DEPARTMENT FOR ADVANCED MATERIALS K-9

The primary activities of the department are the development of new materials and the new processes needed for the preparation of such materials in the form of nanostructures and nanocomposites. The main objective of current projects is the synthesis of new, environmentally friendly materials with special electrical and optical properties, with the emphasis on tunable materials that exhibit a dependence of the electric polarization on external electric, mechanical or magnetic fields. A significant part of the research is devoted to the development of new ceramic dielectrics that can be used at microwave frequencies. A new field of the department's research is aimed at the synthesis of photocatalytically active and antibacterial nanocomposites for their wide area of potential applications: from domestic appliances to medicine.

Head:
Prof. Danilo Suvorov

Development of materials with special electrical properties

Thermoelectric materials have been extensively studied in the last decade, as a possible sustainable solution to the imminent energy problem. The studied materials have the ability to transform the generated heat directly into electrical energy and can therefore be used as a waste-heat collector, in, for example, exhaust systems or they can directly transform the heat generated by chemical or nuclear reactions into electricity. Theoretically, it was predicted that the efficiency of such a device should reach a 100% efficiency of the Carnot cycle; however, only a moderate output was achieved so far. Our study has focused on oxide ceramic semiconductors that are seen as candidates for high-temperature applications, where conventional alloys fail. Among the known oxide thermoelectric, Na_xCoO_2 was reported to exhibit the highest efficiency among p-type thermoelectric oxides. There are, however, severe discrepancies in the reported values, which are not yet understood. Our aim was to prepare a phase-pure ceramic material with a well-defined microstructure, which has so far, based on published results, not yet been realized We employed several different synthesis techniques such as solid-state and sol-gel, to synthesize the Na_xCoO_2 ($0.55<x<0.85$). We investigated the chemical properties, such as temperature stability and reactivity under different atmospheres, and in different solvents. We found that Na_xCoO_2 is very sensitive to water molecules that cause a broadening of the unit cell and, consequently, if the water content is high enough, transform a solid pellet into a gel-like paste. By avoiding moisture in the next steps of the material processing, we have optimized the synthesis process, which gives reproducible results, at least in terms of the microstructure of such ceramics. In order to prevent contamination of the material with moisture we developed an appropriate protective paste, which covers the material well. We also developed a conductive paste to ensure good electrical contact with the measuring instrument, or enables the integration of an application-device. On the other hand, the unusually high average oxidation state of Co is prone to changes at temperatures in the vicinity of 800°C. For the densification of the powder temperatures above 950°C, which is above the decomposition temperature in an air atmosphere, are required. Our findings indicate that high pressures of oxygen need to be employed during the processing of the Na_xCoO_2 ceramics. The thus prepared material withstands temperatures up to 930°C in an air atmosphere and is therefore a potential candidate for a p-type thermo-element in high-temperature thermoelectric modules.

For the applicability of oxide thermoelectric Na_xCoO_2 we have developed an appropriate protection paste, which covers well the material, and prevents the material's contamination with moisture. We have also developed a conductive paste to ensure good electrical contact with the measuring instrument, or enable the integration of an application device.

