ELECTRONIC CERAMICS DEPARTMENT

K-5

The Electronic Ceramics Department is active in research on the synthesis, properties and applications of materials for electronics and energetics, mainly complex multifunctional materials and structures. The materials of interest include ceramic piezoelectrics, ferroelectrics, relaxors, multiferroics and conductive oxides. The emphasis is on developing properties based on 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 materials**, we were particularly interested in alkali-niobate-based ceramics, which are still considered as one of the most important candidates for the replacement of lead-based perovskites in piezoelectric applications. In collaboration with the Montanuniversität Leoben, Austria, University of Nova Gorica, National Institute of Chemistry, Ljubljana, and University of Ljubljana we investigated the influence of strontium additions on the phase composition, microstructure and crystal structure of the $K_{0.5}Na_{0.5}NbO_3$ (KNN) solid solution. By increasing the amount of strontium a decrease of the grain size, segregation of the secondary phase and a change of the KNN crystal structure from monoclinic to cubic symmetry were observed.

Within the activities on **lead-based piezoelectric ceramics**, in the frame of the 7FP EU project CERAMPOL and in collaboration with the company HIPOT-RR, we continued our study of the fabrication of waste-water cleaning systems. The system is based on the integration of piezoelectric Pb(Zr,Ti)O_3 (PZT) actuators onto a porous ceramic substrate. With the support of the numerical modelling and vibration measurements of a substrate with integrated piezoelectric actuators, we defined the optimal geometry of the system. The vibration system was tested under real operating conditions by the project partners.

In collaboration with the Instituto de Ciencia de Materiales de Madrid, Spain, we prepared <001> orientated $0.675Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.325PbTiO_3$ ceramics with a very high piezoelectric coefficient d_{33} of 950 pm/V.

In collaboration with research groups from Switzerland, Australia and the USA we published a feature paper in the Journal of the American Ceramic Society entitled "$BiFeO_3$ ceramics: Processing, Electrical, and Electromechanical Properties". The review article presents the most important achievements of the department and other laboratories around the world in the field of $BiFeO_3$, which has been the most studied perovskite over the past decade.

Within the studies on **multiferroic $BiFeO_3$**, we focused on two systems, i.e., $BiFeO_3$-$SrTiO_3$ and $BiFeO_3$-$REFeO_3$ (RE=Sm, Gd, Dy). We identified the key processing problem associated with the formation of Bi-rich secondary phases, which melted during the sintering and wetted the grains of the final ceramics. This problem was solved with two different approaches: i) by mechanochemical activation of the starting powder mixture, which resulted in an increased powder homogeneity, and ii) by performing the reaction using pre-synthesized $BiFeO_3$ and $SrTiO_3$ binaries, in which case we avoided the use of Bi_2O_3 in the initial mixture and thus the formation of Bi_2O_3-rich phases with low melting points. We have also studied the processing of Sm-modified $BiFeO_3$. We found that during the reactive sintering the Sm_2O_3 reacts preferentially with Si impurities without a large increase in the concentration of the Bi- and Fe-rich secondary phases, which are otherwise formed during the processing of unmodified $BiFeO_3$ due to the reaction between the Si and the Bi_2O_3.

In 2014 we published a review article on piezoelectric $BiFeO_3$ material entitled "$BiFeO_3$ Ceramics: Processing, Electrical, Electromechanical Properties." The article was published in the July issue of the "Journal of the American Ceramic Society" and had a cover picture produced by researchers from the K-5 department. (Figure 1)

Figure 1: Cover of the July issue of the "Journal of the American Ceramic Society", created by researchers from the K-5 department.

In collaboration with the Department of Physics, University of Iasi, Romania, we systematically studied $BaSn_xTi_{1-x}O_3$ ferroelectric–relaxor cross-over induced by an increase of the tin addition (to x=0.20). The tin addition causes a gradual modification in the lamellar domain structure and by approaching the relaxor compositions (x = 0.15 and 0.20) polar nano-regions become crucial in the behaviour of the low- and high-field dielectric properties of the materials.

We studied the **electrocaloric (EC) response** of $PbZrO_3$ bulk ceramics together with colleagues from the Condensed Matter Physics Department at the JSI. The samples were prepared by sintering at a uniaxial pressure of 24.5 MPa and at 950 °C. By direct EC measurements the negative EC effect in this antiferroelectric ceramic was confirmed.

