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, biomaterials, ceramic materials, 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:
Prof. Spomenka Kobe

Magnetic Materials.

The European project **MAG-DRIVE**, coordinated by one of the members of the department, was successfully concluded. The research in MAG-DRIVE was focused on developing novel microstructural-engineering strategies that dramatically improved the properties of magnets based on light rare-earth elements, especially the coercivity, which enables them to be used for electric vehicle (EV) applications above 100°C. These magnets were also designed-to-recycle, with an emphasis on reducing conventional rare-earth magnets' need for easily oxidizing grain boundaries.

The European project **REProMag** entered its second year. The goal is to develop and validate an innovative resource-efficient manufacturing route for **rare-earth magnets** that allows for the economic and efficient production of net-shape magnetic parts with complex structures and geometries, while being 100% waste-free along the whole manufacturing chain. We have successfully prepared a hard magnet from recycled magnetic materials. The rare earths are on the top of the list of **CRMs** (critical raw materials), so the recycling of Nd-Fe-B magnets is one of the top European priorities.

This is also one of the important research topics of the **DEMETER Marie-Curie European Training Network**. Our research is focused on utilizing a contemporary technique of spark plasma sintering (SPS), offering a minimized grain coarsening for the restoration and improvement of the magnetic performance. SPS experiments have demonstrated an improvement of coercivity of the raw HDDR (hydrogenation-disproportionation-desorption-recombination) powder to H_C = 1120 kA/m in a sintered magnet. A post-sinter annealing even resulted in an enhanced H_C= 1190 kA/m, most possibly due to the redistribution of the grain boundary Nd-rich phase. The synthesis part of the work was significantly supported by transmission electron microscopy **studies of interfaces in reprocessed HDDR Nd-Fe-B permanent magnets**. We developed a special Protective Atmosphere Transfer System, which enables advanced micro- and nano-characterization without exposing samples to oxidation. In the frame of DEMETER we also cover the fields of the development of novel hard magnetic $NdFe_{12}N_x$-based magnets by electrodeposition. Recent experiments were performed in ionic-liquid-based 1-Ethyl-3-methylimidazolium dicyanamide ([EMIM][DCA]) electrolytes in a protective atmosphere. Nd-Fe-based microns-thick films were successfully deposited with the composition close to the desired $NdFe_{12}$ ratio. The EDS spectra did not show a significant oxygen content, which shows that these films have the potential to be used as novel permanent magnets.

Complex Intermetallic Alloys.

In the frame of the **International Associated Laboratory (LIA) PACS2** in which the main goal is to improve our understanding of the mechanisms that promote complexity in metallic alloys, we studied the magnetic structure of a single crystal of the composition $Cu_{84}Gd_9Ca_7$ (at.%), which was grown by Czochralski pulling from the melt. Although Ca and Gd do not mix in the binary phase diagram, we could find on which atomic sites Gd and Ca are randomly distributed and completely determine the crystal structure. The low-temperature random anisotropy of the ferromagnetic structure was pointed out and its lock-in behaviour below a critical temperature of 24K was studied. We placed quite some effort on studying the crystallization path of a glass prepared by melt-spinning the well-known $Al_{62}Cu_{25}Fe_{13}$ alloy, which leads to a stable quasicrystal, but replacing Al by another trivalent element such as Ce or Gd. The rare earth kills the aperiodic order at low concentrations, but favours glass formation to such an extent that we could prepare bulk amorphous samples by pulsed electric current sintering of melt-spun ribbons. The crystallization products of these samples were identified and the reaction kinetics is under study. The Al-Cr-Sc system looks very promising so far. For the first time, we discovered a ternary compound in this system, which is still under investigation. It is reminiscent of the γ-brass phase known in the Al-Cr and derived systems. Superstructures with large lattice parameters were also pointed out. Complex lattice defects are observed and delight the electron

microscopy experts attached to the LIA. Finally, we dedicated a substantial amount of work to publish our results as well as those obtained by companion groups at the Faculty of Metallurgy and the Institute of Chemistry, respectively. The first stream of results ends up in the possibility to develop a new family of light alloys that will compete with alloys containing CRMs such as Mg. The second stream of work evidences the catalytic performance for the formation of water of the $Cu_5(Ca,Gd)$ alloy (already mentioned) just above room temperature in the presence of a mixture of H_2 and O_2. More work is required to fully interpret this data.

Structural Materials.

For more than 10 years **fusion** has been one of our important research activities. To achieve high efficiency and safe operation of the future fusion power plants, large efforts are related to the selection and optimization of suitable structural materials capable of withstanding extreme conditions. One of the key problems is the selection of materials for the divertor, which is responsible for power exhaust and impurity removal via guided plasma exhaust and is therefore subjected to very high heat fluxes. The main task of the High-Heat-Flux Materials (HHFM) division within the EUROfusion program, in which we are a partner, is thus the development of the **components for the DEMO divertor**. Tungsten is considered as a primary candidate for high-heat-loaded structural parts in the DEMO device, mainly due to its very high melting point, good thermal conductivity, low sputtering yield and relatively low activation in terms of long-term waste management. Unfortunately, these advantages are accompanied by a low fracture toughness in the lower-temperature regime, and the onset of recrystallization resulting in a loss of strength at high temperatures that severely limits the operating temperature window. We are trying to overcome the disadvantages of pure W by the incorporation of SiC fibres (to increase the fracture toughness) and/or W_2C nanoparticles (to prevent the recrystallization and grain growth of W) into the W matrix. So far we have determined the most suitable carbon precursor and amount of it for the *in-situ* synthesis of W_2C nanoparticles. Furthermore, we have also optimized the sintering conditions for **W-W_2C composites**. Additionally, we have shown that the incorporation of W_2C nanoparticles prevents the W-grain growth, even at temperatures higher than 1000 °C (operating temperature).

Materials for Health and Clean Environment.

Part of the research of the department is focused on **bio materials**. In the frame of the **COST Action NEWGEN** ("New generation biomimetic and customized implants for bone engineering") we continued with the synthesis and physical and biological characterization of fibroin composite scaffolds for the treatment of osteochondral defects. Using HRTEM analysis we were able to explain how the Ca^{2+} ions that are released from the bioactive glass can change the protein secondary structure, mainly the size of beta-sheets domains, that effectively control the scaffold's properties (in collaboration with the Biochemistry Department B2 and the Veterinary Faculty). In collaboration with Animacel d.o.o. we have expanded the knowledge of fibroin to the synthesis of films and patches for the treatment of large skin wounds in animals. Different surface modifications of fibroin films by conjugation with biological molecules were tested and their biological responses were compared. Several films were already used in the **experimental stem-cell treatment** of large skin/underskin wounds on dogs.