Another part of the research was focused on understanding the formation mechanism of ferroelectric $K_{0.5}Bi_{0.5}TiO_3$ ceramics. Control of the solid-state synthesis parameters enabled us to prepare dense $K_{0.5}Bi_{0.5}TiO_3$ ceramics with a minor part of secondary phases, which ensures that the measured electrical properties can be ascribed to the matrix phase. An analysis of the electrical properties revealed an improvement with the extension of the sintering time and, moreover, the peculiarities became sharper. For example, the frequency dispersion of the dielectric properties became smaller, the peaks become sharper and the squareness of the ferroelectric hysteresis increased. After a shorter sintering time the samples exhibit increased conductivity; this deteriorates their electrical properties. Such behavior was connected with the presence of a K_2O-rich secondary phase, concentrated on the grain boundaries. This phase is in a melted state at the sintering temperature and reacts with humidity from the atmosphere. With a prolonged sintering time this phase volatizes and redistributes, which decreases its continuity within the ceramics. Consequently, the resistivity increases and the electrical properties improve for sintering times longer than 15 hours. A characterization of the electrical properties showed the superior properties of the as-prepared samples compared to the literature. The relative permittivity and losses at room temperature and 1 MHz are higher than 500 and smaller than 7%, respectively, whereas the permittivity at the maximum is higher than 5400. The remanent polarization and coercive field were 30 μC/cm^2 and 63 kV/cm, respectively, which indicates strong ferroelectricity and the "hard" nature of the $K_{0.5}Bi_{0.5}TiO_3$ ceramics. Field cooling at 50 kV/cm was performed from 250°C to below 100°C. Under these conditions the piezoelectric coefficient (d_{33}) was as high as 115 pC/N, which is higher than in related $Na_{0.5}Bi_{0.5}TiO_3$. With a potassium non-stoichiometry the dielectric and ferroelectric properties rapidly degrade. However, the piezoelectric properties remain relatively high, with d_{33} values between 75 and 90 pC/N, in samples with –4% to +2% of potassium compared to the stoichiometric $K_{0.5}Bi_{0.5}TiO_3$.

In the scope of an applied project with EPCOS OHG, Deutschlandsberg, Austria, ferroelectric ceramics from the $Pb(Zn_{1/3}Nb_{2/3})O_3$–$BaTiO_3$–$PbTiO_3$ (PZN-BT-PT) and $(Pb_{1-x}Sr_x)(Zr_{0.538}Ti_{0.438}Nb_{0.024})O_3$ (PSZTN) perovskite systems were investigated as potential materials for applications in power electronics. For both systems the variations of the ferroelectric (T_c, ε_{max}) and structural characteristics were examined as a function of the composition. In the PZN-BT-PT system compositional changes enabled a variation of the Curie temperature (T_c) from 100 to 200°C and a dielectric constant maximum (ε_{max}) from 8000-11000. The PSZTN compositions exhibit T_c=150-250°C and ε_{max}=8000-12000. The investigations of the field dependence of the dielectric constant revealed that electric fields of 70-100 kV/cm lowered the e values by 80-95%.

Development of microwave dielectrics

In the investigations of the microwave dielectric materials we have studied the influence of the sintering temperature and different atmospheres on the densification, decomposition of the matrix, and the homogeneity of the components with respect to their dielectric properties in the microwave-frequency region.

We have observed that during the preparation of $Ag(Nb_{1-x}Ta_x)O_3$ ceramics the oxidation and reduction processes of Ag cause problems related to the matrix decomposition and densification. At low sintering temperatures (1040–1080 ° C) the secondary phases related to the heterogeneous distribution of the Nb and Ta appears in addition to the matrix phase. When the sintering temperatures are between 1120 and 1200 °C the homogeneity of the components are improved due to the higher diffusion rates, but on the other hand $Ag(Nb_{0.5}Ta_{0.5})O_3$ partially decomposed into $Ag_2(Nb,Ta)_4O_{11}$, $Ag_8(Nb_{0.5}Ta_{0.5})_{26}O_{69}$ and Ag. Consequently, sintering in air did not result in a single-phase $Ag(Nb_{0.5}Ta_{0.5})O_3$ ceramic. We observed that sintering in pure oxygen under increased pressure retarded the decomposition process according to Le Chatelier´s principle and as a result we were able to synthesize predominantly single-phase ceramics with a high density. Nevertheless, a sample sintered at 1080 °C in air exhibited optimal dielectric properties; i.e., $\varepsilon \approx 440$, $Q{\times}f \approx 622$ GHz, and $\tau_f \approx -16$ ppm/K. We also described how the Nb and Ta distributions in the $Ag(Nb_{0.5}Ta_{0.5})O_3$ material influence the temperature coefficient of the resonant frequency.