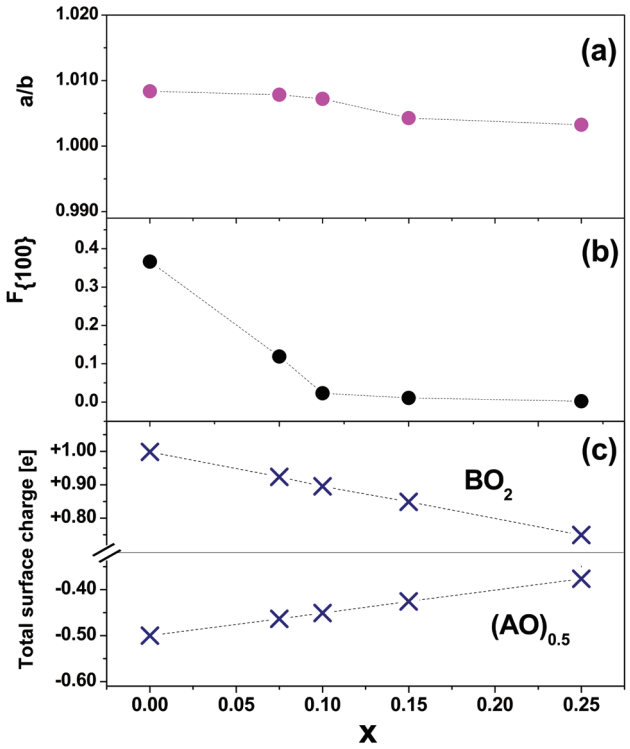

Figure 2: KNN and (1-x)KNN-xSTO thin films: a) ratio of a/b lattice parameters, b) Lotgering factor F{100} and c) the total surface charge of the individual atomic layers in the solid solution (A: K, Na, Sr, B: Nb, Ti).

Dielectric thin films based on tantalum oxide, prepared by solution synthesis upon heating at as low as 300–350 ° C, exhibit suitable electrical and optical properties for use as transparent passive or active electronic components.

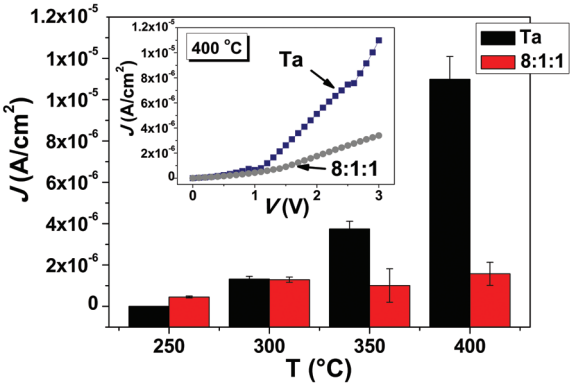

Figure 3: Leakage current density at an applied electric field of 160 kV/cm as a function of processing temperature of the Ta_2O_5 (Ta) and 8:1:1 thin films. The inset shows the current density versus applied voltage for the samples processed at 400 °C.

Within studies of **environment-friendly lead-free ferrolectric and relaxor thin films** by chemical solution deposition, the focus was on the (1-x) $K_{0.5}Na_{0.5}NbO_3$–$xSrTiO_3$ solid solution (KNN-STO), x = 0.075–0.25. Thin films on platinised silicon substrates crystallize in a pure perovskite phase upon rapid thermal annealing at 750 °C for 5 minutes. By increasing the fraction of STO the monoclinic distortion, the volume of the unit cell, the grain size and the degree of preferential {100} orientation in the films decreased (Figure). The latter was connected to the differences in the average surface energies of the {100} crystal planes of the KNN and STO end-members. (Figure 2) The temperature of the dielectric permittivity maximum decreased with the increasing STO content in the films. In collaboration with colleagues from the Condensed Matter Physics Department the relaxor behaviour of the 0.85KNN–0.15STO thin films was confirmed by dielectric spectroscopy and polarization vs. electric field measurements.

