ELECTRONIC CERAMICS DEPARTMENT

K-5

The Electronic Ceramics Department is active in the research of the synthesis, properties and applications of ceramic materials for electronics and energetics, mainly complex multifunctional materials and structures that can perform multiple functions (multifunctional materials). The materials of interest include piezoelectrics, ferroelectrics, relaxors, multiferroics, conductive oxides, low-dimensional magnets and cuprate superconductors. The emphasis is on the creation of properties by the synthesis and structure on the nano-, micro- and macro-levels. The group also works on the principles of basic technologies for ceramic pressure sensors, ceramic MEMS and flexible electronics.

Head:
Prof. Barbara Malič

We continued with the work on **lead-free piezoelectrics**. In collaboration with colleagues from the Technical University of Darmstadt, Germany, we studied the uniaxial deformation of the ferroelectric $KNbO_3$ single crystal in [010] and [101] orientations at room temperature. The mechanical dislocation and ferroelectric domain structure were investigated using piezo-response force microscopy (PFM). The results suggest that the dislocations act as nucleation and pinning sites for the ferroelectric domains, leading to a local increase in the density of the ferroelectric domain walls.

We continued with the work on **polycrystalline $BiFeO_3$**. We performed a comparative study of uncharged and charged domain walls (DWs) in $BiFeO_3$ ceramics from the point of view of the atomically resolved strain and structure using scanning-transmission electron microscopy. We showed that the uncharged {100}pseudo cubic (pc)-type DWs have a larger associated lattice strain than the charged-"tail-to-tail" {100}pc-type DWs, and we were able to explain the result as a pure intrinsic lattice mismatch. As the {100}pc-type DWs have been experimentally shown to be intrinsically different in strain distribution and structure, we assume that their role in the switching mechanism will be different, depending on their particular strain and charged state.

Together with colleagues from the Norwegian University of Science and Technology, Trondheim, Norway, we published a review paper on the alternating-current (AC) properties of domain walls, which includes our work on $BiFeO_3$ ceramics, in particular the implications of the domain-wall conductivity in the emergent macroscopic piezoelectric response.

In collaboration with colleagues at the National Institute of Chemistry, EPFL, Lausanne, Switzerland, Materials Center Leoben, Austria, and the Tokyo Institute of Technology, Japan we conducted an atomic resolution study using aberration-corrected scanning transmission electron microscopy complemented by Raman spectroscopy and directly revealed, visualized, and quantitatively described static 2–4-nm polar nanoclusters in the nominally nonpolar cubic phases of **barium titanate-based ceramics**. These results helped us understand the atomic-scale structure of disordered materials and may help clarify ambiguities about the dynamic-versus static nature of nano-sized clusters [Figure 1].

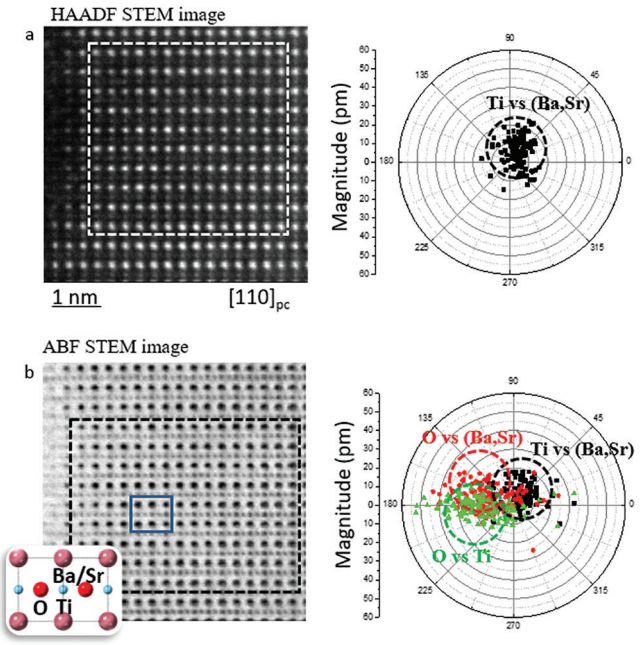

Figure 1: High-angle annular dark-field (HAADF) and annular bright-field (ABF) STEM image of $Ba_{0.6}Sr_{0.4}TiO_3$ in [110] zone axis with corresponding Ti vs (Ba, Sr), O vs (Ba, Sr), and O vs Ti displacements presented in the form of polar plots. The inset in b shows the perovskite unit cell viewed along [110] axis. Dashed rectangles mark areas where displacements were determined. Dashed circles mark areas where majority of the individual types of displacements are present. Displacements of cations and anions do not coincide, indicating non-cubic structure.