In the investigation of MgO-B_2O_3–SiO_2 (MBS) glass ceramic we have studied the effect of TiO_2 as nucleating agent on the nucleation and crystallization processes using several kinetic methods based on non-isothermal DSC measurements. According to the XRD examination after the DSC measurements the $Mg_2B_2O_5$ phase is the main phase in samples with and without a nucleating agent. Selected-area electron diffraction (SAED) confirmed the $Mg_2B_2O_5$ structure of the newly formed phase. The crystallization peak temperature is shifted to lower temperatures and the DSC peak became narrower and more intense with the increase of TiO_2 content. Small additions of TiO_2 (<3 wt. %) were found to have no significant effect on the DSC curve, while the higher concentrations of TiO_2 (>3 wt. %) resulted in the substantial lowering of the crystallization peak (Tp) temperature, which is caused by a high nuclei concentration. The influence of TiO_2 on the growth mechanism was followed by the variation of the Avrami exponent (n), determined by the Ozawa relation, and its relation to the morphology index (m'). The variation of n with TiO_2 content thus reflected the changes in the nucleation rate and the growth-controlling mechanism. The increase of n from 1.5 to 2.5 at 3 wt. % TiO_2 indicated the change from zero to a constant nucleation rate. With a further increase of TiO_2, n changed to 4 and the crystal growth rate became interface controlled with a constant nucleation rate.

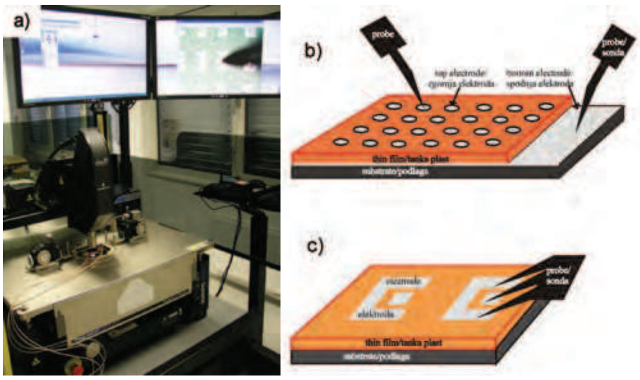

Figure 1: Together with Nanocenter CONIN we have obtained a probe station for the electrical characterization of ceramic thin films (a). In the low-frequency range the electrical measurements were performed by the method of parallel capacitors, where a thin layer is sandwiched between two electrodes (b), while in the microwave range the used method is the planar capacitor configuration, where the electrode is applied only on one side of the thin film (c).

The miniaturization of electronic components favors the replacement of bulk ceramic components with thin-film-based components. One of the methods for the preparation of thin films is the sol-gel method. As part of our thin-film investigation we have studied the influence of heat-treatment conditions (pyrolysis and annealing) on the microstructural development of the 70 mol% $Na_{0.5}Bi_{0.5}TiO_3$ – 30 mol% $NaTaO_3$ thin films. We have observed that by using a one-step pyrolysis and annealing at different temperatures, the obtained thin films show a markedly different microstructure. In the case of using two-step pyrolysis, we have obtained similar microstructures of thin films, regardless at which temperatures we annealed. Such a microstructure displays a columnar grain growth. We have also fabricated multilayer $SrTiO_3$/ $Na0_{.5}Bi_{0.5}TiO_3$ thin films. The preparation of multilayers by employing a dielectric layer between the ferroelectric film and the electrodes enabled us to prepare ferroelectric thin films that exhibit lower values of leakage current as compared to pure $SrTiO_3$ or $Na_{0.5}Bi_{0.5}TiO_3$ films. We have observed that such multilayered structures offer the possibility to improve the electrical characteristics required to achieve applicability and long-lasting reliability of the prepared ferroelectric layers.

The microwave dielectric (MW) properties of ceramic thin films can be determined with the split-post dielectric resonator methods as well as with a planar capacitor measurement configuration, where the interdigital electrodes are a pattern on the same side of the thin film. We were particularly focused on the study of MW dielectric properties of the planar capacitor configuration, which provides MW data over the whole microwave-frequency region. The measuring capacitance must be within the range of $0.03\ pF \leq C \leq 3\ pF$ and can be varied by the design of interdigital electrode structures (Fig. 1), which influences the accuracy of the measuring data. Therefore, the combination of the analytical and numerical modeling for co-planar interdigital electrode structures was used to characterize the dielectric properties of ceramic thin films. The co-planar interdigital electrode structures were prepared using E-beam lithography.