We prepared **thin-film varactors** based on $Ba_xSr_{1-x}TiO_3$ (x = 0.5, 0.4, 0.3) with partners from the Faculty of Electrical Engineering, University of Ljubljana, Experimental Particle Physics Department and Centre of Excellence SPACE.SI within the European Space Agency (ESA) JP PECS project FERROPATCH. The solution-derived films were deposited on polycrystalline alumina substrates and rapid thermally annealed at 900 °C. The in-plane microstructures of the about 240-nm-thin films were not much influenced by the change of the chemical composition, in all cases they were dense and consisted of about 100 nm grains. By increasing the fraction of Sr in the solid solution the dielectric permittivity and losses at 10 GHz decreased from 1310 and 0.142 to 670 and 0.024 for x = 0.5 and 0.3, respectively. Thus the solid solution with x = 0.3 was selected for the design and realization of a frequency and polarisation agile microwave antenna.

Within the 7FP EU project ORAMA we continued our work on transparent conducting oxides and dielectrics for **transparent electronics**. In collaboration with our partners from CNR-INO SENSOR Lab, University of Brescia, Italy, both p- and n-type Cu-Al-O thin films were deposited by RF magnetron sputtering from a single-phase $CuAlO_2$ target. It was shown that the p-type films could be used as innovative gas sensors for ozone detection, since their response towards 70 ppb of ozone was R = 100 at 300 °C and R=10 at 400 °C, i.e., two- and five-orders-of-magnitude higher than that reported for CuO and $CuAlO_2$ thin films at 300 °C, respectively.

We continued the research on high-K dielectric thin films based on Ta_2O_5 and Ta_2O_5-Al_2O_3-SiO_2 in the 8:1:1 molar ratio (further denoted as 8:1:1) for transparent electronics together with colleagues from the Faculty of Electrical Engineering, University of Ljubljana. The solution-derived films were processed at temperatures not exceeding 400 °C. The leakage currents proved to be dependent on the thermal budget of the samples. The Ta_2O_5 sample processed at 400 °C showed a leakage current density (J) of 10^{-5} A/cm² at 3V, i.e., at ~260 kV/cm, whereas the 8:1:1 sample exhibited almost an order of magnitude lower J value. However, the J values measured for both samples processed at 300 °C were in the range 1.4–2×10^{-6} A/cm². (Figure 3) Together with ORAMA project partners from Universidade Nova de Lisboa, Portugal, we verified whether the tantalum-oxide-based thin films processed at 300 and 350 °C, could be implemented as gate-dielectrics in thin-film transistors (TFTs). The TFTs on glass substrates with integrated dielectrics exhibited an on/off ratio > 10^8. Therefore, both Ta_2O_5 and 8:1:1 thin films from solution proved to be suitable for TFT applications.

In the framework of piezoelectric thick films, we dispersed lead-zirconate-titanate powder in ethanol and deposited it onto patterned strip electrodes by the **electrophoretic deposition (EPD) process**. By varying the deposition time, the distance between the electrodes and the geometry of the counter electrode we deposited about 1-mm-wide lines with a uniform

thickness and a distance between the lines of about 0.4 mm. The elements had about 85 % of theoretical density and were about 20-µm thick after sintering at 950 °C. In collaboration with researchers from François-Rabelais University Tours, France, the elements were electromechanically characterized. They had a resonance frequency of around 70 MHz and a dielectric constant of around 370 and can be used for the fabrication of high-frequency linear-array transducers.

We continued the study of processing **porous lead zirconate titanate (PZT) ceramics** with controlled porosity, pore size and pore size distribution. By sintering the powder compacts with a homogeneous distribution of PZT and polymethyl methacrylate (PMMA) particles at selected temperatures we obtained ceramics with a porosity of about 30 % and a narrow pore size distribution with the pore sizes around 1 or 10 µm. The ceramics possess a high attenuation coefficient and will be used as a backing for high-frequency ultrasound transducers.

