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 and conductive oxides. The emphasis is on the creation of the properties through synthesis and structure on the nano-, micro- and macro-levels. The group also works on the principles of basic technologies of ceramic pressure sensors, ceramic MEMS and flexible electronics.

Head:
Prof. Barbara Malič

In the framework of **lead-free piezoelectric ceramics**, we continued the research of sodium potassium niobate (**$K_{0.5}Na_{0.5}NbO_3$, KNN) based** materials, which could replace efficient lead-based piezoelectrics. The focus has been on the control of chemical homogeneity in multi-metal-modified KNN ceramics as the key to achieving reproducible functional properties.

We continued with the work on **polycrystalline $BiFeO_3$**. In collaboration with researchers from the Department for Nanostructured Materials (Jožef Stefan Institute, JSI), and the National Institute of Chemistry, using a combined characterisation of $BiFeO_3$ on the nano and atomic scales, we revealed a pinning mechanism associated with conductive domain walls (DWs), whose origin lies in the dynamic coupling of the p-type defects gathered in the DW regions with the DW displacements under an applied electric field. We confirmed that the degree of defect ordering at the walls, which affect the DW local structure and conductivity, can be tuned by the cooling rate used during the annealing [Figure 1].

Owing to the high electrical conductivity and coercive field, the poling of $BiFeO_3$ ceramics is notoriously difficult. In collaboration with colleagues from Australia (University of New South Wales), China (Tsinghua University) and Norway (Norwegian University of Science and Technology), we performed in-situ structural X-ray diffraction analysis that aimed to understand the poling behaviour of $BiFeO_3$. A peculiar inverse time-dependent trend in the microstrain and non-180° domain texture was observed during poling, attributed to the effect of conductive domain walls in redistributing the internal electric fields inside the grains of the ceramics. The results clarify, for the first time, the microstrain mechanisms in $BiFeO_3$ during static field loading and act as a guideline for tailoring local conductivities in view of the poling behaviour and the post-poling strain relaxation.

Experimental studies on $BiFeO_3$ ceramics modified with a controlled amount of cobalt ions revealed details of the ferroelectric hardening behaviour of this perovskite. The data show two distinct hardening mechanisms related to i) domain-wall pinning effects arising from oxygen-vacancy defect complexes, which are known to dominate the hardening behaviour of hard $Pb(Zr,Ti)O_3$ (PZT), and ii) less-common pinning effects associated with the accumulation of electronic defects inside DW regions. The mechanism (i) plays a dominant role in the polarization switching properties of $BiFeO_3$ at high electric fields, while the mechanism (ii) has a crucial effect on the weak-field piezoelectric response of $BiFeO_3$. In particular, the charges present at domain walls lead to a counterintuitive enhancement of the piezoelectric response of $BiFeO_3$. This happens due to a re-distribution of the internal fields in different grain-families of the polycrystalline matrix, triggered by the charge migration along the domain walls, which effectively enhances the domain-wall contribution in those grains in which the field is increased. The results explain the long-standing question of the complex hardening behaviour of $BiFeO_3$ and provide the means for its control with cobalt or similar acceptor dopants.

The study that reveals a unique dynamic response of relaxor ferroelectrics to external fields, reflecting their complex structure in terms of the hierarchical texture of ferroelectric domains on top of the disorder at the atomic scale, both of which strongly affect the mobility of the domain walls, was published in the journal *Advanced Functional Materials.*

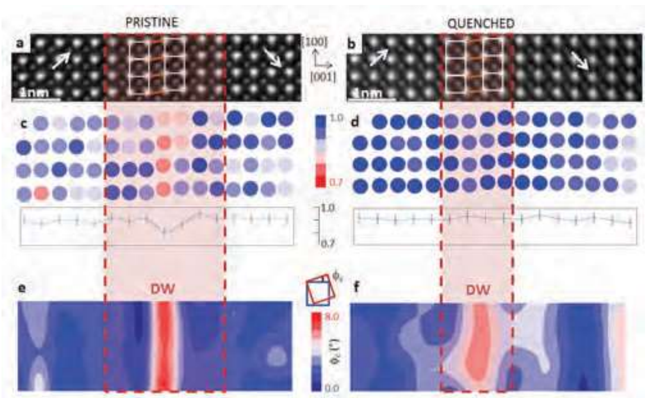

Figure 1: Atomic structure of domain walls (DWs) in pristine and quenched $BiFeO_3$
HAADF-STEM image of a 109° DW in (a) pristine and (b) quenched $BiFeO_3$ with corresponding (c, d) normalized distribution map of Bi-column intensities and average intensity profiles across the DW region and (e,f) lattice-strain maps represented in terms of lattice-distortion angle (φc). The DW region is indicated by a dashed red box. In panels (a,b) the arrows indicate the direction of the Fe displacements from the centre of the Bi sublattice; enlarged distances between the sheared Bi atoms columns (shear lattice strain) inside the DWs are indicated by red lines.