Research of nanostructured materials and nanocomposites

a.) Nanoparticles and nanopowders

The material synthesis approach turns out to be the key parameter in obtaining improved properties of the ceramics. The research of nanostructured materials has been focused on the synthesis of $BaTiO_3$ and $CoFe_2O_4$ nanoparticles prepared by hydrothermal or solvothermal synthesis.

We prepared a ceramic material with artificially created nanostructures. The ordered nanostructures, which consisted of nano-dots or nano-circles of β-Bi_2O_3, were manufactured using electron lithography and the sol-gel method.

The $BaTiO_3$ nano-particles with various morphologies were prepared under different hydrothermal and solvothermal synthesis conditions. We studied the influence of solvent, temperature, concentration and type of the precursors on the shape, crystal structure and size of the synthesized particles. $BaTiO_3$ particles were formed in alkaline solutions of barium precursors from TiO_2 or sodium titanate nanostructures at 100-230°C. $BaTiO_3$ particles in the shape of spheres, stars, rods and squares were obtained using different synthesis conditions (fig. 2).

Cobalt ferrite nanoparticles were prepared via the precipitation-hydrothermal method. The influences of pH and temperature on the structural and magnetic properties were investigated. We observed that with the pH increases the crystallinity and the average particle size increase. The crystallinity of the samples also increased with increased temperature. However, only small changes in the particle size were observed. The results of the magnetic measurement revealed that the increase of temperature and pH causes an increase of the saturation magnetization, remanent magnetization and coercivity of the cobalt ferrite nanoparticles.

In the field of colloidal and nanomaterials, nanostructured spherical particles of $MnCO_3$, with the size of 2 μm were prepared by using a biomimetic synthesis method. Further thermal treatment of these particles at different temperatures and in different atmospheres resulted in the formation of nanostructured particles of MnO, Mn_2O_3 in Mn_3O_4. In a study of the $CaCO_3$ particles' growth in an aqueous medium, we identified a range of complex and nanostructured particles with different crystal structure. Samples were prepared from different precursors with or without the presence of different enzymes that act as templates (base) in the growth of particles and affect the crystal structure and morphology of the generated particles.

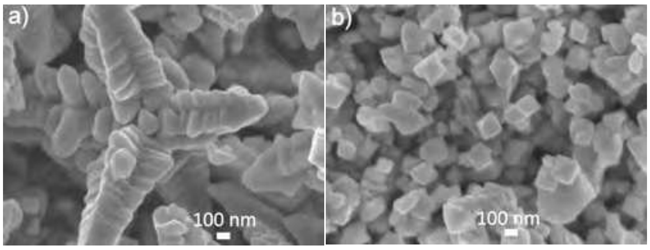

Figure 2: The morphology of the $BaTiO_3$ particles formed from sodium titanate belts in alkaline water solution (a) and in water/ethanol (75/25) alkaline solution (b) at 100°C.

b.) Nanocomposites

The fabrication of nanostructured thin films consisting of hybrid materials based on semiconducting titania and titanate nanostructures have recently been the subject of intense research arising from their enhanced semiconducting properties that have widespread potential for application in photocatalysis, catalysis, photovoltaic's and gas sensing.

The nanocomposites based on TiO_2/Pt were prepared by the sol-precipitation method followed by thermal treatment in a reducing atmosphere at 400°C for 3h. These so prepared TiO_2/Pt nano-composites were a biphasic TiO_2, consisting of anatase (average particle size 14 nm) and rutile (average particle size 15 nm), which were attached with Pt particles (3-15 nm). The measured specific surface area of such nano-composites was 62 m^2/g. The photocatalytic activities of the TiO_2/Pt nano-composites, determined under ultraviolet (UV) irradiation in gaseous