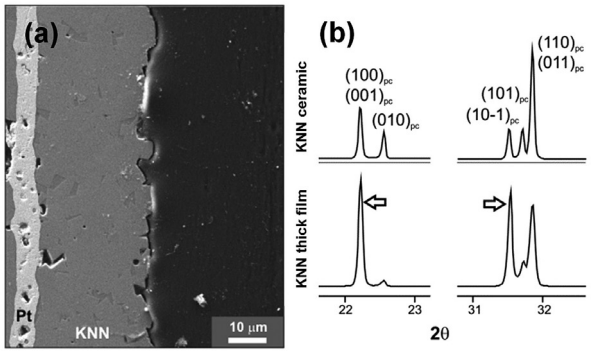

Figure 4: (a) Cross-section of a dense and single-phase KNN thick film with no visible defects. (b) X-ray patterns of KNN in thick-film and ceramic forms, showing the crystallographic orientation of the film (arrows), which was achieved by the appropriate selection of the substrate.

Furthermore, we investigated the influence of the surface roughness of the platinum substrates on the functional properties of $0.65Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.35PbTiO_3$ thick films. The thick-film pastes were screen-printed on the platinum substrates, which differed in the surface roughness by almost an order of magnitude; namely, vertical mean roughness (rms) values, determined by atomic force microscope, of 44 nm and 342 nm, respectively. The films on the flat substrates exhibited a higher degree of (001) orientation of the tetragonal phase, and a higher remnant polarization than the films on the rough substrates.

With colleagues from the Department for Condensed Matter Physics, JSI, we studied the **electrocaloric (EC) response** of the $0.7Pb(Mg_{1/3}Nb_{2/3})O_3$–$0.3PbTiO_3$ thick films on platinum foils. The highest EC temperature change of 1.2 K was observed at 380 K and at an applied electric field of 120 kV/cm.

We have prepared functional thin and thick films of environmentally friendly ferroelectrics based on $K_{0.5}Na_{0.5}NbO_3$.

We prepared $Pb(Zr_{0.53}Ti_{0.47})O_3$–$Pb_2Ru_2O_{6.5}$ (PZT–PRO) thick-film composite materials (with 10, 15, 20 and 25 vol % of PRO). The thick-film pastes were screen-printed and fired on sapphire substrates. In collaboration with colleagues from the Institute of Physics, Academy of Sciences, Czech Republic, we found that unlike the low-frequency permittivity, which diverges at the percolation threshold, near the composition with 17 vol% PRO, the THz and microwave permittivities increase even above the threshold value.

We studied the preparation, structural and microstructural properties of **KNN thick films screen-printed on different substrates.** By optimizing the synthesis conditions, particularly the sintering temperature, the amount of germanate-based liquid-phase sintering additive and the packing powder we successfully prepared single-phase, dense, crystallographically oriented KNN thick films. (Figure 4) By using high-temperature "in-situ" X-ray analysis we explained the mechanism of orientation as being due to the thermal expansion coefficients mismatch of the KNN and Al_2O_3 substrate during cooling. The results raise the possibility of controlling the orientation and hence the functional properties of KNN thick films by the selection of the substrate.

We prepared **$BiFeO_3$ (BFO)/substrate thick-film structures by screen-printing** and studied the influence of different substrates on the density, phase composition and structure of the films. We showed that the structure and phase composition of the BFO is strongly dependent on the annealing temperature and the impurities present in the substrate, which may even in small amounts react with BFO and form unwanted secondary phases.

We continued the investigations of **LTCC (Low Temperature Co-fired Ceramics)**, which are used for the fabrication of 3D structures for different electromechanical (MEMS - Micro Electro Mechanical Systems) and chemical microsystems. Traditional cooperation with research partners from HIPOT-RR and Centre of Excellence NAMASTE continued in all research projects related to thick-film and LTCC technology, in particular, we developed the technological process for the **integration of various functional elements**, such as quartz glass, porous corundum ceramics or piezoelectric ceramics into the structure of LTCC.

In cooperation with the above-mentioned research partners, we designed and created various demonstrators based on LTCC material developed by the company KEKO Equipment d.o.o. An example of such a product is a micro-ozonator, which is composed of several LTCC layers with different dielectric properties.

With the group from the company KEKON d.o.o. we continued our research in the field of functional thick-film materials for multi-layered electronic components.