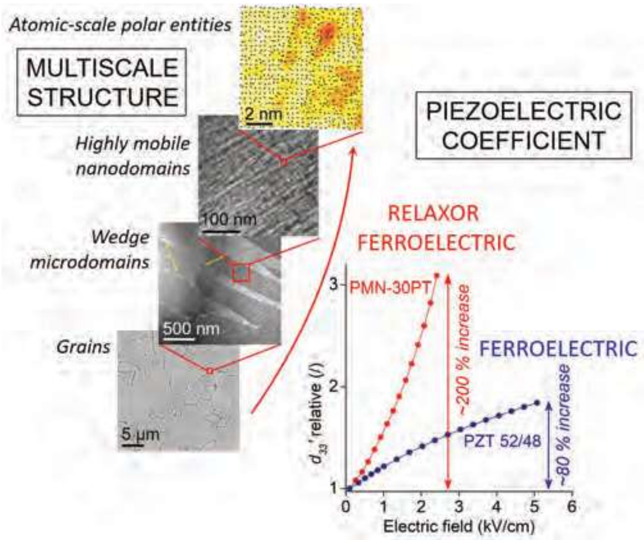

Figure 2: Anomalously large nonlinear piezoelectric response is identified in relaxor ferroelectric PMN-xPT ceramics, revealing a previously unrecognized softening mechanism arising from the highly mobile nanodomain walls, facilitated by the nanoscale polar character and lattice strain disorder, common to relaxors.

A study that reports on a pinning mechanism associated with conductive DWs, whose origin lies in the dynamic coupling of the p-type defects gathered in the DW regions with the DW displacements under an applied electric field, was published in the journal *Nature Communications.*

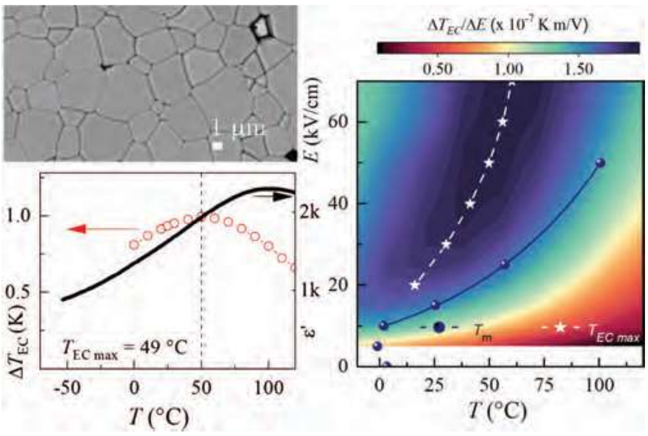

Figure 3: Correlation between the dielectric permittivity (ε) and electrocaloric (EC) temperature change (DT_{EC}) in $Pb(Mg_{1/3}Nb_{2/3})O_3$ (PMN). Left: microstructure of PMN (top) and temperature dependence of ε (@10 kHz) and DT_{EC} at the applied field of 50 kV/cm revealing that the peak of the dielectric permittivity (T_m) is at a higher temperature than the maximum DT_{EC}. Right: EC responsivity ($DT_{EC}/\Delta E$) in the frame of the electric field–temperature phase diagram of PMN.

In collaboration with colleagues from the Norwegian University of Science and Technology, Trondheim, Norway and from the National Institute of Research and Development for Technical Physics, Iasi, Romania, we investigated the magnetic properties of multiferroic $Bi_{0.88}Gd_{0.12}FeO_3$ ceramics. Using piezo-response force microscopy (PFM) and magnetic force microscopy (MFM) we confirmed the intrinsic multiferroicity in the perovskite phase with the coexistence of ferroelectric/ferroelastic and ferromagnetic domains. A strong magnetic hysteresis and high magnetization were produced by heating the sample to 1000 °C due to degeneration of the perovskite phase into iron oxide inclusions. These results highlighted the importance of sample processing, thermal history and the thermodynamic stability of secondary phases when considering the magnetic performance of $Bi_{0.88}Gd_{0.12}FeO_3$ ceramics.