$(Na_{1/2}Bi_{1/2})TiO_3$–$BaTiO_3$ (NBT-BT) lead-free piezoceramics are of interest for high-power piezoelectric applications where the hardening of the electromechanical response is of paramount importance. In collaboration with colleagues from Technical University Darmstadt, Germany, we conducted a study on NBT-BT ceramics aimed at identifying the hardening efficiency of the so-called composite approach. The approach consists of dispersing second-phase inclusions, in this case ZnO, in the ceramics to provide pinning effects and thus reduce the domain-wall displacements and the associated losses. With the support of higher harmonic polarization measurements, performed in our lab, we were able to explain the superior thermal stability of the mechanical quality factor in NBT-BT/ZnO composites as a consequence of robust mechanical pinning effects provided by the inclusions.

In collaboration with colleagues from Friedrich-Alexander-University Erlangen-Nürnberg, Germany, we used piezoforce microscopy (PFM) and transmission electron microscopy to investigate the domain structure of $(Na_{1/2}Bi_{1/2})TiO_3$ ceramics. Ferroelectric domain switching was observed by applying a sufficiently large electric field, no change in domain configuration was observed in the samples subjected to uniaxial compressive stresses up to 750 MPa.

In ferroelectrics, the mechanisms of hardening by acceptor doping are commonly associated with domain-wall pinning effects provided by oxygen vacancies. In **lead-based relaxor ferroelectrics**, these mechanisms are complicated by the nano-polar structure of these materials and their dynamic contribution to the electromechanical properties. To shed light on this issue, we systematically investigated the hardening effects by Mn doping in $Pb(Mg,Nb)O_3$-$PbTiO_3$ (PMN-PT). We found that the oxygen-vacancies-related pinning manifests similarly both in the ergodic and non-ergodic relaxor phases of the PMN-PT. By reducing the freezing temperature, Mn doping was found to be an efficient approach to improving the thermal stability of the electrocaloric response.

PhD students Oana-Andreea Condurache and Matej Šadl won four prizes for presenting their dissertation results at international conferences.

Poling-field-induced changes in the PMN–PT relaxor ferroelectric ceramics around the morphotropic phase boundary (MPB) were investigated, with a detailed examination of the effects of the poling procedure on the piezoelectric and dielectric response, as well as the response of the crystal lattice and the ferroelectric domains. We found that AC poling on the monoclinic (M) side of the phase diagram is more effective than DC poling from the point of a much lower AC field being needed to obtain a similar d33 response as with DC poling. This result was supported by in-situ XRD measurements of the 30 PT M composition, which show a large-strain response at significantly lower AC than the DC field. Furthermore, the Cm M phase possesses low-angle nanodomain walls and exhibits a gradual "cascade-like" motion of the domain walls that starts immediately at low fields (~2 kV/cm) and saturates roughly at 15 kV/cm, contributing to large strains in the material. The tetragonal-like M phase, however, shows sudden domain switching roughly at the coercive field, with no obvious lattice strain up to 30 kV/cm.

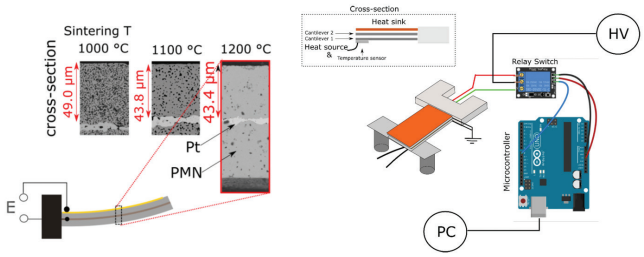

Figure 2: Multifunctional cantilevers as working elements in solid-state cooling devices: microstructures of the sandwich-like structure of cantilevers in cross-section, consisting of two $Pb(Mg,Nb)O_3$ ceramic layers and platinum, sintered at different temperatures. When an electric field (E) is applied to the upper ceramic layer, the cantilever bends, as shown schematically in the bottom inset. Experimental setup for testing the proof-of-concept device with cantilevers arranged in a cascade structure is shown on the right.