A national project on magnetooptically coupled nanomaterials for innovative cancer treatments continued with in-vitro studies of biofunctionalized FePt/SiO_2/Au nanoparticles (NPs) on three cell lines: normal porcine urothelial cells (NPU), low-grade (RT4) and high-grade (T24) cancer urothelial cells in collaboration with the Institute for Cell Biology, University of Ljubljana. After photothermal treatment, a drop in cell viability by 50 % was observed, which is in accordance to the NPs uptake of the RT4 and T24 cell lines, which was 15 and 13 %, respectively. The hybrid FePt/SiO_2/Au NPs, which we have developed produce a significant photothermal effect and can be effectively used on cancerous cells (Figure 1).

In collaboration with Belgrade University, new methods for the production of graded and biphasic scaffolds based on GG (gellan gummi) and BAG (bioactive glass) were utilized and optimized. The obtained results confirmed the possibility to produce scaffolds by the electrophoretic deposition (EPD) technique based on GG with a graded concentration of BAG aimed at osteochondral tissue engineering.

3D printing was investigated for the printing of various scaffolds (Figure 2). Thermosensitive bio-inks based on gellan gum, fibroin and calcium were developed, measuring the rheological properties of ink composites. We also started with the development of a powder-bed 3D printer for printing inorganic scaffolds, i.e., hydroxyapatite.

Within the **Era Chair ISOFood** project, a colorimetric assay for TiO_2 nanoparticle detection in complex matrices of food samples was developed. An established colorimetric method was adopted for the specific detection of the presence of nanosized TiO_2. The influence of surfactants, titania crystallinity and buffer medium on the accuracy of spectrophotometric detection was evaluated.

We analysed the physical and chemical properties of different industrial and commercially used nanoparticles in the frame of the project "Evaluation of possible harmful effects of nanoparticles and underlying mechanisms – from

physio-chemical and in **vitro toxicity characterization** to innate immune system activation". The main focus was on the colloidal properties in different cell media and on the solubility of possible harmful ions from the particles under physiological conditions. The results obtained in a collaboration with the Faculty of Electrical Engineering will help us to understand the response of cells to specific materials.

In the field of **dental ceramics** we are addressing major issues concerning the production of zirconia (3Y-TZP) dental restorations, their cementation and behaviour in clinical conditions (*in vivo*) in close cooperation with the Department of Prosthetic Dentistry, Medical Faculty, University of Ljubljana. An extensive study was published in *Dental Materials* on the complexity of the relationships between the sandblasting, ageing and strength of 3Y-TZP with different grain sizes and therefore different transformability. It was shown that fine-grained ceramic exhibited superior degradation resistance, while the coarse-grained ceramic experienced higher surface strengthening and a substantially improved ageing resistance upon sandblasting.

In the framework of the **Climate-KIC Accelerator programme**, which we have been part of, we have successfully met with a few companies that are spending a substantial amount of money for the treatment of their wastewater and need a highly efficient solution to reduce their treatment costs. An analysis of our device for the purification of their wastewater is planned after testing the new device's efficiency for the degradation of model organic substances such as caffeine and phenol, which we have already successfully mineralized in the past.

In the field of sensing and with the foreseen environmental application, we have developed Ni-based receptor elements for sensing different organic analytes using formaldehyde as an example. The modified Ni (Ni-OOH) electrode displays a remarked electro-catalytic activity for the oxidation of HCHO and exhibits a linear relationship in a wide concentration range with LOD 0.001 M. These advantages of porous Ni film make it promising for providing a low cost and **simple sensing method in real environments**.

In the last year we also studied **the fabrication and design of functionalised coatings** on metals. Such coating is attractive because of the wide range of applications and consequently the large impact, which such materials potentially have. We evaluated the possibilities of hydro- and solvothermal treatment along with simple post-processing methods on metallic aluminium and zinc to obtain **new materials** with novel or improved properties, such as self-cleaning, superhydrophilicity, superhydrophobicity, photocatalytic degradation of organics and dielectric properties. These improved properties were achieved by the formation of nano- and micro-sized coatings of titanium dioxide (TiO_2), zinc oxide (ZnO) and aluminium oxide hydroxide – boehmite (γ-AlO(OH)).

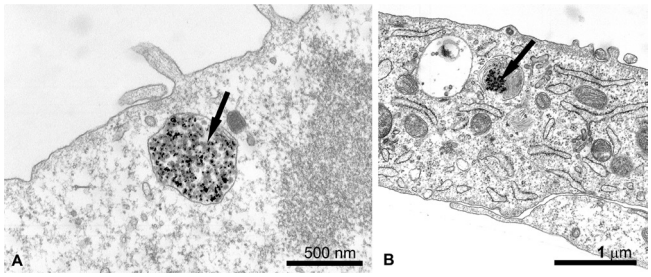

Figure 1: Internalization of hybrid NPs into high-grade cancer urothelial cells in vitro (A and B). (Curtesy of Mateja Erdani Kreft and Samo Hudoklin, Institute for Cell Biology, Medical Faculty, University of Ljubljana)

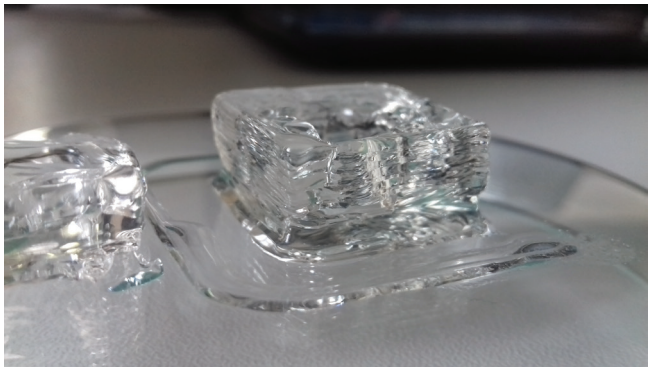

Figure 2: 3D printed gellan gum hydrogel

In the field of photocatalysis we have developed a new, innovative device for efficient water and air purification at relatively high flow rates. The main part of the device is a photocatalytically active material, which we synthesized using an anodic oxidation process. For the purpose of making a bigger device, we have developed a process that enables the simple synthesis of the photocatalytically active titania nanotubes that are rigidly attached to a specially shaped metal titanium foil used in our device.

Engineering and Functional Ceramics.

In collaboration with the Materials Science Institute of Madrid, we have developed cellulose nanofibre-reinforced engineering electro-conductive ceramics and filed a Great Britain patent application. Imparting electrical conductivity to a dielectric ceramic like alumina or zirconia with conducting nanocarbons (nanotubes or graphene) is challenging due to colloidal instability, particle segregation resulting in inhomogeneity. Instead, we used a small addition of cellulose nanofibres, which render highly homogeneous ceramic dispersions due to the increased hydrophilicity character. Nanofibres not only significantly reinforce the ceramic green body, but upon sintering also convert to finely distribute graphitic ex-cellulose carbon nanofibres within a dense and refined ceramic matrix, resulting in highly electro-conducting alumina and zirconia ceramics.