In collaboration with colleagues from the Technical University of Darmstadt in Germany we prepared and characterized **lead-based piezoelectric ceramics** $Pb(Zr_{0.7}Ti_{0.3})O_3$ with grain sizes in the range 3.9 to 10.4 μm. A decrease in the grain size was accompanied by a reduction in the electromechanical properties at switching fields and an increase in the relative permittivity. The PFM analysis indicated an increased local coercive voltage near the grain boundaries. The grain-size-dependent changes in the properties were related to the strained material volume close to the grain boundaries exhibiting reduced DW dynamics.

Despite numerous proposed models and diverse explanations, the origins of the high piezoelectricity in **lead-based relaxor ferroelectrics**, exemplified by $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMN-PT), are still under debate. Using a multiscale analytical approach and a wide range of PMN-PT ceramic compositions, we managed to explain a piece of the puzzle, showing the key role of the so-called, low-angle domain walls to the extrinsic piezoelectric and dielectric response of PMN-PT. The high mobility of these interfaces is intimately linked to the relaxor disorder, hence their dynamics dominate the response of monoclinic PMN-rich compositions. The study was performed in collaboration with colleges from the Department of Systems and Control (JSI), the National Institute of Chemistry, the North Carolina State University, USA, and the Swiss Federal Institute of Technology in Lausanne, Switzerland. The new softening mechanism opens up a plethora of possibilities for designing high-performance piezoceramics via relaxor disorder [Figure 2].

In collaboration with colleagues from the Condensed Matter Department, JSI, and the Technical University of Darmstadt, Germany, we studied the correlation between the dielectric permittivity and the electrocaloric (EC) temperature change (DT_{EC}) in (1-x)$Pb(Mg_{1/3}Nb_{2/3})O_3$–x$PbTiO_3$ (PMN-100xPT, with x = 0, 0.05, and 0.10). Both the peak permittivity temperature and the temperature at which the DT_{EC} is the highest, increased with increasing PT content for a given electric field (E). The peak of the dielectric permittivity is always at a higher temperature than the maximum DT_{EC} and the temperature gap between both maxima progressively increases with an increasing applied field. This is even more evident above the threshold field, which induces the long-range-ordered ferroelectric state. The results are explained in the frame of the electric field–temperature phase diagram of relaxor systems. Our study revealed that the temperature of the peak permittivity only roughly indicates the temperature of the upper boundary of the temperature–electric field window where the EC responsivity ($DT_{EC}/\Delta E$) is the highest [Figure 3].

We proceeded with the preparation and investigation of new **$Pb(Fe_{0.5}Nb_{0.5})O_3$-based** single-phase **multiferroic and multicaloric ceramic** materials. The $Pb(Fe_{0.5}Nb_{0.5})O_3$–$BiFeO_3$ (PFN–BFO) solid solutions offer a bridge between the low-temperature phase transitions of PFN and the high-temperature phase transitions of BFO, which enables the tailoring of the multiferroic properties. Several

(1-x)PFN–xBFO (x = 0–0.5) compositions were prepared by mechanochemical synthesis from constituent oxides, followed by thermal treatment. The addition of BFO to PFN led to an enhanced relaxor-like behavior, which was systematically investigated using a wide range of macroscopic and local characterization techniques [Figure 4]. In addition to promising relaxor-ferroelectric properties, the PFN–BFO system also exhibits magnetic properties. The 0.8PFN–0.2BFO composition possesses both ferroic anomalies at room temperature, and is therefore one of the first single-phase multiferroic materials. Further investigation of caloric properties revealed its multicaloric nature, and with the targeted doping of 0.8PFN–0.2BFO with Gd and Mn ions resulting in the coexistence of the highest electrocaloric and magnetocaloric effects to date in a single-phase material.