In collaboration with colleagues from the Condensed Matter Department, JSI, and from the Technical University Darmstadt, Germany, we investigated **the electrocaloric (EC) properties** of $0.9Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.1PbTiO_3$ (PMN-10PT) ceramics prepared by the conventional columbite route and mechanochemical synthesis. The samples were able to withstand DC electric fields up to 115 kV/cm, resulting in very high EC temperature changes (ΔT_{EC}) of 2.37 K at 107 °C. In contrast, the ceramics prepared by the columbite route could only withstand ~60 kV/cm and therefore exhibited a much lower ΔT_{EC}. A detailed examination of the microstructure revealed that the respective samples contained a semi-crystalline secondary phase at the triple junctions of the grains, which presumably provided an easy pathway for current propagation. In contrast, in the PMN-10PT obtained by mechanochemical synthesis, the grain boundaries were clean and MgO inclusions were identified. These microstructural features contributed to a higher electrical breakdown field of the ceramics.

Despite the challenges of practical implementation, EC cooling remains a promising technology because of its good scalability and high efficiency. To provide a further step in this application area, we fabricated multifunctional cantilever structures made of relaxor ferroelectric PMN-PT, which were stacked in a cascade, forming a proof-of-concept device. Functional testing of the structure revealed that the key element of the device's performance is the poor heat transfer through the cantilever contacts. The study thus clearly showed that further engineering will have to be focused on lowering the thermal contact resistance for an efficient EC operation of the cantilever cascade [Figure 2].

Prof. dr. Goran Dražić received a Zois Award for top achievements in the field of the transmission electron microscopy of materials.

Together with collaborators from McMaster University, Canada, Oakridge National Laboratory in the US, and ANSTO's Australian Synchrotron, we continued the research on **cuprate superconductors**, $La_{1.6-x}Nd_{0.4}Sr_xCuO_4$ (Nd-LSCO). We first used resonant X-ray scattering to measure the evolution of electronic nematicity and charge density wave order with hole doping. We found that electronic nematicity – a rotational symmetry breaking of the electronic structure – is associated with the onset of the pseudo-gap phase. Nd-LSCO exhibits a substantial decrease in electronic nematicity, either by increasing the temperature to the onset of the pseudo-gap phase or by increasing the doping through the pseudo-gap quantum critical point.

Moreover, using elastic and inelastic neutron scattering measurements on single crystals of $x = 0.125, 0.19, 0.24$, and 0.26 we showed that two-dimensional, quasistatic, parallel spin stripes have an onset at temperatures such that the parallel spin stripe phase extends beyond $p*$ and envelops the entirety of the superconducting ground states

in this system. Our measurements of 2D TN and the onset of 2D parallel stripes at optimal and high hole-doping levels in Nd-LSCO, allowed us to complete the phase diagram for 2D parallel stripes and examine their relation to superconductivity.

In the framework of our studies on **low-dimensional magnetism**, we continued our investigations of **manganates**. We performed the synthesis, structural and magnetic characterisation of the $Ba_{1-x}La_{1+x}MnO_{4+\delta}$ ($0 \le x \le 0.5$) series. We found that each member of the $Ba_{1-x}La_{1+x}MnO_{4+\delta}$ series exhibits the same spin-glass behaviour previously found in the x = 0.2. Moreover, Tg varies with x reaching a maximum of 26.4(4) K for x = 0.20 [Figure 3].

Furthermore, using X-ray absorption near-edge structure (XANES) studies we found out that the oxidation state of Mn in the $Ba_{1-x}La_{1+x}MnO_{4+\delta}$ samples varies with x: for $x \le 0.2$ Mn is in +3.0(1) oxidation state only, whereas a mixed +2/+3 oxidation state was found for $x > 0.2$. The origin of the spin-glass state in the $Ba_{1-x}La_{1+x}MnO_{4+\delta}$ series shows two regimes depending on the oxidation state of the Mn.