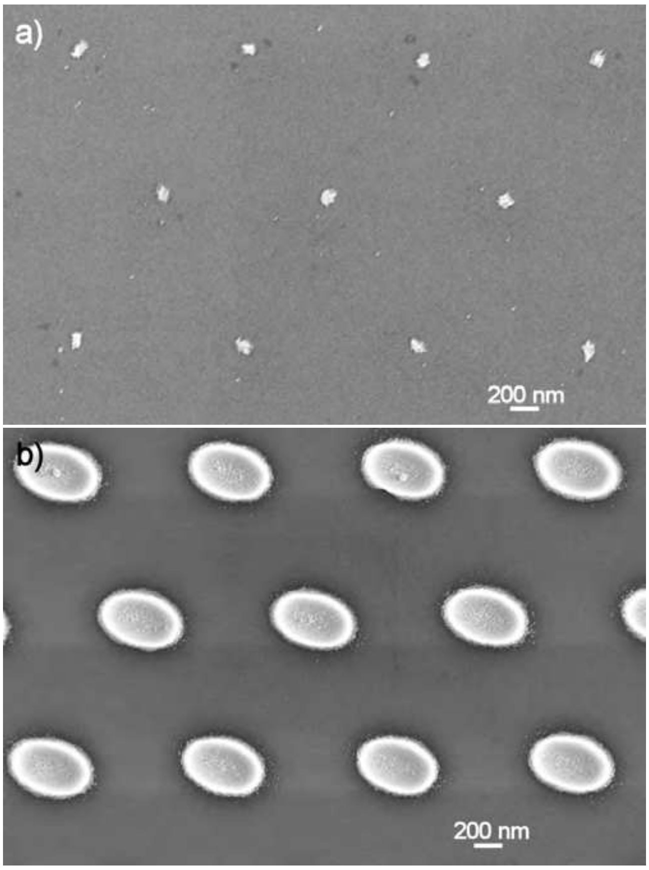

Figure 3: Ordered nanostructures consisted of a) nano-dots or b) nano-circles of β-Bi_2O_3 prepared by using electron lithography and the sol-gel method.

media (photocatalytic oxidation of isopropanol), exceeded the photocatalytic efficiency of the bare TiO_2 nano-powders. The enhancement of the UV photocatalytic activity with the TiO_2/Pt when compared to the bare TiO_2 was also observed in aqueous media for the photocatalytic discoloration of an azo-dye solution of methylene blue.

In the field of photo-catalytic processes an effective approach to expand the photoactive range and enhance the activity of titanate-based 1D nanostructures has been achieved by coupling the wide-semiconducting titanate nanobelts (Ti-NBs) with the metallic (Cu) or narrow-band-gap (CuO) semiconducting nanoparticles. For the CuO/Ti-NBs and Cu/Ti-NBs film fabrication the weak-polyelectrolyte multilayer (PEM) coated Ti-NBs were subsequently utilized as a nanoreactor for the *in-situ* synthesis of metallic Cu nanoparticles. The as-synthesized single-crystalline *fcc* Cu nanoparticles are spherical and uniformly distributed within the PEM on the surface of the Ti-NBs. The as-formed Cu-loaded PEM/Ti-NBs precursor structures were then utilized for the fabrication of 10 and 20 bilayered film assemblies with the layer-by-layer self-assembly methodology. The cross-sectional FE-SEM images of 10 and 20 layered Ti-NBs films revealed that multilayered films formed by the layer-by-layer assembly yield the orientation of Ti-NBs in the film, which is not parallel with the substrate. This induces nanoscale porosity and yields a high specific area of the as-formed nanostructured films, making as-formed multilayered Ti-NB thin films an ideal potential photocatalytic structure for the degradation of organic contaminants.

The ability to manipulate the internal structure of materials at nanometer-length scales and control the dimensions of nanostructures is in the forefront of current research for multi-functional materials. Therefore, part of our research was focused on the preparation of ceramic materials with artificially created nanostructures. By using electron lithography and the sol-gel method we had ordered nanostructures consisting of nano-dots or nano-circles of β-Bi_2O_3 (Fig. 3).