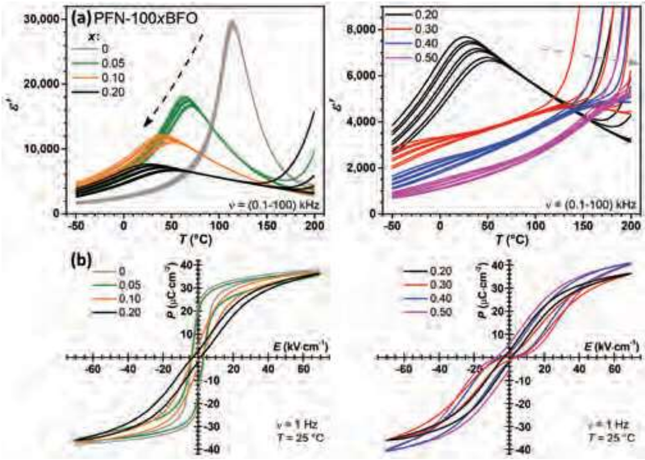

Figure 4: Pb($Fe_{0.5}Nb_{0.5}$)O_3–$BiFeO_3$ (PFN–BFO) solid solutions (a) Temperature and frequency dependences of the real component of relative permittivity, (b) P–E hysteresis loops.

In collaboration with researchers from Canada (McMaster University and Université de Sherbrooke) and the USA (Oak Ridge National Laboratory) we carried out a comprehensive study of underdoped and overdoped $La_{1.6-x}Nd_{0.4}Sr_xCuO_4$ **cuprate superconductors**. We were able to map the structural and superconducting phase transitions that take place as a function of temperature and hole doping, p, and to propose an updated temperature–doping phase diagram for $La_{1.6-x}Nd_{0.4}Sr_xCuO_4$. In addition, we also found out that the structural and pseudogap critical points are well separated in this system, similar to the parent compound, $La_{1-x}Sr_xCuO_4$.

Another focus of our research was on the double perovskite La_2LiMoO_6. Our study performed in collaboration with scientists from the Oak Ridge National Laboratory, University of Tennessee, USA, and McMaster University and University of Winnipeg, Canada, elucidated the magnetic ground state in this material. In contrast to other Mo^{5+} double perovskites, we found that La_2LiMoO_6 is the first one showing long-range **antiferromagnetic** order with a T_N of 18 K, as evidenced by resolution-limited magnetic Bragg peaks. These differences might be explained on the basis of the Mo-O coordination polyhedra that further determines the nature of the orbital ordering.

Hybrid **organic-inorganic ferroelectrics**, such as those based on tetramethylammonium bromotrichloroferrate ($N(CH_3)_4[FeBrCl_3]$), hold promises as the next generation of functional materials for sensing and energy-harvesting applications. While these so-called plastic crystals are structurally well understood, their essential ferroelectric and electromechanical properties are largely unknown. Through a collaboration with the group from the Norwegian University of Science and Technology in Trondheim we characterized and recently reported the functional properties of N(CH3)4[FeBrCl3] plastic crystals. The data suggested a classic ferroelectric response arising from domain switching with a contribution from leakage current observed in the low-frequency polarization response. The strong dependence of the strain response on the driving frequency and field cycling indicated pinning effects mediated by point defects. The results highlight the need for a further investigation of the defect chemistry in this promising group of hybrid materials.

The achievement Innovative approaches to controlled functional responses of multiferroics was selected for 'Excellent in Science 2020' recognition by Slovenian Research Agency. It is the result of collaboration of researchers from Departments of Electronic Ceramics, Condensed Matter Physics, Nanostructured Materials (JSI), National Institute of Chemistry, and colleagues from Poland and the US.

In collaboration with the Department for Gaseous Electronics (JSI) we investigated the ferroelectric domain structure of undoped and Cu-doped $Sn_2P_2S_6$ single crystals by PFM. In both cases a-few-hundred-nanometres-large ferroelectric domains were observed; however, in the undoped samples, the domains were more rhombus-like with sharp edges, while in Cu-doped samples the domains were more irregular in shape. The PFM amplitude and phase hysteresis loops indicated a good domain-switching ability of both types of single crystals.

In collaboration with the Institute for Multidisciplinary Research, University of Belgrade, Serbia, we studied the influence of strontium doping on the phase composition, microstructure and functional properties of **sodium potassium niobate thin films**. The solution-derived films were deposited on platinized silicon substrates and rapid thermally annealed. Sr-doping (0.5, 1 mol%) contributed to the fine-grained and dense thin-film microstructure, and improved ferroelectric characteristics. Benefiting from improved leakage current characteristics at high electric fields, the films showed a high local piezoelectric activity (d_{33} ~110 pm/V) determined by piezo-response force microscopy (PFM) and an ability to reach a fully saturated local hysteresis.

