DEPARTMENT FOR ADVANCED MATERIALS K-9

At the Advanced Materials Department we investigate novel materials through an understanding of the mutual dependence of their structural, microstructural and functional characteristics. Modern technologies that enable the synthesis of materials with atomic and microscale precision are used to prepare pre-designed structural 3D materials, thin films and nanoparticles with the desired crystal structure, chemical composition, microstructure and morphology. Among our important objectives is the development of i) novel functional oxides for electronic applications and energy conversion, ii) antibacterial and piezoelectrical biocompatible materials and iii) heat-insulation materials with improved properties and sustainability.

Head:
Asst. Prof. Matjaž Spreitzer

Novel functional oxides

In the scope of the M-era.Net project "SunToChem", the engineering of perovskite photocatalysts was focused on the hydrothermal epitaxial growth of $SrTiO_3$ on $Bi_4Ti_3O_{12}$ nanoplatelets. An in-depth understanding of the mechanism for formation of $SrTiO_3/Bi_4Ti_3O_{12}$ is of broader importance for the design of two-dimensional (2D/2D) nanoheterostructures. Intimate contact on a larger surface in the 2D/2D heterojunction is expected to enhance the stability of composites and enables fast charge transfer, resulting in improved photocatalytic performance. Since a strong chemical bond between two semiconductors is formed during hydrothermal epitaxial growth, this is a promising approach for the preparation of new, efficient heterostructured photocatalysts. In the design of nanoheterostructures, electron band structure and crystal lattice matching of both semiconductors should be considered. The latter is crucial for successful epitaxial growth. $SrTiO_3$ and $Bi_4Ti_3O_{12}$ show a good structural match in the [001] $Bi_4Ti_3O_{12}$ || [100] $SrTiO_3$; {110} $Bi_4Ti_3O_{12}$ || (100} $SrTiO_3$ orientational relationship with the lattice spacings of {110} $Bi_4Ti_3O_{12}$ and {100}$SrTiO_3$ being 0.3842 nm and 0.3905 nm, respectively. Experimental conditions for the epitaxial growth were determined based on the thermodynamics for $SrTiO_3$ formation. Advanced methods of aberration-corrected electron microscopy allowed us to gain an in-depth insight into the microstructural characteristics of the initial $Bi_4Ti_3O_{12}$ precursor, $SrTiO_3/Bi_4Ti_3O_{12}$ interface, final $SrTiO_3$ platelets and thus describe the process of epitaxial growth in detail, down to the atomic scale. In this epitaxial growth, the $Bi_4Ti_3O_{12}$ platelets act as a source of $Ti(OH)_6^{2-}$ species and at the same time as a substrate for the epitaxial growth of $SrTiO_3$. The dissolution of the $Bi_4Ti_3O_{12}$ platelets proceeds faster from the lateral direction, whereas the epitaxial growth of $SrTiO_3$ occurs on both the bismuth-oxide-terminated basal surface planes of the $Bi_4Ti_3O_{12}$ platelets. In the progress of the TC reaction, the $Bi_4Ti_3O_{12}$ platelet is being replaced from the lateral ends toward the interior by the $SrTiO_3$, while the $Bi_4Ti_3O_{12}$ is preserved in the core of the heterostructural platelet. The mechanism of the epitaxial growth is presented in Figure 1.

