructured Materials
   Prof. Sašo Šturm
2. Ceramics and complementary materials for advanced engineering and biomedical applications
   Asst. Prof. Andraž Kocjan
3. Fusion technologies
   Prof. Saša Novak Krmpotič

R & D GRANTS AND CONTRACTS

1. W- and WC-based composites for high thermally loaded parts in the fusion demonstration power plant DEMO
   Prof. Saša Novak Krmpotič
2. Catalytically-assisted high efficiency and low-cost nanostructured sensors based on modified screen printed electrodes for analytical chemistry
   Prof. Kristina Žužek Rožman
3. Towards reliable implementation of monolithic zirconia dental restorations
   Asst. Prof. Andraž Kocjan
4. Mineral inclusions in garnet from macroscopic to atomic scale: Opening the petrogenetic archive
   Prof. Aleksander Rečnik
5. High performance nanostructured acrylamide sensors
   Dr. Kristina Žagar Soderžnik
6. Nanoscale investigations of diffusion controlled topotaxial phase transformations in rutile-corundum host systems
   Prof. Aleksander Rečnik
7. Characterization of fractal structures and scale-up parameters in their synthesis
   Dr. Matejka Podlogar
8. Development of a new reactor concept for microkinetic studies and its use for selective oxidative dehydrogenation of alkanes and methane coupling
   Dr. Luka Suhadolnik
9. Role of estrogens in active brain feminisation? and development of a novel hormone implant, mimicking estrous cycle
   Prof. Saša Novak Krmpotič
10. Selective extraction of high value molecules from forest products processing residues in the speciality chemicals sector
    Dr. Petra Jenuš
11. UV sensors nanoparticles embedded into PA fibres
    Prof. Spomenka Kobe
12. Effective recycling of abrasive sludge in the production of Sm2Co17 magnets for a waste-free economy
    Prof. Kristina Žužek Rožman
13. Development of complex shape multicomponent permanent magnets with the use of advanced 3D printing technology
    Prof. Spomenka Kobe
14. Degradation of textile microplastic for domestic wastewater treatment
    Dr. Matejka Podlogar
15. Strategic Research & Innovation Partnership Factories of the Future (SRIP FoF)
    Dr. Kristina Žagar Soderžnik
    Ministry of Economic Development and Technology
16. Services for the Exports
    Dr. Zoran Samardžija
17. External Services
    Asst. Prof. Andraž Kocjan

NEW CONTRACTS

1. Degradation of textile microplastic for domestic wastewater treatment
   Dr. Matejka Podlogar
   Gorenje Gospodinjski Aparati,d.d.
2. Development of complex shape multicomponent permanent magnets with the use of advanced 3D printing technology
   Prof. Spomenka Kobe
   Kolektor Group d. o. o.
3. Corrosion protection of magnetic powders to improve their resistivity to liquids at higher temperatures
   Prof. Spomenka Kobe
   Kolektor Group d. o. o.

4. Implementation of surface modification of Nd-Fe-B powders to increase the coercivity of bonded magnets
Prof. Spomenka Kobe
Kolektor Group d. o. o.
5. Microstructural analyses of abrasive materials
Dr. Zoran Samardžija
Swatycomet, WEILER Abrasives d.o.o.
6. Effective recycling of abrasive sludge in the production of Sm2Co17 magnets for a waste-free economy
Prof. Kristina Žužek Rožman
Magneti d.d.
7. Development of a new magnetic powder
Prof. Sašo Šturm
RLS Merilna tehnika d.o.o.
8. NextGenHVEC: Advanced materials, technologies and prototypes for cost effective hybrid varistor electronic components with improved thermal stability
Prof. Sašo Šturm
Kekon keramični Kondenzatorji, d.o.o.
9. Coating of Nd-Fe-B powders for corrosion protection - transfer to pilot production
Prof. Spomenka Kobe
Sieva, podjetje za razvoj in trženje v avtomobilski industriji d.o.o.
10. Development of complex shape multicomponent permanent magnets with the use of advanced 3D printing technology
Prof. Spomenka Kobe
Kolektor Group d. o. o.
11. Carrying out a study of the possibility of galvanic deposition of nickel on magnetic dust and improving the corrosion protection of magnetic dust
Prof. Spomenka Kobe
Kolektor Group d. o. o.
12. Implementation of VSM, XRD, TEM and CoNiP measurements
Prof. Sašo Šturm
RLS Merilna tehnika d.o.o.