The research of piezoelectric thick films was performed in collaboration with researchers from the GREMAN/CNRS/University of Tours, France. We continued the study of the **electrophoretic deposition (EPD) of thick films** for the processing of environmentally benign $(K_{0.5}Na_{0.5})_{0.99}Sr_{0.005}NbO_3$ (KNNSr) thick films on metalized ceramic substrates for energy harvesting. The dielectric, ferro- and piezoelectric properties of the thick films increased with the increasing sintering temperature, regardless of the sintering atmosphere. The KNNSr thick films sintered at 1100 °C for 2 hours in oxygen were 28 μm thick with k_t of 40 %, similar to that for a bulk ceramic with the same nominal composition.

We continued with the processing of $Pb(Zr,Ti)O_3$ (PZT) based thick-film structures by **piezoelectric inkjet printing**, a computer-controlled, low-cost and environmentally benign patterning technology. By adjusting the surface tension, viscosity and wetting properties of the aqueous suspension (ink) and the printing conditions, we prepared uniform, defect-free patterns with dimensions of 4 mm × 4 mm on metalized alumina substrates. After sintering at 850 °C the 15-μm-thick film with a relative density of 86 % and a grain size up to ~2 μm had an effective thickness coupling factor k_t of 46 %, which is comparable to that of the bulk ceramic.

Prof. Barbara Malič received the Zois Award for achievements in the research of electrocaloric ceramic materials.

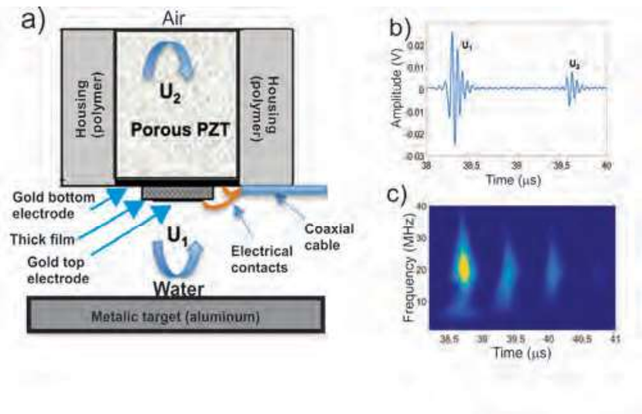

Figure 5: a) Schematic of the acoustic measurements of ultrasound transducer at frequencies over 10 MHz; b) time responses (U1 and U2 signals) and c) its wavelet transforms (c).

Together with colleagues from Tours, we developed a prototype of a miniature, high-frequency ultrasonic transducer and established a method for measuring the acoustic properties of backing in water in the frequency range of 15 to 25 MHz. We were the first to report on this effective method. The transducer consisted of a PZT thick film and a gold electrode that were screen-printed on a backing. The backing consisted of a porous PZT ceramic, and was fabricated by a sacrificial template method combined with a hetero-coagulation process. The backing with 30 % porosity and spherical pores with a diameter of 10 μm had an attenuation coefficient α of 33 dB/mm at 19 MHz, which is three times higher than the values reported in the literature. The PZT backing with a high value of α effectively dampens the ultrasonic waves, which makes it possible to reduce its thickness and thus the total size of the transducer suitable for medical investigations [Figure 5].

We continued with the preparation of **thick films using the aerosol deposition method**. The aerosol deposition system is a part of the Laboratory for the ultracool preparation of complex oxides, for which financial support was granted by **the Director's fund ULTRACOOL project**. In April 2020 the project was successfully completed [Figure 6]. Current research related to aerosol deposition is focused on the optimization of processing parameters of functional PMN-PT thick films on metal and polymer substrates.

In the scope of the ULTRACOOL laboratory, the dedicated cold-sintering press made it possible to perform a series of sintering experiments of the effects of pressure, temperature and liquids used in a **cold-sintering** process of the multiferroic BFO ceramic. The optimization of parameters led to ceramics with improved properties compared to the conventional high-temperature sintering from the inclusion of a secondary phase point of view, as well as lower conductivity and larger field-induced strains.