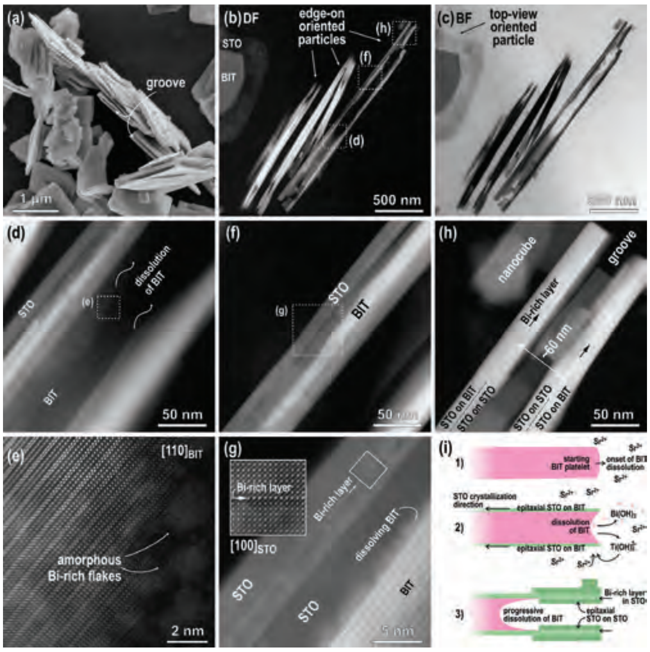

*Figure 1: (**a**) SEM and (**b-h**) STEM micrographs of $SrTiO_3/Bi_4Ti_3O_{12}$ heterostructural platelets (mainly edge-on-oriented platelets, which were thinned to electron transparency) as obtained after 1 h of a reaction at 200°C (6-M NaOH, Sr/Ti=12). (**b**) DF and (**c**) BF images showing (mainly) edge-on platelets along the whole side length, (**d**) DF of the central part of the platelet (showing $SrTiO_3$ layers and partially disintegrated $Bi_4Ti_3O_{12}$ inside the groove). (**e**) HR image of the area marked in (d) showing the disintegration of the $Bi_4Ti_3O_{12}$. (**f**) Another DF of the part between the central area and the edge of the platelet. (**g**) Magnified area from the image (f) presenting dissolution of the $Bi_4Ti_3O_{12}$ and the as-formed $SrTiO_3$ with the incorporated Bi-rich layer (HR image of this part is in the inset). (**h**) DF image of the edge of the platelet with two parallel $SrTiO_3$ platelets with incorporated Bi-rich layers. (**i**) Schematically shown processes of the TC reaction from $Bi_4Ti_3O_{12}$ to $SrTiO_3$ as reconstructed from STEM results, presented in b-h (ACS Applied Materials & interfaces, 13 (2021) 370-381).*

Since $SrTiO_3$ possesses more negative conduction band potential (E_{CB}) and Fermi level (E_F) than $Bi_4Ti_3O_{12}$, the electrons are transferred from $SrTiO_3$ to $Bi_4Ti_3O_{12}$ near the interface until Fermi-level equalization. This results in the formation of slightly positive and negative charge on the $SrTiO_3$ and $Bi_4Ti_3O_{12}$ sides, respectively. In the photocatalytic process, this internal electric field at the interface favour the migration of photogenerated electrons from the E_{CB} of $Bi_4Ti_3O_{12}$ to the valence band (E_{VB}) of $SrTiO_3$, where they recombine. Consequently, the photogenerated electrons in the E_{CB} of $SrTiO_3$ and holes in the E_{VB} of $Bi_4Ti_3O_{12}$ are available for the reduction of H^+ to H_2 and oxidation of methanol, respectively. This so-called direct Z-schemes mechanism explains the enhanced H_2 evolution on $SrTiO_3$/

$Bi_4Ti_3O_{12}$ nano-heterostructures. An in-depth understanding of the reaction mechanism for the formation of $SrTiO_3$/$Bi_4Ti_3O_{12}$ platelets expands the possibility of using the hydrothermal epitaxial growth approach for the design of other 2D/2D hetero-structural photocatalysts.

Without any support from noble-metal doping or co-catalysts, the $SrTiO_3/Bi_4Ti_3O_{12}$ platelets show a considerably higher photocatalytic H_2 evolution than individual materials and commercial $SrTiO_3$. The explanation for the improved photocatalytic performance of $SrTiO_3/Bi_4Ti_3O_{12}$ nanoheterostructural platelets was established based on the electronic band structures of $SrTiO_3$ and $Bi_4Ti_3O_{12}$.

A large emphasis of our research was on the integration of functional oxides with silicon using the pulsed-laser deposition technique. This year we focused on the mechanisms for the formation of a silicate layer at the junction between a $SrTiO_3$ thin film and a silicon substrate. The formation of such interlayers is not desirable because it prevents the transfer of electric charge across the STO-Si junction and therefore their use in certain applications. We found that by repeating the annealing to crystallize the STO layer, the thickness of the silicate interlayer is gradually increased to values of 1.2–1.9 nm. On the other hand, the expansion of the silicate layer does not significantly affect the quality of the STO layer itself. A crystallographic analysis using the XRD technique with a synchrotron light source has shown that ~3.7-nm-thick STO layers are highly crystalline, single-phase, and can be used for the epitaxy of thicker STO films, which was confirmed with additional experiments. XRD investigations also showed that thin layers of STO predominantly exhibit a cubic unit cell with a slightly larger unit cell (u.c.) volume compared to the bulk STO u.c. volume. The increase in the u.c. volume indicates the presence of oxygen vacancies in the STO films, which is a consequence of performing the STO deposition in an inert atmosphere. The results of this research will help us to further optimize the process for the growth of STO thin films on silicon.

A part of the research in the field of HfO_2 thin-film synthesis was carried out as part of the postdoctoral training of dr. Urška Trstenjak at the Peter Grünberg Institute (PGI-7), Forschungszentrum Jülich. HfO_2 is a material that exhibits interesting electrical properties, while being compatible with established processes in the electronics industry. The purpose of our work was to study the growth of HfO_2 thin films prepared by pulsed-laser deposition on amorphous substrates coated with graphene. Unlike the conventional preparation of epitaxial thin layers directly on crystalline substrates, in the synthesis on graphene the film binds to the substrate via van der Waals forces which enables dislocation-free strain relaxation. In the first phase of research, we focused on the prevention of graphene oxidation during the growth of the oxide film. We found that the use of bilayer graphene most effectively maintained the integrity of the graphene layers. The second-most important role was played by the gas atmosphere during deposition, where the growth of HfO_2 at a relatively high Ar pressure protected the graphene better than the deposition under UHV conditions, which is attributed to a decrease in the kinetic energy of the plasma particles, leading to reduced mechanical deformation of graphene. We found that graphene plays a key role in the successful crystallization of HfO_2 on SiO_2 substrates. We also found that HfO_2 on graphene grows in a thermodynamically stable monoclinic phase. By changing the deposition conditions, we were able to influence the crystallographic texture of the film.