Some outstanding publications in the past year

1. Marija Vukomanović, Ines Bračko, Ida Poljanšek, Dragan Uskoković, Srečo D. Škapin, Danilo Suvorov, "The growth of silver nanoparticles and their combination with hydroxyapatite to form composites via a sonochemical approach", *Cryst. growth des.*, vol. 11, issue 9, pp. 3802-3812, 2011
2. Mojca Otoničar, Srečo D. Škapin, Boštjan Jančar, "TEM analyses of the local crystal and domain structures in $(Na_{(1-x)}K_x)_{0.5}Bi_{0.5}TiO_3$ perovskite ceramics", *IEEE trans. ultrason. ferroelectr. freq. control*, vol. 58, no. 9, pp. 1928-1938, 2011
3. Matjaž Spreitzer, Danilo Suvorov, "Electrical characteristics of $Na_{0.5}Bi_{0.5}TiO_3$-$Li_{0.45}La_{0.52\ 0.03}TiO_3$ system", *J. Am. Ceram. Soc.*, vol. 94, issue 7, pp. 2104-2108, 2011
4. Marjeta Maček, Manca Logar, Bojan Budič, Danilo Suvorov, "Dielectric and microstructural study of the $SrWO_4$, $BaWO_4$, and $CaWO_4$ scheelite ceramics", *J. Am. Ceram. Soc.*, vol. 94, no. 8, pp. 2464-2472, 2011
5. Ines Bračko, Boštjan Jančar, Manca Logar, Dejan Caglič, Danilo Suvorov, "Silver nanoparticles on titanate nanobelts via the self-assembly of weak polyelectrolytes: synthesis and photocatalytic properties", *Nanotechnology (Bristol)*, vol. 22, issue 8, pp. 085705-1-085705-11, 2011

Awards and appointments

1. Andreja Šestan: Award for contribution to the sustainable development of society for the year 2010, Ljubljana, The Slovene Human Resources and Scholarship Fund, Microstructure characteristics of materials based on Ni-GDC and GDC prepared by citrate-nitrate combustion synthesis.
2. Vojka Žunič: Award for contribution to the sustainable development of society for the year 2010, Ljubljana, The Slovene Human Resources and Scholarship Fund, Sol-gel synthesis of TiO2 nano-powders, which are photocatalytically active under visible light irradiation.
3. Vojka Žunič: Award for the best poster, 10th Brazilian MRS Meeting, Gramado, Brazil, Brazilian Materials Research Society, Photocatalytic activity of TiO2 nano-powders prepared via two different synthesis methods.

Organization of conferences, congress and meetings

1. Brazilian - Slovenian Workshop on synthesis methods of nanostructured materials, Araraquara, Brazil, 19–23 September 2011 (co-organizers)
2. Materials Science & Technology 2011 Conference and Exhibition, Columbus, USA, 16 – 20 October 2011 (co-organizers)
3. 19th Conference on Materials and Technologies, Portorož, 22–23 November 2011 (co-organizers)
4. Workshop on MATERA ERA-NET project "Novel inorganic inks for hybrid printed electronic demonstrators", Ljubljana, 21–22 November 2011