The aerosol deposition method was the main method used in the frame of a **European project** Key Enabling Technologies for Clean Production **KET4CP** - *Alternative process for producing metal electrodes on ceramic electronic components* with the partners Stelem d.o.o., Slovenia, Bay Zoltán Nonprofit Ltd., Hungary, and the JSI.

In the **KET4CP** project "Developing a new clean manufacturing process for ceramic pressure sensors" the partners KEKO Equipment, Slovenia, Hahn-Schickard, Germany and JSI a ceramic pressure-sensing element with the operation up to 500 °C was designed, developed and successfully tested. Compared to the conventional alumina-based sensing elements the use of LTCC (Low-Temperature Co-fired Ceramic) materials and technology leads to a 'cleaner' manufacturing process based on lower energy and material consumption, and reduced generation of waste and pollution.

In 2020, two European KET4CP projects, in which we were developing new products and technologies for Slovenian companies, were successfully concluded.

In the **KET4CP** project "Manufacturing of invisible interconnections from solutions of low-cost transparent conduction oxides by screen printing" we collaborate with RC eNeM, Slovenia and Institute of Solid State Physics from Latvia. We have been studying procedures for the deposition of zinc-oxide-based films on glass from solution by Chemical Solution Deposition and screen-printing technology.

Some outstanding publications in the past year

1. Otoničar, Mojca, Bradeško, Andraž, Fulanović, Lovro, Kos, Tomaž, Uršič Nemevšek, Hana, Benčan, Andreja, Cabral, Matthew, Henriques, Alexandra, Jones, Jacob L., Riemer, Lukas, Damjanović, Dragan, Dražić, Goran, Malič, Barbara, Rojac, Tadej. Connecting the multiscale structure with macroscopic response of relaxor

ferroelectrics. **Advanced functional materials**, ISSN 1616-301X, [in press] 2020, 13 str., doi: 10.1002/adfm.202006823. [COBISS.SI-ID 32051715]

2. Benčan, Andreja, Dražić, Goran, Uršič Nemevšek, Hana, Makarovič, Maja, Komelj, Matej, Rojac, Tadej. Domain-wall pinning and defect ordering in $BiFeO_3$ probed on the atomic and nanoscale. **Nature communications**, ISSN 2041-1723, 2020, vol. 11, str. 1762-1-1762-8, doi: 10.1038/s41467-020-15595-0. [COBISS.SI-ID 33296423]
3. Prah, Uroš, Dragomir, Mirela, Rojac, Tadej, Benčan, Andreja, Broughton, Rachel, Chung, Ching-Chang, Jones, Jacob L., Sherbondy, Rachel, Brennecka, Geof, Uršič Nemevšek, Hana. Strengthened relaxor behavior in $(1-x)Pb(Fe_{0.5}Nb_{0.5})O_3xBiFeO_3$. **Journal of materials chemistry. C**, Materials for optical and electronic devices, ISSN 2050-7526. [Print ed.], 2020, vol. 8, no. 10, str. 3452–3462, doi: 10.1039/C9TC05883D. [COBISS.SI-ID 33157415]
4. Kuščer, Danjela, Bustillo, Julien, Bakarič, Tina, Drnovšek, Silvo, Lethiecq, Marc, Levassort, Franck. Acoustic properties of porous lead zirconate titanate backing for ultrasonic transducers. **IEEE transactions on ultrasonics, ferroelectrics, and frequency control**, ISSN 0885-3010, 2020, vol. 67, no. 8, str. 1656-1666, doi: 10.1109/TUFFC.2020.2983257. [COBISS.SI-ID 33285671]
5. Fulanović, Lovro, Bradeško, Andraž, Novak, Nikola, Malič, Barbara, Bobnar, Vid. Relation between dielectric permittivity and electrocaloric effect under high electric fields in the $Pb(Mg_{1/3}Nb_{2/3})O_3$ and $Pb(Mg_{1/3}Nb_{2/3})O_3$–$PbTiO_3$ ceramics. **Journal of applied physics**, ISSN 0021-8979, 2020, vol. 127, no. 18, str. 184102-1-184102-7, doi: 10.1063/5.0002096. [COBISS.SI-ID 14687491]