Translucent, self-reinforced mullite ceramic was developed by SPS sintering. Small amounts of yttria and silica in combination with SPS sintering provided enhanced densification, also provoking anisotropic grain growth at low sintering temperatures and pressures. Thus, it was possible to meet the conflicting demands for obtaining a dense mullite with anisotropic grains, ensuring good mechanical properties, while preserving a high light transmittance. The results were published in the *Journal of the American Ceramic Society* and received a best poster award

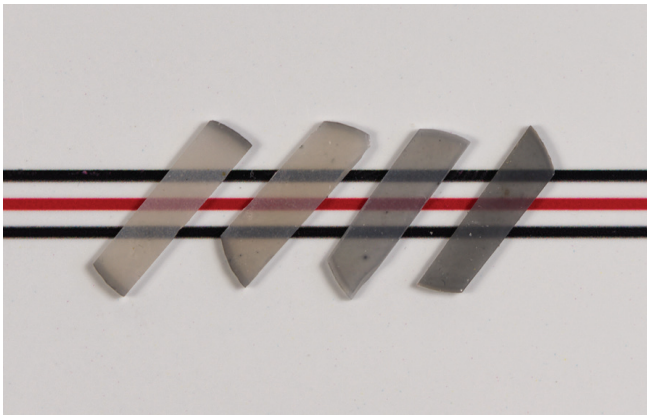

Figure 3: Translucent mullite ceramics.

among 129 competitors at the 41st International Conference and Expo on Advanced Ceramics and Composites, in Daytona Beach, Florida (Figure 3).

In the field of **thermoelectrics**, we studied the nanostructure and thermoelectric properties of an n-type thermoelectric material based on $Sr(Ti,Nb)O_3$ that has a perovskite structure. The addition of SrO and CaO into this structure caused the formation of a three-dimensional network of Rudlesden-Popper-type planar faults within the material. The random stacking of planar faults increased the phonon scattering and lowered the thermal conductivity. Consequently, the material exhibited an increased figure of merit ZT. The influence of the synthesis parameters on the microstructure development and consequently the thermoelectric characteristics was also studied in a p-type $Ca_3Co_4O_9$ ceramics and n-type ceramics of $Zn_kIn_2O_{k+3}$ (k=5,11,18) homologous phases. The thermoelectric characteristics of the $Ca_3Co_4O_9$ ceramics were significantly improved by optimizing the microstructural texturing. In the $ZnO\text{-}In_2O_3$ system, we determined a mechanism of the $Zn_kIn_2O_{k+3}$ homologous phase formation and explained its influence on the microstructure development and consequently thermoelectric characteristics of ceramics.

The influence of the hydrothermal synthesis process on the development of ZnO crystals with a specific morphology was studied. We associated the diverse morphology of the precipitated crystals to the differences in the transient crystallization processes during the precipitation. By altering the pH of the suspension after the precipitation, we gain control over the morphology of the ZnO and show how to grow identical crystallites with different shapes and crystal sizes. We were the first to find how ZnO platelets grow in a certain Zn^{2+}/OH^- ratio along the basal and one of the prismatic directions to form **spherolites** with a very high surface area. We also explained how sphere-like hierarchical structures composed of plate- or rod-like ZnO crystals form through self-assembly driven processes. The research on the hydrothermal synthesis of the **transparent conductive ZnO films** was focused on the influence of the Al-doping on growth, microstructure and optical properties of the ZnO films. The applications are foreseen in LC displays, touch screens and photovoltaic panels.

Within the frame of collaboration with the research group from Sabanci University, Istanbul, Turkey, we successfully realized several studies related to structure-property relationships of **functional oxide ceramics**. One is related to the development of long persistence phosphors as promising materials for energy-saving applications, due to their ability to temporarily store and release light. We confirmed that boron dramatically extends the afterglow persistence to longer than 8 h in strontium aluminates. A second study is related to flash sintering experiments that were for the first time performed on sodium potassium niobate (KNN) ceramics. A theoretical density of 94% was achieved in 30 s under a 250 V/cm electric field at 990°C. These conditions are around 100°C lower and faster than the conventional sintering conditions. Detailed microstructural and chemical investigations of the sample showed that there was inhomogeneous Na, K distribution, resembling a coreshell structure where K is more in the shell and Na is more in the core region (Figure 4). Our latest study deals with the structural and electronic modifications on TiO_2 anatase by Li, K or Nb doping below and above the solubility limit. XRD results have shown that the anatase-to-rutile phase transition as a function of temperature was suppressed by potassium and niobium incorporation, whereas it was facilitated by lithium incorporation.

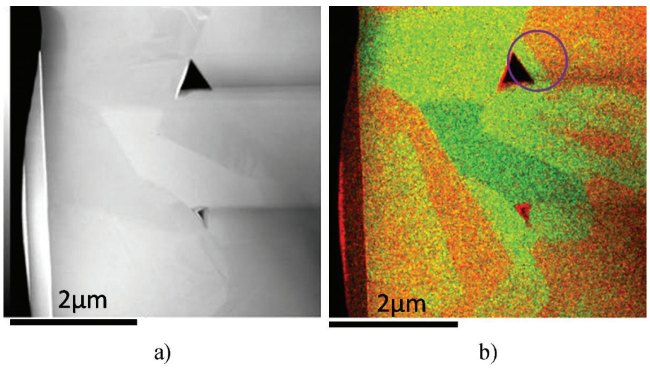

Figure 4: Flash sintering experiments, a) STEM-ADF image, b) STEM-EDX colour maps: K and Na ion atom distribution (K: green, Na: red).

The theoretical part of our research encompassed the density-functional theory to investigate the influence of the substrate on the potentially technologically interesting properties of **the borophene- a single atomic layer of boron atoms**, similar to graphene.

Minerals.

Part of the activities of the Department for Nanostructured Materials is focused on minerals as natural heritage. These basic studies help us to understand and use the knowledge in tailoring new materials. In the area of **twinning, epitaxies and phase transformations in minerals** we studied twinning in **pyrite (FeS_2)** from the Mt. Katarina locality near Ljubljana, where interpenetration pyrite twins occur in addition to single pyrite crystals. Analyses of twin boundaries and inclusions in pyrite crystals with techniques of high-resolution transmission electron microscopy showed that remnants of mineralizing fluids entrapped at the interfaces between the inclusions and hosting pyrite contain trace amounts of Pb and Cu, indicating their presence in the surrounding solutions throughout the

pyrite crystallization period. The atomic-scale analysis of the twin boundaries revealed that the formation of the interpenetrating twins is a consequence of complex 3D intergrowths of primary {110} twins enriched in Cu and secondary interfaces along {100} planes which are chemically unchanged. The results indicate that the formation of twins in pyrite is in accordance with the chemically induced twinning mechanism.