INTERNATIONAL PROJECTS

1. Development of Wear Resistant Coatings based on Complex Metallic Alloys for Functional Applications
   AppliCMA
   7. FP, 214407
   EC; Andreas Merstallinger, Aerospace & Advanced Composites GmbH, Wiener Neustadt, Austria
   Asst. Prof. Srečo D. Škapin, Asst. Prof. Miha Čekada, Prof. Janez Dolinšek, Asst. Prof. Kristoffer Krnel
2. Novel Inorganic Inks for Hybrid Printed Electronic Demonstrators
   INNOINKS
   MNT ERA NET
   University of Oulu (UOULU), Finland
   Prof. Danilo Suvorov
3. Nanostructured Ferroelectric Films for Biosensor
   NAFERBIO
   MNT ERA NET II
   Chalmers Tekniska Hogskola AB, Sweden
   Prof. Danilo Suvorov
4. Functional Nanostructured Ceramic Materials
   BI-AR/09-11-001
   Prof. Noemí Elisabeth Walsõe de Reca, CINSO (Centro de Investigaciones en Sólidos), CITEFA-CONICET, Buenos Aires, Argentine
   Prof. Danilo Suvorov
5. Thermoelectric Oxide Materials
   Agreement IJS/EPCOS, NBT Project
   Dr. Manfred Schweinzger, Hermann Gruenbichler, EPCOS OHG Ceramic Components Division, Deutschlandsberg, Austria
   Prof. Danilo Suvorov, Asst. Prof. Boštjan Jančar
6. High K Dielectrics for Mobile Phone Base Stations
   4502220319/302
   Dr. Christian Hoffmann, Pavol Dudesek, EPCOS OHG Ceramic Components Division, Deutschlandsberg, Austria
   Prof. Danilo Suvorov
7. High K Dielectrics for Mobile Phone Base Stations
   Agreement IJS/EPCOS, Microwave Ceramics
   Dr. Christian Hoffmann, Pavol Dudesek, EPCOS OHG Ceramic Components Division, Deutschlandsberg, Austria
   Prof. Danilo Suvorov, Asst. Prof. Boštjan Jančar
8. High Dielectric Constant Ferroelectric Material; Thermoelectric Oxide Materials
   Agreement IJS/EPCOS, NBT
   Dr. Guenter Engel, dr. Andrea Testino, EPCOS OHG Ceramic Components Division, Deutschlandsberg, Austria
   Prof. Danilo Suvorov, Dr. Marjeta Maček Kržmanc, Asst. Prof. Boštjan Jančar
9. High K Dielectrics for Mobile Phone Base Stations
   Agreement IJS/EPCOS, Microwave Ceramics
   Dr. Christian Hoffmann, Pavol Dudesek, EPCOS OHG Ceramic Components Division, Deutschlandsberg, Austria
   Prof. Danilo Suvorov, Asst. Prof. Boštjan Jančar
10. The Synthesis of Dielectric Materials by Chemical Solution Deposition and Characterization of their Dielectric Properties
   BI-BR/11-13-002
   Prof. José Arana Varela, Instituto de Quimica-UNESP, Araraquara, Brazil
   Prof. Danilo Suvorov
11. Ultra-low Dielectric Constant LTCC Material
   BI-CN/09-11-013
   Dr. Xing Hu, South China University of Technology, Guangzhou, China
   Asst. Prof. Srečo Davor Skapin
12. Synthesis of Piezoelectric Thin Films and Magnetoelectic Composites by a Layer-by-layer Self Assembly
   BI-KR/09-11-001
   Dr. Jae-Ho Jeon, Korea Institute of Materials Science, Changwon, Korea
   Prof. Danilo Suvorov
13. Mixed Rare Earth Oxide Nanoparticles: Synthesis, Characterisation, Applications
   BI-SR/10-11-016
   Dr. Bratislav Antić, "Vinča" Institute of Nuclear Sciences, Beograd, Serbia
   Asst. Prof. Boštjan Jančar

R & D GRANTS AND CONTRACTS

1. Nanoengineering of self-assembled materials
   Prof. Danilo Suvorov
2. Self-cleaning antibacterial fotocatalitic coatings in whitewear production
   Prof. Danilo Suvorov
3. Functionalization of the surface of organic pigments for durable, efficient and colour-stable paints
   Asst. Prof. Srečo Davor Škapin
4. Physis and chemistry of porous aliminium for Al panels, capable of higly efficient energy absorbtion
   Prof. Danilo Suvorov
5. New materials for power conversion: Oxide semiconductor thermoelectrics
   Prof. Danilo Suvorov

RESEARCH PROGRAM

1. Contemporary inorganic materials and nanotechnologies
   Prof. Danilo Suvorov

NEW CONTRACTS

1. Development and characterisation of mineral wool fibres
   Knauf Insulation, d. o. o., Škofja Loka
   Prof. Danilo Suvorov
2. Self-Cleaning antibacterial fotocatalitic coatings in whitewear productions
   Gorenje Household Appliances
   Prof. Danilo Suvorov
3. New materials for energy conversion
   Gorenje Household Appliances
   Prof. Danilo Suvorov

MENTORING

Ph. D. Thesis

1. Urban Došler, The synthesis and characterization of glass-ceramic based on ternary system $MgO-B_2O_3-SiO_2$ (mentor Danilo Suvorov; co-mentor Marjeta Maček Kržmanc).