Figure 5: Researchers from the K-5 department in cooperation with ETI d.d. from Izlake received the Silver Award for Innovation "New cordierite material C 410 for electrical engineering and its process for manufacturing"

In collaboration with the company ETI Elektroelement d.d. from Izlake we developed a new C410 type of cordierite material that is used in electrical engineering as a heat or electrical insulator. The cordierite ceramic is fabricated from numerous natural raw materials. Since the properties of raw materials may vary from batch to batch it is difficult to fabricate products with reproducible properties. By optimising the number of raw materials and their quantities, we developed a new material with the required flexural strength and thermal expansion coefficient. The low-priced material enables the fabrication of products with reproducible properties and is used in mass production in the company. The researchers from the K-5 department and ETI Elektroelement, d. d., received for this invention the Silver Award for innovation "New cordierite material C 410 for electrical engineering and its process for manufacturing", by Regional Chamber of Commerce of Zasavje, in June 2014 (Figure 5).

Some outstanding publications in the past year

1. Rojac, T., Benčan, A., Malič, B., Tutuncu, G., Jones, J. L., Daniels, J. E., Damjanović, D.: $BiFeO_3$ ceramics : processing, electrical, and electromechanical properties. *Journal of the American Ceramic Society*, ISSN 0002-7820, 2014, 97 [7], 1993–2011
2. Koruza, J., Malič, B.: Initial stage sintering mechanism of $NaNbO_3$ and implications regarding the densification of alkaline niobates. *Journal of the European ceramic society*, ISSN 0955-2219, 2014, 34 [8], 1971–1979
3. Frunza, R. C., Kmet, B., Jankovec, M., Topič, M., Malič, B.: Ta_2O_5-based high-K dielectric thin films from solution processed at low temperatures. *Materials research bulletin*, ISSN 0025-5408, 2014, 50, 323–328
4. Pavlič, J., Malič, B., Rojac, T.: Microstructural, structural, dielectric and piezoelectric properties of potassium sodium niobate thick films. *Journal of the European ceramic society*, ISSN 0955-2219, 2014, 34 [2], 285–295
5. Noshchenko, O., Kuščer, D., Mocioiu, O. C., Zaharescu, M., Bele, M., Malič, B.: Effect of milling time and pH on the dispersibility of lead zirconate titanate in aqueous media for inkjet printing. *Journal of the European ceramic society,* 2014, 34 [2], 297–305

Awards and appointments

1. Ines Bantan, Janez Holc, Danjela Kuščer, Joži Prašnikar, Helena Razpotnik: Silver acknowledgment for the inovation, Chamber of Commerce and Industry of Slovenia, Zagorje ob Savi, New Cordierite material C410 for the electrotechnics and the procedure of its fabrication
2. Hana Uršič Nemevšek: Award at the conference COST MP0904 Action, Bucharest, Romania, Internal Advisory Board of the COST Single-and multiphase ferroics and multiferroics with restricted geometries (SIMUFER), Unusual structural-disorder behavior of $Pb(Sc_{0,5}Nb_{0,5})O_3$
3. Jitka Hreščak: Acknowledgement for the presentation of the research achievements from the view of science quality and their usefulness: Ljubljana, Jožef Stefan International Postgraduate School, The role of different niobium pentoxide precursors in the solid-state synthesis of potassium sodium niobate
4. Julian Walker: Excellence Award for the Best Oral Presentation of young scientist, Ekaterinburg, Russian Federation, Organizational Board of the Joint International Conference Piezoresponse Force Microscopy and Nanoscale Phenomena in Polar Materials, Electrical, electromechanical properties and domain structure of Sm-modified-$BiFeO_3$ ceramics prepared by mechanochemical activation

INTERNATIONAL PROJECTS

1. 7FP - ORAMA; Oxide Materials Towards a Matured Post-silicon Electronics Era
   Prof. Barbara Malič
   European Commission
2. 7FP - CERAMPOL; Ceramic and Polymeric Membrane for Water Purification of Heavy Metal and Hazardous Organic Compound
   Asst. Prof. Danjela Kuščer Hrovatin
   European Commission
3. 7FP - PI; The Piezo Institute - European Expertise Centre for Multifunctiona and Integrated Piezoelectric Devices
   Prof. Barbara Malič
   European Commission
4. FERRO-PATCH; Frequency and Polarisation Agile Microstrip Patch Antenna based on Ferrelectric Varactors
   Prof. Barbara Malič
   ESA/ESTEC.
5. COST MP0904; SIMUFER: Single- and Multiphase Ferroics and Multiferroics with Restricted Geometries
   Prof. Barbara Malič
   COST Office
6. COST MP1308; Towards Oxide Based Electronics
   Dr. Katarina Vojisavljević
   COST Office
7. Study on the Process and Mechanism of Novel Electronic Ceramics
   Prof. Barbara Malič
   Slovenian Research Agency
8. Multiferroic Composites for Novel Applications
   Asst. Prof. Andreja Benčan Golob
   Slovenian Research Agency
9. Processing-properties Relationship in Lead-free (K,Na)NbO3-based Piezoelectric Materials
   Asst. Prof. Tadej Rojac
   Slovenian Research Agency