In collaboration with the Department of Advanced Materials, JSI, we investigated the relaxor ferroelectric domain structure in the epitaxial $0.67Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.33PbTiO_3$ (PMN-33PT) films on different substrates. PFM analysis was used to show that the domain structure of PMN-33PT films is sensitive to the compressive strain induced in the films. A relaxor-like behaviour was observed at a strain state below 1.1%, while irregularly shaped ferroelectric domains were observed at a higher compressive strain (> 1.9%). The results suggest that epitaxial strain engineering could be an effective approach to tailor and improve the functional properties of **relaxor ferroelectric thin films**.

Patterning of nanostructures of functional-oxide materials by inkjet printing of solution-based inks was studied with colleagues from the Condensed Matter Physics Department, JSI, Faculty of Mathematics and Physics, University of Ljubljana, and CENN Nanocenter. The importance of contact line mobility– either pinned or mobile – on the deposit morphology, either dome-like, flat or ring-like, was addressed. By adjusting the ink solvent composition and controlling the substrate wetting behaviour, deposits with a uniform thickness in the nanometre range could be printed.

Within the field of chemical solution deposition of lead-free ferroelectric thin films our focus was on barium-titanate-based solid solutions with an enhanced ferro- and piezoelectric response.

We continued the research of **thick films** of environmentally benign piezoelectrics based on $K_{0.5}Na_{0.5}NbO_3$ on ceramic substrates for energy harvesting and ultrasound transducer applications. The research was conducted within the Proteus project in collaboration with researchers from the University of Tours, France.

We studied how sintering in different atmospheres affects the structural, microstructural, and functional properties of ~30-µm-thick films of $K_{0.5}Na_{0.5}NbO_3$ (KNN) modified with 0.38 mol% $K_{5.4}Cu_{1.3}Ta_{10}O_{29}$ and 1 mol% CuO. The films were **screen printed** on platinized alumina substrates and sintered at 1100 °C in oxygen or in the air with or without the packing powder. Thick films sintered in oxygen exhibit a piezoelectric d_{33} coefficient of 64 pm/V and an effective thickness coupling coefficient k_t of 43%, as well as very low mechanical losses of less than 0.5%, making them promising candidates for lead-free piezoelectric energy-harvesting applications. The study was conducted in collaboration with researchers from the University of Tours, France.

We continued with the preparation of **thick films using an aerosol deposition method**. The aerosol deposition system is a part of the Laboratory for the Ultracool Preparation of Complex Oxides, for which the financial support was granted by **the Director's fund ULTRACOOL project**. We focused on optimization of processing parameters of functional $0.9Pb(Mg_{1/3}Nb_{2/3})$

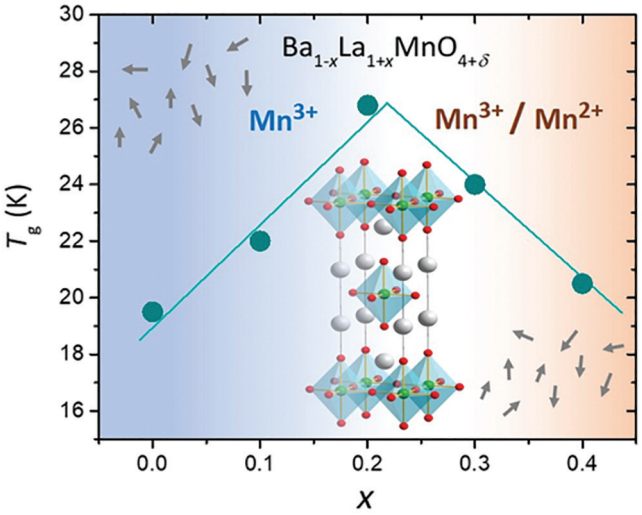

Figure 3: $Ba_{1-x}La_{1+x}MnO_{4+\delta}$ ($0 \le x \le 0.4$) series exhibits a rare anisotropic spin-glass behaviour. The freezing temperature, T_g, varies with x, reaching a maximum of 26.4(4) K for x = 0.20. The oxidation state of Mn is also dependent on x.

Prof. dr. Mojca Otoničar and Prof. dr. Tadej Rojac were awarded 'Excellent in science' by the Slovenian research agency in the field of electronic components and materials, for disclosing the influence of polar disorder on the response dynamics of ferroelectric materials. The results of this study were published in the prestigious international journal Advanced Functional Materials.