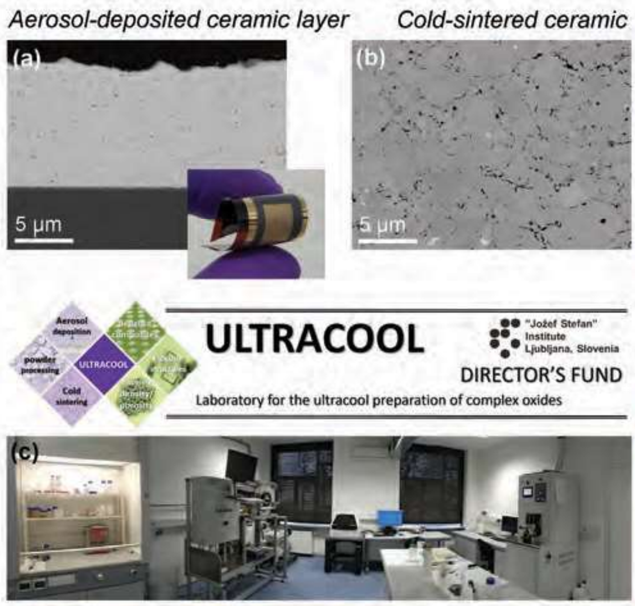

Figure 6: Successfully equipped and tested ULTRACOOL laboratory, supported by the 2017 Director's fund, for the preparation of functional materials at low temperatures. (a) dense ceramic layer prepared by aerosol deposition method. (b) Multiferroic $BiFeO_3$ ceramic prepared by the cold sintering method. (c) panoramic view of the laboratory.

Awards and Appointments

1. Andreja Benčan Golob, Andraž Bradeško, Mirela Dragomir, Goran Dražić, Maja Makarovič, Barbara Malič, Uroš Prah, Tadej Rojac, Hana Uršič Nemevšek: Achievement Excellent in Science 2020 for Innovative approaches to the control of functional responses of multiferroices, Slovenian Research Agency
2. Mirela Dragomir: Seal of Excellence for project application QMAT – Towards Quantum States of Matter via Chemistry under Ambient and Extreme Conditions, European Commission
3. Barbara Malič: Zois Award for top achievements in the field of electrocaloric ceramic, Government of the Republic of Slovenia

INTERNATIONAL PROJECTS

1. Minor Services - Foreign Customers
Prof. Barbara Malič
2. Laboratory Measurements
Prof. Barbara Malič
Tdk Electronics Gmbh & Co Og
3. Electrical Measurements
Prof. Tadej Rojac
Tdk Electronics Gmbh & Co Og
4. Laboratory Measurements
Prof. Andreja Benčan Golob
Tdk Electronics Gmbh & Co Og
5. Atomic Force Microscope Measurements
Asst. Prof. Hana Uršič Nemevšek
Tdk Electronics Gmbh & Co Og
6. Cold Sintering of Complex Oxide Materials
Dr. Mojca Otoničar
Slovenian Research Agency
7. Low Bandgap Ferroelectric Solar Cell Absorbers: Synthesis and Characterization
Asst. Prof. Hana Uršič Nemevšek
Slovenian Research Agency
8. Interface Stability of Piezoelectric Ceramic Oxides
Prof. Tadej Rojac
Slovenian Research Agency
9. Environmental Benign Sodium Potassium Niobate-based Thick Films for Piezoelectric Energy Harvesting Applications
Prof. Danjela Kuščer Hrovatin
Slovenian Research Agency
10. Understanding Size Effects in Antiferroelectric Materials
Dr. Mojca Otoničar
Slovenian Research Agency
11. Multiferroics for Solid-State Cooling Applications
Asst. Prof. Hana Uršič Nemevšek
Slovenian Research Agency
12. Processing – Structure - Properties Study of Environmentally Friendly Piezoelectric Nanoparticles of Tailored Surface Morphology
Prof. Andreja Benčan Golob
Slovenian Research Agency
13. High-Pressure Synthesis and Characterization of Selected Ferroics
Dr. Kristian Radan
Slovenian Research Agency
14. Crystal Growth and Magnetic Properties of Double Perovskites
Dr. Mirela Dragomir
Slovenian Research Agency
15. Porous Lead-Free Relaxor Ferroelectric Films for Energy Storage
Asst. Prof. Hana Uršič Nemevšek
Slovenian Research Agency
16. Environment-Friendly Ferroelectric Oxide Thin Films for Energy Harvesting and Energy Storage Applications
Prof. Barbara Malič
Slovenian Research Agency