VISITORS FROM ABROAD

1. Dr Melike Mercan Yildizhan Özyar, Linköping University, Linköping, Sweden, 20 January – 3 February 2019
2. Dr Lavinia Scherf, Dr Jaćim Jaćimović and Dr Reto Kessler, ABB Switzerland Ltd., Baden, Switzerland, 22–23 January 2019
3. Hans Willemsen, 3D-CAT, Additively manufactured chemical processing units, Epe, Netherlands, 25 January 2019
4. Prof. Takao Mori, National Institute for Materials Science (NIMS), Tsukuba, Japan, 25–27 January 2019
5. Dr Blaž Belec, Institute of materials for electronics and magnetism, CNR, Parma, Italy, 4–13 February 2019
6. Ana Damnjanović, Kolektor Group, d.o.o., Idrija, Slovenia, 1 March – 31 May 2019
7. Dr Andrasz Kovacs, Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Institute for Microstructure Research, Research Centre Jülich, Germany, 5–8 March 2019
8. Dr Ismail Özgür Özer in Ertuğrul İşlek, Anadolu University, Eskişehir, Turkey, 11–14 March 2019
9. Vesna Ribić, University of Belgrade, Belgrade, Serbia, 21 March – 7 April 2019
10. Prof. Jean-Claude André, CNRS - L'institut des sciences et de l'ingénierie des systèmes, Nancy, France, 27–28 March 2019
11. Dr Andreja Gajović and Ivana Panžić, Institut Ruđer Bošković, Zagreb, Croatia, 15–18 April 2019
12. Prof. Dragoljub Mirjanić, Academy of Sciences and Arts of the Republika Srpska, Banja Luka, Bosnia and Herzegovina, 29–30 April 2019
13. Dr Andreja Gajović, Institut Ruđer Bošković, Zagreb, Croatia, 15–17 May 2019
14. Dr Andreja Gajović, Institut Ruđer Bošković, Zagreb, Croatia, 27–31 May 2019
15. Prof. Cleva Ow-Yang and Prof. Mehmet Ali Gülgün, Sabanci University, Faculty of Engineering & Natural Science, Istanbul, Turkey, 22–25 May 2019
16. Vesna Ribić, University of Belgrade, Belgrade, Serbia, 1 July – 1 October 2019
17. Dr Blaž Belec, Institute of materials for electronics and magnetism, CNR, Parma, Italy, 3–9 July 2019
18. Dr Andreja Gajović and Dr Tihana Čižmar, Institut Ruđer Bošković, Zagreb, Croatia, 19 July 2019
19. Weicheng He, École des Mines Nancy, Université de Lorraine, Nancy, France, 22 July – 28 August 2019
20. Dr Goran Branković, University of Belgrade, Belgrade, Serbia, 28 July – 12 August 2019
21. Dr Melike Mercan Yildizhan Özyar, Linköping University, Linköping, Sweden, 11–31 August 2019
22. Dr María Jazmin Duarte Correa and Dr Aleksander Kostka, Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf, Germany, 30 August – 2 September 2019
23. Sergio Floriano Toribio, Sergio Haro Murcia and Jose Maria Cantarero Alonso, Rey Juan Carlos University, Madrid, Spain, 9 September – 9 December 2019
24. Dr Richard Wheeler, Edinburgh Scientific, Edinburgh, Scotland, 9–12 September 2019
25. Dr Daniel Meljanac, Institut Ruđer Bošković, Zagreb, Croatia, 15–21 September 2019
26. Laia Alfonso, Marina Salord Fiol in Maria Fernandez, University of Barcelona, Barcelona, Spain, 16 September 2019 – 16 January 2020
27. Prof. Bojana Obradović, University of Belgrade, Belgrade, Serbia, 14 October 2019
28. Dr Masato Sagawa, Dr Yutaka Yoshida and Dr T. Iiriyama, Daido Steel Co., Ltd., Higashi-ku, Nagoya, Aichi, Japan, 21 October 2019
29. Dr Michael Cattell, Institute of Dentistry, London, Great Britain, 21–22 October 2019
30. Ivana Jelić, University of Belgrade, Belgrade, Serbia, 21–27 October 2019
31. Dr Richard Wheeler, Edinburgh Scientific, Edinburgh, Scotland, 30 October 2019
32. Vesna Ribić, University of Belgrade, Belgrade, Serbia, 12–26 November 2019
33. Dr María Jazmin Duarte Correa, Prof. Gerhard Dehm, Dr Subin Lee and Dr Aleksander Kostka, Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf, Germany, 27 November – 1 December 2019
34. Dr Melike Mercan Yildizhan Özyar, Linköping University, Linköping, Sweden, 1–21 December 2019
35. Prof. Zeynep Başaran Bundur, Prof. Cleva Ow-Yang and Prof. Mehmet Ali Gülgün, Sabanci University, Faculty of Engineering & Natural Science, Istanbul, Turkey, 4–5 December 2019
36. Prof. Gerald Kothleitner, FELMI-ZFE Institut für Elektronenmikroskopie und Nanoanalytik, Graz, Austria, 5 December 2019
37. Dr Milan Vukšić and Martina Kocijan, Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia, 8–14 December 2019
38. Dr Richard Wheeler, Edinburgh Scientific, Edinburgh, Scotland, 2–6 December 2019
39. Dr Andreja Gajović and Ivana Grčić, Institut Ruđer Bošković, Zagreb, Croatia, 23 December 2019
40. Vesna Ribić, University of Belgrade, Belgrade, Serbia, 5–16 December 2019 and 18–31 December 2019