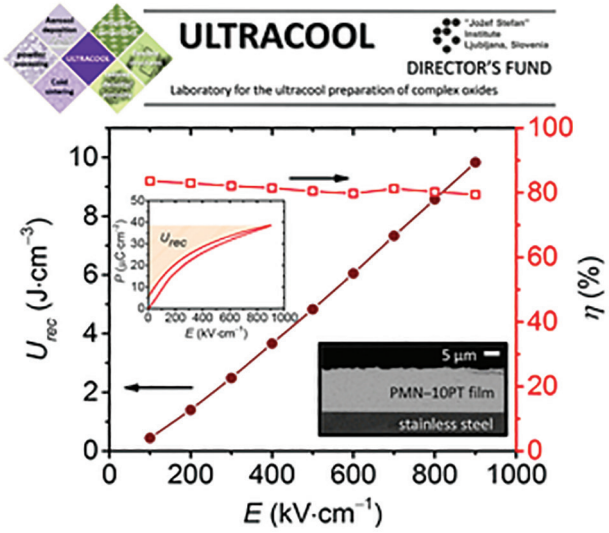

Figure 4: Room temperature energy storage properties of PMN-10PT thick films deposited on stainless steel; recoverable energy density (U_{rec}) and efficiency (η) as a function of electric field (E). Inset (bottom): microstructure of the sample in cross-section taken with a scanning electron microscope. Inset (top): Measurement of polarization (P) as a function of E.

O_3–0.1$PbTiO_3$ (PMN-10PT) thick films deposited on stainless steel. The as-deposited films withstand electric fields of 900 kV/cm and exhibit promising room-temperature energy-storage properties: the recoverable energy density reached 7.0 J/cm^3 with an energy-storage efficiency of ~70%. A post-deposition stress relaxation by annealing at 500 °C further improved the recoverable energy density, leading to 9.8 J/cm^3 with an efficiency of ~80% [Figure 4]. The energy-storage performance exhibited excellent temperature stability up to 200 °C and electric-field cycling stability up to 16 million cycles.

In collaboration with the Laboratory for Refrigeration and District Energy, the Faculty of Mechanical Engineering, University of Ljubljana we prepared multilayer composites using the aerosol-deposition method. The composite was made of Al_2O_3/Al/Al_2O_3 layers on a magnetocaloric gadolinium substrate. Such ceramic-metal multilayers represent a simple, reliable, and cost-effective approach to functionalizing and protecting existing magnetocaloric substrates and provide an excellent starting point for the development of future electrowetting-on-dielectric devices.

We progressed the research on the **cold sintering** of functional oxides in our **ULTRACOOL** laboratory, expanding the sintering from $BiFeO_3$ ceramics to (K,Na)NbO_3 perovskites and composites with piezoelectric polymers (PVDF). While the optimization of all parameters for the successful cold sintering of the ceramic compounds is still an ongoing process, the first measured electromechanical properties of the sintered ceramics are very promising and show a great perspective of cold-sintered oxides for actuator and energy-storage applications. Preliminary studies show that the main benefits of the cold sintering of ceramics are, besides the energy savings due to the low-temperature processing, their dielectric breakdown strength that allows high voltages applied to the materials without their disintegration, as well as high dielectric permittivity and low dielectric losses.

A miniature ozone generator in the form of a **monolithic three-dimensional ceramic structure** was fabricated by low-temperature co-fired ceramic (LTCC) technology utilising the principle of electric discharge. A multilayered ceramic structure with dimensions of 63.6 mm × 41.8 mm × 1.3 mm included integrated electrodes, buried channels and cavities in micro and millimetre scales. The highest ozone concentration in the LTCC-based ceramic device was around 1.1 vol. % at a voltage of about 7 kV and an oxygen flow rate of 10 ml/min. Its yield is comparable to much larger ozone generators available on the market. The LTCC technology was also implemented to fabricate a 3D structure with a buried cavity for the radio-frequency dielectric heating of polar liquids. The power used to heat water in the cavity with the volume of 0.3 mL ranges from 5 to 40 W. This novel application of dielectric heating could enable the miniaturisation of microfluidic systems. Furthermore, LTCC and high-temperature cofired ceramic (HTCC) materials were tested to fabricate three-dimensional power modules. A dual-pulse electrical test of the power modules confirmed, the quality of metallization, wire bonding, and assembly in combination with selected materials. The research was conducted in collaboration with the company KEKO Equipment and Centre of Excellence NAMASTE.