We have explained the mechanism of self-assembling of rutile mesocrystals under hydrothermal synthesis conditions leading to the formation of hierarchical nanostructures which exhibit superior efficiency in photo-electrochemical production of hydrogen and **improved solar-energy conversion efficiency**. We have shown that complex branched structures form as a result of the oriented assembly of precipitated fibres along {110} and {101} planes, resulting in lateral attachment and twinning. As precipitates are thermally agitated, their electromagnetic fields are coupled, and nanocrystals are aligned parallel to their longer axis. Due to a multiplicity of interactions, the particles are first attracted into a loosely associated arrangement. However, as the distance between the fibres becomes shorter the crystallographic alignment along the lowest energy planes becomes dominant. Our pioneering study was the first to clearly indicate the presence of electromagnetic force fields that convey critical structural information through which the oriented attachment of nanocrystals is accomplished. The results are published in the prestigious "Scientific Reports". In collaboration with our colleagues from Novosibirsk we studied the conditions that lead to the perfect splicing of beryl seeds into one larger single crystal under hydrothermal conditions. In our group we characterized the contact region between the intergrown crystals down to the atomic scale. We found that the presence of Si-rich amorphous pockets at the interface compensates for the small angular misfit between the oppositely growing domains (Figure 5).

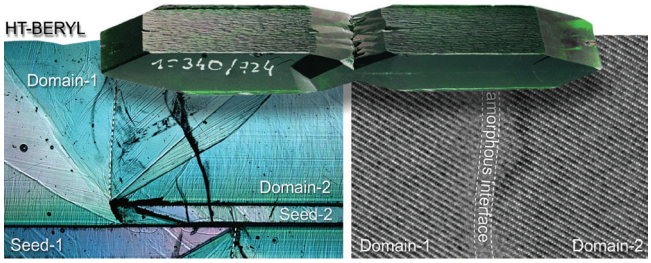

Figure 5: The possibility of the intergrowth of two bulk crystals to a single crystal was demonstrated on the example of beryl, growing under hydrothermal conditions.

Analytical Electron Microscopy

For the microstructural characterization of modern materials, we have applied advanced high-resolution scanning electron microscopy (FEGSEM) and analytical methods of energy-dispersive and wavelength-dispersive spectroscopy (EDS, WDS) for qualitative and quantitative elemental analysis. With the implementation of the method of electron backscatter diffraction (EBSD) we have investigated crystallographic characteristics of the materials: crystallinity, orientation of phases and texture.

The FEGSEM, EDS, WDS and EBSD methods were modified and optimized taking into account the specificity of individual materials with the aim to achieve the most precise and accurate analytical results. We investigated a variety of innovative materials such as ceramic thermoelectrics, complex metallic alloys and quasicrystalline alloys, magnetic materials, abrasives, and phosphorescent ceramics.

Using the EBSD analysis we have confirmed the presence and determined the type of twins in thermoelectrics based on polycrystalline SnO_2. We investigated the effects of heat treatment on the microstructure and phase composition of complex metallic alloys formed in Al-Cr-Sc materials. With advanced quantitative WDS analysis we have accurately determined small concentrations of rare-earth dopants Dy and Eu in phosphorescent ceramics based on $Sr_4Al_{14}O_{25}$.

We successfully finished the **ESTEEM2 project**, which was the only EU project dealing with methodology in **electron microscopy** analytical techniques. In view of this, we have successfully implemented electron microscopy techniques such as electron energy-loss spectroscopy (EELS), high-resolution scanning transmission electron microscopy (STEM, HAADF-STEM), electron holography and mechanical preparation of the TEM samples. Implementation of various electron microscopy analytical techniques and the possibility for the researchers to access research infrastructure for electron microscopy within the **Center for Electron Microscopy and Microanalysis** (CEMM) is of utmost importance for the research group.

The main part of our research within the frame of Liquid TEM studies was focused on the nucleation and early growth of TiO_2 and yttrium-based nanoparticles using the liquid cell inside of a transmission electron microscope (TEM). During heating of the solution to elevated temperatures we were able to record high-frame-rate videos of dynamic changes in electron diffraction patterns during the entire nucleation and growth process of the crystals, enabling us to later exactly reconstruct crystallographic changes during the whole process (Figure 6).

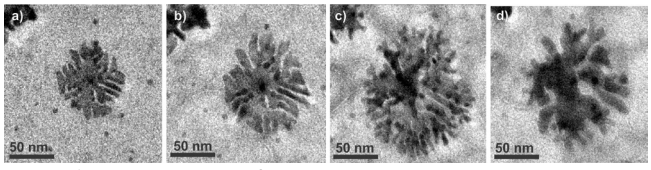

Figure 6: Growth sequence of dendritic nanoparticles in solution observed under dynamic conditions using the liquid TEM method (a-c).

Industrial partners.

We have provided high-temperature laboratory ceramics to Lithoz GmbH Vienna, Hidria Rotomatika Spodnja Idrija, ESAL d.o.o., and Brno Universtiy of Technology, Brno. We have collaborated with many partners from

industry and other research institutions by performing the analyses of specific materials. Main collaborations were with Domel Železniki, Akrapovič Ivančna Gorica, Ustna Medicina Ljubljana, Silkem Kidričevo and Errantech Hangzhou. For SwatyComet, we have conducted analyses of innovative composite abrasives within the project "Microstructural investigations of abrasive materials", which are intended to develop and manufacture improved cutting and grinding tools with a significantly prolonged lifetime. For RC eNeM we were developing microvaristor powder for composites with nonlinear resistivity.

Education and outreach activities.

The members of the Department are heavily involved in the educational system in Slovenia and abroad. Especially, our members dedicate themselves to the educational process of the Jožef Stefan International Postgraduate School, FKKT, NTF, and FMF.

In the frame of the project **Science on the street** (Znanost na cesti - ZnC) founded and coordinated by the members of the department, we are closely involved in raising public awareness in the promotion of science. For the last 4 years, the project activities were performed under the patronage of SATENA (the Slovenian Scientific–Technological Association). In the last year, we organized two cycles of popular scientific talks, scientific slam, round table, and we published several scientific blogs. We organized the scientific competitions for young scientists and students.