STAFF

Researchers
1. Prof. Slavko Bernik
2. Prof. Miran Čeh
3. Prof. Jean Marie Dubois
4. Prof. Spomenka Kobe
5. Asst. Prof. Andraž Kocjan
6. Asst. Prof. Matej Andrej Komelj
7. Prof. Saša Novak Krmpotič
8. Dr. Matejka Podlogar
9. Dr. Benjamin Podmiljšak
10. Prof. Aleksander Rečnik
11. Dr. Zoran Samardžija
12. Dr. Marko Soderžnik
13. **Prof. Sašo Šturm, Head**
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15. Dr. Kristina Žagar Soderžnik
16. Prof. Kristina Žužek Rožman

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19. Dr. Nataša Drnovšek*
20. Dr. Aljaž Iveković
21. Dr. Petra Jenuš
22. Dr. Vanja Jordan
23. Dr. Nina Kostevšek
24. Dr. Luka Suhadolnik
25. Dr. Tomaž Tomše

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26. Hermina Hudelja, B. Sc.
27. *Awais Ikram, B. Sc., left 08.05.19*
28. Matej Kocen, B. Sc.
29. Matic Korent, B. Sc.
30. Anja Korent, B. Sc.
31. Abhilash Krishnamurthy, B. Sc.
32. Monika Kušter, B. Sc.
33. *Ana Lazar, B. Sc., left 01.12.19*
34. Živa Marinko, B. Sc.
35. *Muhammad Farhan Mehmood, B. Sc., left 13.05.19*

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39. Anubhav Vishwakarma, B. Sc.
40. Dr. Xuan Xu

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41. Sabina Cintauer, B. Sc.
42. Sanja Fidler, B. Sc.
43. Tina Radošević, B. Sc.

Technical and administrative staff

44. Darko Eterović
45. Tomislav Pustotnik

Note:
* part-time JSI member

BIBLIOGRAPHY

Original Article

1. Miloš Ognjanović, Magdalena Radovič, Marija Mirković, Željko Prijović, Maria del Puerto Morales, Miran Čeh, Sanja Vranješ-Đurić, Bratislav Antić, "^{99m}Tc-, ^{90}Y-, and ^{177}Lu-labeled iron oxide nanoflowers designed for potential use in dual magnetic hyperthermia/radionuclide cancer therapy and diagnosis", *ACS applied materials & interfaces*, 2109, **11**, 44, 41109-41117.
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