As part of the **KET4CP** project "Manufacturing of invisible interconnections from solutions of low-cost transparent conduction oxides by screen printing", with project partners RC eNeM and the Institute of Solid State Physics from Latvia, we developed a novel method for fabricating transparent zinc oxide-based thin films on glass from low-cost precursor solutions by chemical solution deposition and screen-printing processes. A high optical transmittance of over 90 % and electrical conductivity of 0.002 S/cm were obtained for 150-nm-thick films processed by screen printing. The solution-derived screen-printing process was successfully demonstrated in the large-scale production line of the company RC eNeM. The Slovenian project partners were awarded the Silver Recognition of the Zasavje Regional Chamber of Commerce in 2021 for the invention.

In collaboration with the Condensed Matter Physics Department, JSI, we studied the memory effect in polydomain liquid-crystal elastomer particles dispersed in a polymer. We confirmed the applicability of flow-induced shear stress in the alignment and deformation of liquid crystal elastomer microparticles in a viscous resin by analysing the rheological behaviour of the composite in terms of temperature and shear-rate-induced changes.

In collaboration with the Condensed Matter Department, JSI, and colleagues from Morocco and France, we investigated lead-free piezoelectric composites for energy harvesting. The composites consist of $Ba_{0.85}Ca_{0.15}Zr_{0.10}Ti_{0.90}O_3$ nanoparticles embedded in a biodegradable polymer. The piezoelectricity and ferroelectricity of the nanoparticles before and after embedding in the polymer matrix were determined by PFM. The maximum power density achieved in the prepared samples was 7.5 mW/cm^3.

In collaboration with the Slovenian company Lotrič Metrology d.o.o., we developed an economical process for producing a non-biological fluid for testing protective medical equipment according to EN 14683 in accordance with ISO 22609: 2004. The technical improvement "Process of preparing a fluid for testing medical protective equipment" was registered.

Some outstanding publications in the past year

1. Kuščer, Danjela, Drnovšek, Silvo, Levassort, Franck. Inkjet-printing-derived lead-zirconate-titanate-based thick films for printed electronics. Materials & design. 2021, vol. 198, str. 109324-1-109324-9. ISSN 0264-1275. DOI: 10.1016/j.matdes.2020.109324. [COBISS.SI-ID 36937475]
2. Benčan, Andreja, Oveisi, Emad, Hashemizadeh, Sina, Veerapandiyan, Vignaswaran K., Hoshina, Takuya, Rojac, Tadej, Deluca, Marco, Dražić, Goran, Damjanović, Dragan. Atomic scale symmetry and polar nanoclusters in the paraelectric phase of ferroelectric materials. *Nature communications*. 2021, vol. 12, no. 1, str. 3509-1-3509-9, ilustr. ISSN 2041-1723. https://www.nature.com/articles/s41467-021-23600-3, DOI: 10.1038/s41467-021-23600-3. [COBISS.SI-ID 65810179]
3. Bradeško, Andraž, Fulanović, Lovro, Vrabelj, Marko, Matavž, Aleksander, Otoničar, Mojca, Koruza, Jurij, Malič, Barbara, Rojac, Tadej. Multifunctional cantilevers as working elements in solid-state cooling devices. *Actuators*. [Online ed.]. 2021, vol. 10, no. 3, str. 58-1-58-13. ISSN 2076-0825. DOI: 10.3390/act10030058. [COBISS.SI-ID 55105027]
4. Šadl, Matej, Condurache, Oana, Benčan, Andreja, Dragomir, Mirela, Prah, Uroš, Malič, Barbara, Deluca, Marco, Eckstein, Udo, Hausmann, Daniel, Khansur, Neamul Hayet, Webber, Kyle Grant, Uršič, Hana. Energy-storage-efficient 0.9Pb($Mg_{1/3}Nb_{2/3}$)O_3–0.1$PbTiO_3$ thick films integrated directly onto stainless steel. Acta materialia, ISSN 1359-6454. [Print ed.], Dec. 2021, vol. 221, str. 117403-1-117403-11, ilustr., doi: 10.1016/j.actamat.2021.117403. [COBISS.SI-ID 81773059]
5. Otoničar, Mojca, Bradeško, Andraž, Salmanov, Samir, Chung, C. C., Jones, Jacob L., Rojac, Tadej. Effects of poling on the electrical and electromechanical response of PMN-PT relaxor ferroelectric ceramics. Open ceramics. 2021, vol. 7, 100140-1-100140-14, ilustr. ISSN 2666-5395. DOI: 10.1016/j.oceram.2021.100140. [COBISS.SI-ID 67640323]