Awards and appointments

1. **Luka Suhadolnik**, 3rd Best Oral Presentation at the 24th International Conference on Materials and Technology, Portorož, Slovenia, 28-30 September 2016. Title of the awarded contribution: Optimization of Photoelectrocatalytic Activity of TiO_2-based Microreactor (co-authors: Andrej Pohar, Blaž Likozar and Miran Čeh)
2. **Ana Gantar**, Nataša Drnovšek, Rok Kocen, Saša Novak, Special prize for Innovations for Economy for "SilkPatch - Innovative Solution for Chronic Skin Wounds", 9th International Technology Transfer Conference & Innovation Day 2016, Brdo pri Kranju, 21 September 2016
3. **Nina Kostevšek**, Best Young Lecturer Award, 2nd International Symposium on Nanoparticles-Nanomaterials and Applications (ISN2A-2016), Lisbon, Portugal, 8-21 January 2016. Title of the awarded contribution: "Multimodal hybrid FePt/SiO_2/Au nanoparticles for nanomedical applications: New synthesis approach for improved magnetic and optical properties" (co-authors: Sašo Šturm, Igor Serša, Ana Sepe, Matjaž Spreitzer, Spomenka Kobe, Kristina Žužek Rožman)

Organization of conferences, congresses and meetings

1. Symposium: Design and Recycling of Rare-Earth (RE) Permanent Magnet (PM) Motors and Generators in Hybrid and Full Electric Vehicles – DEMETER, Ljubljana, 14 March 2016
2. EMAS 2016 - 12th Regional Workshop on Electron Probe Microanalysis of Materials Today - Practical Aspects, Bagnols-sur-Cèze, France, 8–11 May 2016 (members of European Microbeam Analysis Society Board)
3. 24th International Conference on Materials and Technology – 24 ICM&T, 28–30 September, Portorož (co-organisers)
4. C-MAC Days 2016, Bratislava, Slovakia, 21–23 November 2016 (members of Science Board and General Assembly in European Integrated Center for the Development of New Metalic Alloys and Compounds (C-MAC))

Patent granted

1. Luka Suhadolnik, Matic Krivec, Miran Čeh, Kristina Žagar, Goran Dražič, Photocatalytic reactor, SI24802 (A), Slovenian Intellectual Property Office, 31. 03. 2016

INTERNATIONAL PROJECTS

1. Selective Laser Melting (SLM) and Spark Plasma Sintering (SPS) of Cost Effective Rare-earth based Permanent Magnets for Electrical Machines
   Prof. Spomenka Kobe
   Abb Switzerland Ltd
2. PurBox - Prototype of the Photoelectriocatalitic Reactor
   Luka Suhadolnik, B. Sc.
   Provadis School Of International
3. 7FP - ESTEEM 2; Enabling Science and Technology through European Electron Microscopy
   Prof. Miran Čeh
   European Commission
4. 7FP - MAG-DRIVE; New Permanent Magnets for Electric-Vehicle Drive Application
   Asst. Prof. Matej Andrej Komelj
   European Commission
5. 7 FP; ERA CHAIR ISO-FOOD - Era Chairs for Isotope Techniques in Food Quality, Safety and Traceability
   Prof. Saša Novak Krmpotič
   European Commission
6. COST MP1301 NEWGEN; New Generation Biomimetic and Customized Implants for Bone Engineering
   Prof. Saša Novak Krmpotič
   Cost Office
7. COST ES1205; The Transfer of Engineered Nanomaterials from Wastewater Treatment & Stormwater to Rivers
   Prof. Saša Novak Krmpotič
   Cost Office
8. H2020 - REProMag; Resource Efficient Production Route for Rare Earth Magnets
   Dr. Benjamin Podmiljšak
   European Commission
9. H2020 - DEMETER; Training Network for the Design and Recycling of Rare-Earth Permanent Magnet Motors and Generators in Hybrid and Full Electric Vehicles
   Asst. Prof. Kristina Žužek Rožman
   European Commission

10. H2020, EUROFUSION;Materials-PPPT-FU: WC and SiC Reinforced Tungsten
    Prof. Saša Novak Krmpotič
    European Commission
11. H2020, Education-ED-FU, EUROFUSION
    Prof. Saša Novak Krmpotič
    European Commission
12. Advanced Methods and Technologies for Processing of a New Generation of ZnO-based Varistor Ceramics
    Prof. Slavko Bernik
    Chinese Academy of Sciences, Shanghai
13. Irradiation and Analysis of Nano SiC Samples
    Dr. Aljaž Iveković
    National Nuclear Research Center, Azerbaijan
14. Determination of Minority Phases, Quantitative Analysis and Determination of Lattice Parameters in SPS Sintered Samples Analysis and Determination of Lattice Parameters in SPS Sintered Samples
    Dr. Petra Jenuš Brdnik
    Jecs Trust
15. Electron Microscopy Study of the Degradation Kinetics of Porous Bioactive Glass based Novel Drug Eluting Implants (Coating/3D Scaffolds) as a Function of Hard Tissue Regeneration for Treatment of Osteoporotic Fractures in Elderly Patients
    Asst. Prof. Nina Daneu
    BI-IN/15-17-015
    Slovenian Research Agency
16. Nucleation and Photocatalytic Activity of Nanoparticles Studied in Actual Liquid Environment under Transmission Electron Microscope
    Prof. Sašo Šturm
    Slovenian Research Agency
    BI-JP/15-17-001
17. Atomic-scale Studies of Topotaxial Reactions in Minerals with the Rutile and Corundum-type Structures
    Asst. Prof. Nina Daneu
    Slovenian Research Agency
    BI-US/15-16-065
18. 0D to 3D ZnO Nanostructures for Optical, Electonic and Energy Applications
    Dr. Matejka Podlogar
    Slovenian Research Agency
    BI-RS/16-17-053
19. Synthesis of Core/Shell MgAl2O4 Spinel Powders for Transparent Armor and IR Applications – CSMASP
    Prof. Slavko Bernik
    Slovenian Research Agency
    BI-TR/16-18-003
20. Processing of High-performance Zirconia Bioceramics for Dental Application
    Asst. Prof. Andraž Kocjan
    Slovenian Research Agency
    BI-HR/16-17-035
21. Investigations of Twinning and Topotaxial Reactions in Sulphide Minerals
    Prof. Aleksander Rečnik
    Slovenian Research Agency
    BI-HR/16-17-029
22. Crystal and Electronic Structure of NbS3 Phases
    Prof. Sašo Šturm
    Slovenian Research Agency
    BI-RU/16-18-048
23. Crystallography, Twinning and Phase Transformations in Minerals with Aragonite-Type Structure ($CaCO_3$, $SrCO_3$, $BaCO_3$, $PbCO_3$)
    Prof. Aleksander Rečnik
    Slovenian Research Agency
    BI-RU/16-18-004
24. Structural and Microstructural Engineering of ZnO Thermoelectrics (SMEZ)
    Prof. Slavko Bernik
    Slovenian Research Agency
    BI-FR/15-16-PROTEUS-007