VISITORS FROM ABROAD

1. Ruben Zowada, B. Sc., Cascade Microtech Inc., München, Germany, 25 January 2011
2. Dr. Ivan Sondi, Rudjer Bošković Institute, Zagreb, Croatia, 24 February 2011
3. Prof. Dragoljub Uskoković, Institute of Technical Sciences, SASA, Belgrade, Republic of Serbia, 16–17 March 2011
4. Dr. Bratislav Antić, Vinča Institute of Nuclear Sciences, Belgrade, Republic of Serbia, 27 March to 1 April 2011
5. Zoran Jovanović, B. Sc., Faculty of Physical Chemistry, University of Belgrade, Belgrade, Republic of Serbia, 1 April 2011
6. Gorazd Šebenik, B. Sc., Markus Mente, B. Sc., Knauf Insulation, Škofja Loka, 5 April 2011

7. Markus Mente, B. Sc., Knauf Insulation, Škofja Loka, 18 May 2011
8. Gorazd Šebenik, B. Sc., Knauf Insulation, Škofja Loka, 24 May 2011
9. Dr. Smilja Marković, Institute of Technical Sciences, SASA, Belgrade, Republic of Serbia, 21 – 31 May 2011
10. Prof. Ling Zhi Yuan, South China University of Technology, Gangzhou, China, 25 May to 3 June 2011
11. Dr. Hu Xing, South China University of Technology, Gangzhou, China, 25 May to 3 June 2011
12. Dr. Ivan Sondi, Rudjer Bošković Institute, Zagreb, Croatia, 16 June 2011
13. Hermann Gruenbichler, B. Sc., Dr. Manfred Schweinzger, Yongli Wang, B. Sc., TDK EPCOS, Deutschlandsberg, Austria, 1 September 2011
14. Dr. Jae Ho Jeon, Korea Institute of Material Science, Changwon, Korea, 10–13 September 2011
15. Dr. Somnuk Sirisoonthorn, National Metal and Materials Technology Center, Pathumthani, Thailand, 13–14 October 2011
16. Dr. Marija Vukomanović, Institute of Technical Sciences, SANU, Belgrade, Republic of Serbia, 23–24 October 2011
17. Dr. Bratislav Antić, Vinča Institute of Nuclear Sciences, Belgrade, Republic of Serbia, 7–13 November 2011
18. Prof. Malgorzata Jakubowska, Institute of Electronic Materials Technology, Warsaw, Poland, 21–22 November 2011
19. Prof. Heli Jantunen, Dr. Jari Juuti, Dr. Merja Teirikangas, University of Oulu, Oulu, Finland, 21– 22 November 2011
20. Dr. Juha Kuusisaari, Sachtleben Pigments Oy, Finland, 21–22 November 2011
21. Prof. Velimir Radmilović, Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Republic of Serbia, 1–3 December 2011
22. Mag. Peter Bastl, Mag. Vladimir Vrečko, Cinkarna Celje, Celje, 2 December 2011
23. Hermann Gruenbichler, B. Sc., Dr. Manfred Schweinzger, Yongli Wang, B. Sc., TDK EPCOS, Deutschlandsberg, Austria, 22 December 2011

Visiting Researchers:
1. Dr. Marija Vukomanović, Institute of Technical Sciences, SASA, Belgrade, Republic of Serbia, 1 January to 30 September 2011
2. Dr. Ismael Fabregas, Centro de Investigaciones en Sólidos, CITEFA, Buenos Aires, Argentina, 12 October to 31 August 2012

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19. Vojka Žunič, B. Sc.

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21. Maja Šimaga Saje, M. Sc.
22. Silvo Zupančič

Note:
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BIBLIOGRAPHY

[redacted]

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