Awards and Appointments

1. Oana-Andreea Condurache: Awarded 3rd place at the Virtual Workshop Contest: YCN Pitch me your Idea!, Young Ceramicst Network Pitch Contest
2. Oana-Andreea Condurache: Awarded 3rd place at the Student Paper Contest, 27th Annual Meeting the Slovenian Chemical Society (SKD 2021)
3. Danjela Kuščer: Silver Award for Innovation: "Manufacture of transparent electrodes from solutions of affordable conductive oxides using screen printing" awarded by Chamber of Comerce Zasavje
4. Andreja Benčan Golob, Goran Dražić, Barbara Malič, Mojca Otoničar, Tadej Rojac, Hana Uršič Nemevšek, Achievement for the paper "Connecting the Multiscale Structure with Macroscopic Response of Relaxor Ferroelectrics" was included in the selection Excellent in science ARRS 2021
5. Matej Šadl: "Alessandro de Vita" award for curiosity and multidisciplinary approach at Crossnano Cross-border Workshop in Nanoscience and Nanotecnology 2021
6. Matej Šadl: Awarded 2nd place at student competition "2021 Joint ISAF ISIF-PMF virtual conference"

Patent granted

1. Vid Bobnar, Barbara Malič, Aleksander Matavž, A method for producing polymeric surface modification layers, SI25887 (A), Slovenian Intellectual Property Office, 31. 03. 2021.

INTERNATIONAL PROJECTS

1. H2020 - ATHENA; Implementing Gender Equality Plans to Unlock Research Potential of RPOs and RFOs in Europe
   Prof. Barbara Malič
   European Commission
2. H2020 - QMatCh; Towards Quantum States of Matter via Chemistry under Extreme Conditions
   Asst. Prof. Mirela Dragomir
   European Commission
3. Cold Sintering of Complex Oxide Materials
   Dr. Mojca Otoničar
   Slovenian Research Agency
4. Low Bandgap Ferroelectric Solar Cell Absorbers: Synthesis and Characterization
   Prof. Hana Uršič Nemevšek
   Slovenian Research Agency
5. Interface Stability of Piezoelectric Ceramic Oxides
   Prof. Tadej Rojac
   Slovenian Research Agency
6. Environmental Benign Sodium Potassium Niobate-based Thick Films for Piezoelectric Energy Harvesting Applications
   Prof. Danjela Kuščer Hrovatin
   Slovenian Research Agency
7. Multiferroics for Solid-State Cooling Applications
   Prof. Hana Uršič Nemevšek
   Slovenian Research Agency

8. Processing – Structure - Properties Study of Environmentally Friendly Piezoelectric Nanoparticles of Tailored Surface Morphology
   Prof. Andreja Benčan Golob
   Slovenian Research Agency
9. High-Pressure Synthesis and Characterization of Selected Ferroics
   Dr. Kristian Radan
   Slovenian Research Agency
10. Crystal Growth and Magnetic Properties of Double Perovskites
    Asst. Prof. Mirela Dragomir
    Slovenian Research Agency
11. Porous Lead-Free Relaxor Ferroelectric Films for Energy Storage
    Prof. Hana Uršič Nemevšek
    Slovenian Research Agency
12. Environment-Friendly Ferroelectric Oxide Thin Films for Energy Harvesting and Energy Storage Applications
    Prof. Barbara Malič
    Slovenian Research Agency
13. Realizing In-Situ Studies of Dynamic Mechanisms in Ceramic Oxides in the Reducing Environment in a Transmission Electron Microscope
    Prof. Andreja Benčan Golob
    Slovenian Research Agency
14. Engineering the Microstructure and Performance of Lead-Free Piezoelectrics for Energy Harvesting
    Prof. Barbara Malič
    Slovenian Research Agency
15. Environment-Friendly Processing of Lead-Free Functional-Oxide Thin Films for Micro-Electro-Mechanical Systems (MEMS) Applications
    Prof. Barbara Malič
    Slovenian Research Agency
16. Smart Design of New Multifunctional Composites with Optimized Energy Transfer Across Interfaces between the Components (SoMwOT)
    Prof. Barbara Malič
    Slovenian Research Agency