RESEARCH PROGRAMS

1. Engineering and bio-ceramics
   Asst. Prof. Andraž Kocjan
2. Nanostructured Materials
   Prof. Spomenka Kobe

R & D GRANTS AND CONTRACTS

1. Atomic-scale studies of initial stages of phase transformations in minerals
   Asst. Prof. Nina Daneu
2. Structure and Chemical Composition Study of Surfaces and Interfaces with Highresolution Scanning Transmission Electron Microscopy at Atomic Level
   Prof. Aleksander Rečnik
3. Bio-responsive magneto-optically coupled nanomaterial-based systems for innovative skin cancer treatments
   Prof. Sašo Šturm
4. High-Performance Nanostructured Coatings - breakthrough in concentrated solar power
   Asst. Prof. Andraž Kocjan
5. From the synthesis of metal oxides to the humidity and oxygen prototype nanosensors
   Dr. Kristina Žagar Soderžnik
6. High-coercivity Nd-Fe-B permanent magnets with minimum amount of heavy rare earths
   Dr. Marko Soderžnik

NEW CONTRACTS

1. Preparation of microvaristor powder for composites with nonlinear resistivity
   Prof. Slavko Bernik
   Razvojni Center eNeM Novi Materiali d. o. o.
2. Research & development of dental materials
   Dr. Nataša Drnovšek, Asst. Prof. Andraž Kocjan
   Ustna medicina, d.o.o.
3. Microstructural investigations of abrasive materials
   Dr. Zoran Samardžija
   SwatyComet, d.o.o.

VISITORS FROM ABROAD

1. Dr. Cristina Echevarria-Bonet, Institute for Energy Technology (IFE), Physics Department, Kjeller, Norway, 30 January – 7 February 2016
2. Nerea Gonzales, Marta Navarro, Universidad Rey Juan Carlos, Madrid, Spain, 16 February – 14 May 2016
3. Prof. Mihály Pósfai, University of Pannonia, Veszprém, Hungary, 18–22 February 2016
4. Prof. István Dódony, dr. Ildikó Cora, Erzsi Dodony, Eötvös Loránd University, Budapest, Hungary, 18 – 22 February 2016
5. Dr. Milivoj Plodinec, Ruđer Bošković Institute, Zagreb, Croatia, 25–27 February 2016
6. Prof. Cleva Ow Yang, Sabanci University, Istanbul, Turkey, 6–10 March 2016
7. Dr. Milivoj Plodinec, Dr. Irena Kereković, Ruđer Bošković Institute, Zagreb, Croatia, 14–26 March 2016
8. Dr. Julian Ledieu, Joris Kadok, Institut Jean Lamour, Nancy, France, 25–29 March 2016
9. Prof. Kazuhiro Hono, National Institute for Materials Science (NIMS), Tsukuba, Japan, 7–9 May 2016
10. Dr. Elinor Grace Castle, Queen Mary University of London – QMUL, London, United Kingdom, 13 May – 4 June 2016
11. Dr. Goran Štefanić, Ruđer Bošković Institute, Zagreb, Croatia, 17–18 May 2016
12. Dr. Magnus H. Sørby, Institute for Energy Technology, Physics Department, Kjeller, Norway, 25–28 May 2016
13. Dr. Richard Wheeler, Edinburgh Scientific, Edinburgh, Scotland, 28 May – 1 June 2016
14. Dr. Goran Branković, Marina Vuković, Vesna Ribić, Institute for Multidisciplinary Research, University of Belgrade, Belgrade, Serbia, 1–8 June 2016
15. Dr. Bernd Wicklein, Instituto de Ciencia de Materiales de Madrid – ICMM, Madrid, Spain, 13–24 June 2016
16. Dr. Émilie Gaudry, Institut Jean Lamour, Nancy, France, 8–15 July 2016
17. Fabian Burkhardt, University of Applied Sciences Aalen, Engelsbrand, Germany, 1 Avgust 2016 – 28 January 2017
18. Dr. Mauro Alini, AO Foundation, Davos, Switzerland, 24–25 August 2016
19. Dr. Yuki Kimura, Dr. Jun Kawano, Tomoya Yamazaki, University of Hokaido, Hokaido, Japan, 24–27 August 2016
20. Dr. Pavel Gavryushkin, Sobolev Institute of Geology and Mineralogy, Novosibirsk, Russia, 2–19 September 2016
21. Prof. Makoto Shiojiri, Kyoto Institute of Technology, Kyoto, Japan, 4–7 September 2016
22. Dr. Richard Wheeler, Edinburgh Scientific, Edinburgh, Scotland, 4–9 September, 2016
23. Matej Baláž, Institute of Geotechics, Slovak Academy of Sciences, Košice, Slovakia, 10–16 September 2016
24. Dr. Ulrike Wolff, Leibniz-Institut für Festkörper- und Werkstoffforschung, Dresden, Germany, 3 October – 31 December 2016
25. Prof. Peter A. van Aken, Stuttgart Center for Electron Microscopy, Max Planck Institute for Solid State Research, Stuttgart, Germany, 11–13 October 2016
26. Sayanthan Ray, Central Glass and Ceramic Research Institute – CSIR, Kolkata, India, 20 October – 20 November 2016
27. Dr. Richard Wheeler, Edinburgh Scientific, Edinburgh, Scotland, 23–28 October 2016
28. Jovana Zvicer, Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia, 29 October – 4 December 2016

29. Dr. Reinhard Simon, ABB Corporate Research Center, Baden-Dättwil, Switzerland, 9 November 2016
30. Dr. Andrea Čobić, Prof. Vladimir Bermanec, Dr. Snježana Mikulčić Pavlaković, Marin Soufek, M.Sc., Faculty of Science, Universty of Zagreb, Zagreb, Croatia, 10 November 2016
31. Vesna Ribić, Institute for Multidisciplinary Research, University of Belgrade, Belgrade, Serbia, 16 November – 16 December 2016
32. Dr. Goran Branković, Marina Vuković, Institute for Multidisciplinary Research, University of Belgrade, Belgrade, Serbia, 16–23 November 2016
33. Prof. Mehmet Ali Gülgün, Sabanci University, Istanbul, Turkey, 23–25 November 2016
34. Dr. Andrea Čobić, Dr. Snježana Mikulčić Pavlaković, Faculty of Science, Universty of Zagreb, Zagreb, Croatia, 24–29 November 2016
35. Prof. Emmanuel Guilmeau, Cédric Bourgès, Laboratoire CRISMAT, Caen, France, 28 – 30 November 2016
36. Asst. Prof. Ismail Özgür Özer, Anadolu University, Department of Materials Science and Engineering, Eskişehir, Turkey, 7–11 December 2016
37. Dr. Julian Ledieu, Dr. Vincent Fournée, Dr. Marie-Cécile de Weerd, Institut Jean Lamour, Nancy, France, 12–15 December 2016