RESEARCH PROGRAM

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

R & D GRANTS AND CONTRACTS

1. Oxide-based Components for Transparent Electronics
   Prof. Barbara Malič
2. Nanostructures for High-efficiency Solar Cells and Photovoltaic
   Prof. Barbara Malič
3. Tunable Ferroelectric Thin Film Capacitors for Agile Microwave Antennas
   Prof. Barbara Malič
4. High-performance Piezoelectric Materials for Sensors and Actuators in High-temperature Applications
   Asst. Prof. Tadej Rojac
5. New Advanced Electrocaloric Materials for Novel Environmentally Friendly Dielectric Refrigeration Technology
   Prof. Barbara Malič
6. Materials and Technologies for Chemical Microsystems
   Asst. Prof. Andreja Benčan Golob
7. Micro-electromechanical and Electrocaloric Layer Elements
   Prof. Barbara Malič
8. Processing of Stable Aqueous Suspensions for Fabrication of Electrotechnical Elements based on Steatite Ceramic
   Dr. Katja Makovšek

NEW CONTRACTS

1. Research of Steatite Materials C220, C221, C230
   Asst. Prof. Danjela Kuščer Hrovatin
   Development Centre RC eNeM, Ltd.
2. Research of Cordierite Materials C410, C520, C530
   Prof. Barbara Malič
   Development Centre RC eNeM, Ltd.

VISITORS FROM ABROAD

1. Naonori Sakamoto, Department of Electronics and Materials Science, Shizuoka University, Shizuoka, Japan, 13 March–13 September 2014
2. Andreas Klein, Technische Universität Darmstadt, Institute for Materials Science, Darmstadt, Germany, 12–15 March 2014
3. Nadia El Felss, Université de Limoges, Faculté des Sciences et Techniques, Limoges, France, 7 April–13 July 2014
4. Maria Zaharescu, "Ilie Murgulescu" Institute of Physical Chemistry of Romanian Academy, Bucharest, Romania, 6–8 April 2014
5. Mahdi Feizpour, Ceramics Division-Materials and Energy Research Center, Meshkin-dasht, Karaj, Alborz, Iran, 15 July–15 December 2014
6. Dragan Damjanović, Ceramics Laboratory, Swiss Federal Institute for Technolgoy-EPFL, Lausanne, Switzerland, 23–26 June 2014
7. Andre-Pierre Abellard, Université François Rabelais, Tours, France, 19–26 June 2014
8. Tomoya Ohno, Kitami Institute of Technology, Kitami, Japan, 21–24 June 2014
9. Takashi Arai, Kitami Institute of Technology, Kitami, Japan, 21–24 June 2014
10. Garry L. Messing, Penn State University, Penn State, USA, 4–5 June 2014
11. John Daniels, School of Materials Science and Engineering, UNSW Australia, Sydney, Australia, 21–23 September 2014
12. Leszek Golonka, Faculty of Microsystem Electronics and Photonics, Wroclaw University of Technology, Wroclaw, Poland, 7–10 October 2014
13. Vincenzo Buscaglia, National Research Council, Institute for Energetics and Interphases IENI, Genova, Italy, 22–24 October 2014
14. Andrei Kholkin, Ural Federal University, Ekaterinburg, Russian Federation, 11–14 December 2014

STAFF

Researchers

1. Asst. Prof. Andreja Benčan Golob
2. Asst. Prof. Goran Dražić*
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13. Dr. Katja Makovšek
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16. Dr. Julian Bradley Walker

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17. Tina Bakarič, B. Sc.
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21. Evgeniya Khomyakova, B. Sc.
22. *Dr. Oleksandr Noshchenko, left 01. 05. 14*
23. Jernej Pavlič, B. Sc.
24. Tanja Pečnik, B. Sc.
25. *Jerca Praprotnik, B. Sc., left 01. 09. 14*
26. Marko Vrabelj, B. Sc.