RESEARCH PROGRAMME

1. Electronic Ceramics, Nano-, 2D and 3D Structures
   Prof. Barbara Malič

R & D GRANTS AND CONTRACTS

1. In situ atomic level Quantitative Scanning Transmission Electron Microscopy of Functional Materials
   Prof. Andreja Benčan Golob
2. TCCbuilder: An open-source simulation tool for thermal control circuits
   Prof. Barbara Malič
3. Multicaloric cooling
   Prof. Hana Uršič Nemevšek
4. Electrocaloric elements for active cooling of electronic circuits
   Prof. Barbara Malič
5. Advanced inorganic and organic thin films with enhanced electrically-induced response
   Prof. Barbara Malič
6. The quest for high-temperature superconductvity and exotic magnetism in fluoridoargentates(II)
   Asst. Prof. Mirela Dragomir
7. Designing functionality of lead-free ferroelectrics through domain wall engineering
   Prof. Andreja Benčan Golob
8. The cool way to polarize
   Dr. Mojca Otoničar
9. Engineering of relaxor ferroelectric thin films for piezoelectric and energy storage applications
   Prof. Tadej Rojac
10. Structures of elusive noble-gas compounds elucidated by 3D electron diffraction
    Asst. Prof. Mirela Dragomir
11. All in One: Multi-caloric and Multi-scavenging Elements for Green Future
    Prof. Hana Uršič Nemevšek
12. Enhanced piezoelectricity via structural disorder in polycrystalline relaxor ferroelectrics
    Prof. Tadej Rojac
13. MIcrofluidic Sensor System for PESticides detection (MISS PES)
    Prof. Danjela Kuščer Hrovatin
14. Flexible elements with multi-physical properties
    Prof. Hana Uršič Nemevšek
15. Process intensification for the continuous synthesis of high purity hydrogen peroxide using a micro-scale electrocatalytic reactor
    Prof. Barbara Malič

VISITORS FROM ABROAD

1. Maria Karypidou, Aristotle University of Thessaloniki, Thessaloniki, Greece, July 2– August 29, 2021
2. Maximilian Gehringer, Technische Universität Darmstadt, Darmstadt, Germany, September 1 – October 29, 2021
3. Reham Elsurhafa, University of Ankara, Ankara, Turkey, September 13– November 24, 2021
4. Matthieu Fricaudet, Universite Paris-Saclay, Paris, France, October 22 – 29, 2021
5. Maxime Vallet, Universite Paris-Saclay, Paris, France, November 25 – December 4, 2021
6. Prof. Brahim Dkhil, Centrale Supélec, Université Paris-Saclay, Paris, France, December 19 – 21, 2019

STAFF

Researchers
1. Prof. Andreja Benčan Golob
2. Dr. Mirela Dragomir
3. Prof. Goran Dražić*
4. Prof. Danjela Kuščer Hrovatin
5. Dr. Kostja Makarovič*
6. **Prof. Barbara Malič, Head**
7. Dr. Mojca Otoničar
8. Prof. Tadej Rojac
9. Prof. Hana Uršič Nemevšek

Postdoctoral associates
10. *Dr. Uroš Prah, on leave since 15.06.21*
11. *Dr. Kristian Radan, 01.02.21, transferred to Department K1*

Postgraduates
12. Matic Belak Vivod, B. Sc.
13. Oana Andreea Condurache, M. Sc.
14. Sabi William Konsago, M. Sc.
15. Barbara Repič, B. Sc.
16. Samir Salmanov, M. Sc.
17. Matej Šadl, B. Sc.
18. Lia Šibav, B. Sc.
19. Katarina Žiberna, B. Sc.

Technical officers
20. Silvo Drnovšek, B. Sc.
21. Brigita Kmet, B. Sc.
22. Maja Koblar, B. Sc.

Technical and administrative staff
23. Andrej Debevec
24. Tina Ručigaj Korošec, B. Sc.

Note:
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