STAFF

Researchers
1. Prof. Slavko Bernik
2. Prof. Miran Čeh
3. Asst. Prof. Nina Daneu
4. Prof. Jean Marie Dubois
5. **Prof. Spomenka Kobe, Head**
6. Asst. Prof. Andraž Kocjan
7. Asst. Prof. Matej Andrej Komelj
8. Prof. Saša Novak Krmpotič
9. Dr. Benjamin Podmiljšak
10. Prof. Aleksander Rečnik
11. Dr. Zoran Samardžija
12. Prof. Sašo Šturm
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Postdoctoral associates
15. Dr. Nataša Drnovšek
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17. *Dr. Aljaž Iveković, on leave 01.03.16*
18. Dr. Petra Jenuš Brdnik
19. *Dr. Martina Lorenzetti, left 21.12.16*
20. *Dr. Darja Pečko, left 01.03.16*
21. Dr. Matejka Podlogar
22. Dr. Marko Soderžnik

Postgraduates
23. Anže Abram, B. Sc.
24. Bojan Ambrožič, B. Sc.
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29. Vanja Jordan, B. Sc.
30. Luka Kelhar, B. Sc.
31. Rok Kocen, B. Sc.
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33. Nina Kostevšek, B. Sc.
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35. Ana Lazar, B. Sc.
36. Muhammad Farhan Mehmood, B. Sc.
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38. Sara Tominc, B. Sc.
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41. Xuan Xu, B. Sc.

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42. *Dr. Jana Ferčič, left 01.07.16*
43. Sanja Fidler, B. Sc.
44. *Martin Topole, B. Sc., left 01.10.16*

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45. Teja Đukić
46. Darko Eterović
47. *Mojca Hren, left 21.12.16*
48. Tomislav Pustotnik

BIBLIOGRAPHY

Original Article

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2. Anže Abram, Andreja Eršte, Goran Dražić, Vid Bobnar, "Structural and dielectric properties of hydrothermally prepared boehmite coatings on an aluminium foil", *J. mater. sci., Mater. electron.*, vol. 27, no. 10, pp. 10221-10225, 2016.
3. Guliz Inan Akmehmet, Sašo Šturm, Laura Bocher, Mathhieu Kociak, Bojan Ambrožič, Cleva Ow-Yang, "Structure and luminescence in long persistence Eu, Dy, and B codoped strontium aluminate phosphors: the boron effect", *J. Am. Ceram. Soc.*, vol. 99, iss. 6, pp. 2175-2180, 2016.
4. Muhammad Shahid Arshad, Mariana P. Proenca, Špela Trafela, Volker Neu, Ulrike Wolff, Sven Stienen, Manuel Vazques, Spomenka Kobe, Kristina Žužek Rožman, "The role of the crystal orientation (c-axis) on switching field distribution and the magnetic domain configuration in electrodeposited hcp Co-Pt nanowires", *J. phys., D, Appl. phys.*, vol. 49, no. 18, pp. 1-13, May 2016.
5. Slavko Bernik, Mateja Košir, Emmanuel Guilmeau, "Microstructure and thermoelectric characteristics of $(ZnO)_kIn_2O_3$- based ceramics (k = 5 and 11", *Zašt. mater.*, vol. 57, no. 2, pp. 318-345, 2016.
6. Klemen Bohinc, Goran Dražić, Anže Abram, Mojca Jevšnik, Barbara Jeršek, Damijan Nipič, Marija Kurinčič, Peter Raspor, "Metal surface characteristics dictate bacterial adhesion capacity", *Int. j. adhes. adhes.*, vol. 68, pp. 39-46, July 2016.
7. Danielle Cavalcante Guedes de Lima, Tibério Andrade Dos Passos, Marie-Cecile De Weerd, Samuel Kenzari, Rodinei Gomes Medeiros, Severino Jackson Guedes De Lima, Jean-Marie Dubois, "Indirect assessment of the surface energy of the Al-Cu-Fe quasicrystal", *J. Mater. Sci.*, vol. 51, no. 8, pp. 4070-4078, 2016.
8. Gulcan Corapcioglu, Mehmet Ali Gülgün, Kim Kisslinger, Sašo Šturm, Shikhar K. Jha, Rishi Raj, "Microstructure and microchemistry of flash sintered $K_{0.5}Na_{0.5}NbO_3$", *J. Ceram. Soc. Jpn.*, vol. 124, no. 4, pp. 321-328, 2016.
9. Jasna Cotič, Peter Jevnikar, Andraž Kocjan, Tomaž Kosmač, "Complexity of the relationships between the sintering-temperature-dependent grain size, airborne-particle abrasion, ageing and strength of 3Y-TZP ceramics", *Dent Mater*, vol. 32, iss. 4, pp. 510-518, Apr. 2016.
10. Aleš Dakskobler, Andraž Kocjan, Paul Bowen, "Predicting the yield stress of paraffin-wax suspensions", *Powder technol.*, vol. 291, pp. 1-6, 2016.
11. Nataša Drnovšek, Rok Kocen, Ana Gantar, Marinka Drobnič-Košorok, Adrijana Leonardi, Igor Križaj, Aleksander Rečnik, Saša Novak, "Size of silk fibroin β-sheet domains affected by Ca^{2+}", *J. mater. chem. B* , vol. 4, iss. 40, pp. 6597-6608, 2016.
12. Ana Gantar, Nataša Drnovšek, Pablo Casuso, Adrián Pérez-San Vicente, Javier Rodriguez, Damien Dupin, Saša Novak, Irada Loinaz, "Injectable and self-healing dynamic hydrogel containing bioactive glass nanoparticles as a potential biomaterial for bone regeneration", *RSC advances*, vol. 6, no. 73, pp. 69156-69166, 2016.
13. Petra Jenuš, Martin Topole, Paul J. McGuiness, Cecilia Granados-Miralles, Marian Stingaciu, Mogens Christensen, Spomenka Kobe, Kristina Žužek Rožman, "Ferrite-based exchange-coupled hard-soft magnets fabricated by spark plasma sintering", *J. Am. Ceram. Soc.*, vol. 99, iss. 6, pp. 1927-1934, 2016.