17. 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
18. Engineering the Microstructure and Performance of Lead-Free Piezoelectrics for Energy Harvesting
Prof. Barbara Malič
Slovenian Research Agency
19. Environment-Friendly Processing of Lead-Free Functional-Oxide Thin Films for Micro-Electro-Mechanical Systems (MEMS) Applications
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. Multicaloric cooling
Asst. Prof. Hana Uršič Nemevšek
2. Electrocaloric elements for active cooling of electronic circuits
Prof. Barbara Malič
3. Advanced inorganic and organic thin films with enhanced electrically-induced response
Prof. Barbara Malič
4. The quest for high-temperature superconductvity and exotic magnetism in fluoridoargentates(II)
Dr. Mirela Dragomir
5. Designing functionality of lead-free ferroelectrics through domain wall engineering
Prof. Andreja Benčan Golob
6. The cool way to polarize
Dr. Mojca Otoničar
7. Engineering of relaxor ferroelectric thin films for piezoelectric and energy storage applications
Prof. Tadej Rojac
8. Domain engineered ferroelectric ceramic layer elements for efficient energy harvesting and energy conversion applications
Prof. Barbara Malič
9. Strategic Research & Innovation Partnership Factories of the Future (SRIP FoF)
Prof. Barbara Malič
Ministry of Economic Development and Technology
10. Reimbursement of costs of scientific publications in golden open access for 2019, 2020
Prof. Barbara Malič
Slovenian Research Agency
11. Stay of Oana Andreea Condurache in AI CUZA Iasi, Romania - Functional Characterisation of Potassium Sodium Niobate-Based and Bismuth Ferrite-Based Ceramics
Oana Andreea Condurache
Jecs Trust

NEW CONTRACTS

1. Developing clean manufacturing process for ceramic pressure sensors
Asst. Prof. Hana Uršič Nemevšek
Stelem d. o. o. Žužemberk
2. Developing clean manufacturing process for ceramic pressure sensors
Prof. Barbara Malič
Keko - Oprema d. o. o. Žužemberk
3. Development of new production process for manufacturing of invisible interconnections from solutions of low-cost transparent conduction oxides by screen printing
Prof. Danjela Kuščer Hrovatin
Razvojni center Enem Novi Materiali d. o. o.

VISITORS FROM ABROAD

1. Kristijan Kovačić, Bjelovar University of Applied Sciences, Bjelovar, Croatia, 16 September 2019 to 13 March 2020
2. Anja Mirjanić, University of Banja Luka, Faculty of Natural Sciences and Mathematics, Bosnia and Hercegovina, 17 October 2019 to 30 November 2020
3. Prof. Dragan Damjanovic, École polytechnique fédérale de Lausanne - EPFL, Lausanne, Switzerland, 5-11 January 2020
4. Dr Marco Deluca, Materials Center Leoben Forschung GmbH, Leoben, Austria, 9-11 January 2020
5. Vignaswaran Kaliyaperumal Veerapandiyan, Materials Center Leoben Forschung GmbH, Leoben, Austria, 9-11 January 2020
6. Konstantin Rokas, University of Ioannina, Ioannina, Greece, 13 January to 13 March 2020
7. Gianni Ferrero, Meggitt Sensing Systems, Kvistgaard, Denmark, 13 January 2020 to 16 March 2020 and 1–27 October 2020
8. Mustafa Çağrı Bayir, Gebze Technical University, Department of Materials Science and Engineering, Kocaeli, Turkey, 3 February to 12 March 2020
9. Katharina Schuldt, Techniche Universität Darmstadt, Darmstadt, Germany, 7–12 March 2020

STAFF

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

Postdoctoral associates
8. *Dr. Andraž Bradeško, left 01.07.20*
9. Dr. Mirela Dragomir
10. Dr. Kostja Makarovič*
11. Dr. Kristian Radan

Postgraduates
12. Matic Belak Vivod, B. Sc.
13. Oana Andreea Condurache, B. Sc.
14. Sabi William Konsago, B. Sc.
15. *Maja Makarovič, B. Sc., left 09.11.20*
16. Dr. Uroš Prah
17. Samir Salmanov, B. Sc.
18. Matej Šadl, B. Sc.
19. Lia Šibav, B. Sc.
20. Katarina Žiberna, B. Sc.

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21. Silvo Drnovšek, B. Sc.
22. Brigita Kmet, B. Sc.
23. *Marija Šebjan Pušenjak, B. Sc., left 01.10.20*

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

Note:
* part-time JSI member