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28. Andraž Bradeško, B. Sc.
29. *Jena Cilenšek, B. Sc., retired 01. 10. 14*
30. Silvo Drnovšek, B. Sc.
31. Brigita Kmet, B. Sc.

Technical and administrative staff

32. Tina Ručigaj, B. Sc.

Note:
* part-time JSI member

BIBLIOGRAPHY

Original Article

1. Andre-Pierre Abellard, Danjela Kuščer, Jean Marc Grégoire, Barbara Malič, Franck Levassort, "Lead zirconate titanate-based thick films for high-frequency focused ultrasound transducers prepared by electrophoretic deposition", *IEEE trans. ultrason. ferroelectr. freq. control*, vol. 61, no. 3, pp. 547-556, 2014.
2. Andre-Pierre Abellard, Danjela Kuščer, Marc Lethiecq, Jean Marc Grégoire, Barbara Malič, Franck Levassort, "Lead zirconate titanate multi-element structure by electrophoretic deposition", *Inf. MIDEM*, vol. 44, no. 1, pp. 32-39, 2014.
3. Harvey Amorín, Hana Uršič, Pablo Ramos, Janez Holc, Rodrigo Moreno, Daniel Chateigner, Jesús Ricote, Miguel Algueró, "$Pb(Mg_{1/3}Nb_{2/3})O_3PbTiO_3$ textured ceramics with high piezoelectric response by a novel templated grain growth approach", In: MS&T'13, Materials Science & Technology 2013, October 27-31, 2013, Montreal, Quebec, Canada, *J. Am. Ceram. Soc.*, vol. 97, no. 2, pp. 420-426, 2014.
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6. Andreja Eršte, Alja Kupec, Brigita Kmet, Barbara Malič, Vid Bobnar, "Stable dielectric response in lead-free relaxor $K_{0.5}Na_{0.5}NbO - SrTiO_3$ thin films", *Journal of advanced dielectrics*, vol. 4, issue 2, pp. 1450012-1-1450012-5, 2014.
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8. Raluca-Camelia Frunză, Marko Jankovec, Brigita Kmet, Marko Topič, Barbara Malič, "Current transients in solution-derived amorphous Ta[sub]2O[sub]5-based thin-film capacitors", *Inf. MIDEM*, vol. 44, no. 1, pp. 21-26, 2014.
9. Raluca-Camelia Frunză, Brigita Kmet, Marko Jankovec, Marko Topič, Barbara Malič, "Ta_2O_5-based high-K dielectric thin films from solution processed at low temperatures", *Mater. res. bull.*, vol. 50, pp. 323-328, 2014.
10. Nadejda Horchidan, A. C. Ianculescu, Cora Vasilescu, M. Deluca, V. Musteata, Hana Uršič, Raluca-Camelia Frunză, Barbara Malič, Liliana Mitoseriu, "Multiscale study of ferroelectric-relaxor crossover in $BaSn_xTi_{1-x}O_3$ ceramics", *J. Eur. Ceram. Soc.*, vol. 34, no. 15, pp. 3661-3674, 2014.
11. Marko Hrovat, Darko Belavič, Kostja Makarovič, Jena Cilenšek, Barbara Malič, "Characterisation of thick-film resistors as gauge sensors on different LTCC substrates", *Inf. MIDEM*, vol. 44, no. 1, pp. 6-13, 2014.
12. Petra Jenuš, Darja Lisjak, Danjela Kuščer, Darko Makovec, Mihael Drofenik, "The low-temperature cosintering of cobalt ferrite and lead zirconate titanate ceramic composites", *J. Am. Ceram. Soc.*, vol. 97, no. 1, pp. 74-80, 2014.
13. Evgeniya Khomyakova, Andreja Benčan, Barbara Malič, "Compositional and microstructural study of sol-gel-derived $PbZr_{0.3}Ti_{0.7}O_3/Al_2O_3/SiO_2$/Si thin-film structures", *Inf. MIDEM*, vol. 44, no. 1, pp. 27-33, 2014.
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