14. Marja Jerič, Johannes de Boor, Boštjan Jančar, Miran Čeh, "An enhanced thermoelectric figure of merit for $Sr(Ti_{0.8}Nb_{0.2})O_3$ based on a Ruddlesden-Popper-polytype-induced microstructure", *J. Eur. Ceram. Soc.*, vol. 36, nol. 5, pp. 1177-1182, 2016.
15. Marja Jerič, Johannes de Boor, Janez Zavašnik, Miran Čeh, "Lowering the thermal conductivity of $Sr(Ti_{0.8}Nb_{0.2})O_3$ by SrO and CaO doping emicrostructure and thermoelectric properties: microstructure and thermoelectric properties", *J. Mater. Sci.*, vol. 51, no. 16, pp. 7660-7668, 2016.
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18. Luka Kelhar, Jana Bezjak, Pascal Boulet, Marjeta Maček, Sašo Šturm, Martin Lamut, Boštjan Markoli, Spomenka Kobe, Jean-Marie Dubois, "Stabilisation of Ce-Cu-Fe amorphous alloys by addition of Al", *Philos. mag. (2003)*, vol. 96, iss. 30, pp. 3143-3185, 2016.
19. Luka Kelhar, Janez Zavašnik, Paul J. McGuiness, Spomenka Kobe, "The impact of processing parameters on the properties of Zn-bonded Nd-Fe-B magnet", *J. magn. magn. mater.*, vol. 419, pp. 171-175, 2016.
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23. Mitja Krnel, Stanislav Vrtnik, Primož Koželj, Andraž Kocjan, Zvonko Jagličić, Pascal Boulet, Marie-Cecile De Weerd, Jean-Marie Dubois, Janez Dolinšek, "Random-anisotropy ferromagnetic state in the $Cu_5Gd_{0.54}Ca_{0.42}$ intermetallic compound", *Phys. rev., B, Condens. matter mater. phys.*, vol. 93, no. 9, pp. 094202-1-094202-14, 2016.
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33. Mojca Presečnik, J. de Boor, Slavko Bernik, "Synthesis of single-phase $Ca_3Co_4O_9$ ceramics and their processing for a microstructure-enhanced thermoelectric performance", *Ceram. int.*, vol. 42, no. 6, pp. 7315-7327, 2016.
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42. Janja Vidmar, Radmila Milačič, Viviana Golja, Saša Novak, Janez Ščančar, "Optimization of the procedure for efficient dispersion of titanium dioxide nanoparticles in aqueous samples", *Analytical methods*, vol. 8, no. 5, pp. 1194-1201, 2016.
43. Miloš Vittori, Vesna Šrot, Kristina Žagar, Birgit Bussmann, Peter van Aken, Miran Čeh, Jasna Štrus, "Axially aligned organic fibers and amorphous calcium phosphate form the claws of a terrestrial isopod (Crustacea)", *J Struct Biol*, vol. 195, iss. 2, pp. 227-237, 2016.
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45. Melike Melike Yildizhan, Sašo Šturm, Mehmet Ali Gülgün, "Structural and electronic modifications on TiO[sub]2 anatase by Li, K or Nb doping below and above the solubility limit", *J. Mater. Sci.*, vol. 51, no. 12, pp. 5912-5923, 2016.
46. Maša Zalaznik, Mitjan Kalin, Saša Novak, "Influence of the processing temperature on the tribological and mechanical properties of poly-ether-ether-ketone (PEEK) polymer", *Tribol. int.*, vol. 94, pp. 92-97, Feb. 2016.
47. Maša Zalaznik, Mitjan Kalin, Saša Novak, Gregor Jakša, "Effect of the type, size and concentration of solid lubricants on the tribological properties of the polymer PEEK", *Wear*, vol. 364-365, pp. 31-39, Oct. 2016.
48. Maša Zalaznik, Saša Novak, Miroslav Huskić, Mitjan Kalin, "Tribological behaviour of a PEEK polymer containing solid MoS2 lubricants", *Lubr. sci.*, vol. 28, iss. 1, pp. 27-42, 2016.
49. Kristina Žagar, Andraž Kocjan, Spomenka Kobe, "Magnetic and microstructural investigation of high-coercivity net-shape Nd-Fe-B-type magnets produced from spark-plasma-sintered melt-spun ribbons blended with DyF_3", *J. magn. magn. mater.*, vol. 403, pp. 90-96, 2016.

Published Conference Contribution (invited lecture)

1. Blaž Leskovar, Iztok Naglič, Zoran Samardžija, Boštjan Markoli, "Influence of modification of Al-Mn-based alloy on ability to form quasicrystals", In: *Innovation: the foundation of competitive casting production: proceedings book*, 15th International Foundrymen Conference, Opatija, May 11th-13th, 2016, pp. 25-34.

Published Conference Contribution

1. Klemen Bohinc, Ágota Deák, Karmen Godič Torkar, Goran Dražić, Anže Abram, László Janovák, Imre Dékány, "Bacterial adhesion to material surfaces covered by thin films", In: *EURADH 2016 [and] Adhesion '16*, 11th European Adhesion Conference and 13th International Triennial Conference on the Science and Technology of Adhesion and Adhesives, 21 - 23 September 2016, Glasgow, UK, pp. 54-57.
2. Marja Jerič, Johannes de Boor, Miran Čeh, "High-temperature thermoelectric materials based on $SrTiO_3$", In: *Conference proceedings 2016*, 52nd International Conference on Microelectronics, Devices and Materials and the Workshop on Biosensors and Microfluidics, September 28 - 30 2016, Ankaran, Slovenia, pp. 11-15.
3. Aysen Kaya, Matejka Podlogar, Damjan Vengust, Damjan Svetin, Süleyman Kahraman, Aleksander Rečnik, Slavko Bernik, "Hydrothermal growth of doped ZnO films on amorphous substrates", In: *Conference proceedings 2016*, 52nd International Conference on Microelectronics, Devices and Materials and the Workshop on Biosensors and Microfluidics, September 28 - 30 2016, Ankaran, Slovenia, pp. 37-42.
4. Matej Komelj, "Development of permanent mahnets for electric vehicles", In: *Moving forward: innovative solutions for tomorrow's mobility*, 6th European Transport Research Conference, TRA 2016, 18-21 April 2016, Warsaw, Poland, 8 pp.
5. Mateja Košir, Etienne Savary, Sylvain Marinel, Emmanuel Guilmeau, Slavko Bernik, "Preparation of $(ZnO)_k \cdot In_2O_3$ thermoelectric ceramics by microwave sintering", In: *Conference proceedings 2016*, 52nd International Conference on Microelectronics, Devices and Materials and the Workshop on Biosensors and Microfluidics, September 28 - 30 2016, Ankaran, Slovenia, pp. 16-21.
6. Ivana Kumpová, D. Vavřík, T. Fila, Petr Koudelka, I. Jandejsek, J. Jakůbek, Daniel Kytýř, Petr Zlámal, M. Vopálenský, Ana Gantar, "High resolution micro-CT of low attenuating organic materials using large area photon-counting detector", In: *Proceedigs of the 17th International Workshop on Radiation Imaging Detectors (IWORID2015) June 28-July 2, 2015, Hamburg, Germany*, (Journal of instrumentation, vol. 11, 2016), pp. C02003-1-C02003-8.
7. Branko Matović, Dušan Bučevac, Vladimir Urbanović, Nadežda Stanković, Nina Daneu, Tatjana Volkov Husović, Biljana Babić, "Monolithic nanocrystalline SiC ceramics", In: *Engineering Ceramics 2015 Materials for Better Life, 10-14 May 2015, Smolenice, Slovakia*, (Journal of the European Ceramic Society, vol. 36, iss. 12, 2016), pp. 3005-3010.
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