The use of a high Ar pressure decreases the kinetic energy of the plasma particles and consequently reduces the mechanical deformation in the graphene layer.

We continued the study of growth and functional properties of the relaxor ferroelectric $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMN-PT) thin films. In particular, we were interested in studying the effect of the epitaxial strain in thin films with a thickness < 100nm. The principal aim was the growth of high-quality epitaxial relaxor ferroelectric PMN-PT thin films, which, in turn, enables the investigation of the role of biaxial misfit strain in driving changes to the domain structures and piezoelectric and ferroelectric response of the functional layer. PMN-33PT/SRO heterostructures were grown using pulsed-laser deposition on atomically smooth and singly-terminated oxide single-crystalline $SrTiO_3$ (STO) and $ReScO_3$ (*Re*= Dy, Tb, Gd, Sm, and Nd) (RSO) substrates (with a rocking curve value <0.05°). These substrates permit the application of a wide range of compressive strains on the PMN-33PT films from -2.90% (STO substrate) to -0.10% (NSO substrate). To avoid the pyrochlore phases and the deficiency in lead and magnesium (produce stoichiometric PMN-33PT thin films), 20 mol. % PbO and 10 mol.% MgO excess were used in the targets. We controlled the epitaxial growth mode at the unit-cell level of the deposited materials using *in-situ* high-pressure reflection high-energy electron diffraction (RHEED); first for the SRO on singly terminated STO and RSO substrates and then for the PMN-33PT layer on the SRO/STO and SRO/ RSO templates. RHEED and high-resolution X-ray diffraction (HR-XRD) analysis confirmed high-quality and epitaxial single-phase thin films with smooth 2D surfaces. Combining HR-XRD reciprocal space maps (RSMs) and HR-STEM investigations, fully strained PMN-33PT/SRO heterostructures free from defects were revealed on DSO, TSO, GSO, and SSO substrates with sharp interfaces confirming the 2D cube-on-cube growth mode of both SRO and PMN-33PT layers. In addition, from the RSMs patterns, an evolution from butterfly-shaped diffraction pattern for mildly strained PMN-33PT layers, which is evidence for the stabilization of relaxor domains, to disc-shaped diffraction patterns for high compressive strains with a highly distorted tetragonal structure, was revealed (Figure 2). The PFM amplitude and phase of the PMN-33PT thin films confirmed the relaxor-like response for a strain state below ~1.13%, while, for higher compressive strain (~1.9%), the irregularly shaped and poled ferroelectric domains were observed. Interestingly, the PFM phase hysteresis loops of the PMN-33PT heterostructures grown on the SSO substrates (strain state of ~ 0.8%) exhibited an enhanced coercive field, which is about two times larger than that of the thin films grown on GSO and NSO substrates. The obtained results demonstrated that the domain structures of the PMN-33PT heterostructures are sensitive to the applied compressive strain and this later could serve as an effective approach for tailoring and enhancing the functional properties in relaxor ferroelectrics.

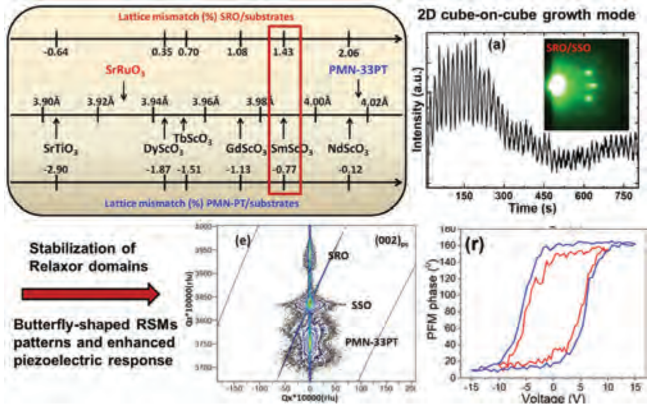

Figure 2: Strain engineering in epitaxial PMN-33PT films revealing a butterfly-shaped diffraction pattern for mildly strained films, evidencing the stabilization of relaxor nanodomains.

In collaboration with CRISMAT-CNRS Laboratory (Caen, France) we investigated thermoelectric materials inspired by the natural mineral colusite with complex crystal structure. The compound belongs to a new class of environmentally friendly copper-based sulphides composed of abundant, low-cost, industrial-grade raw materials. Mechanical alloying in combination with spark plasma sintering was used for the synthesis. The approach leads to the formation of various types of nano-to-microscale defects, from local Sn-site structural disorder to nano-inclusions and vanadium-rich core-shell microstructures (Figure 3a). We studied the recrystallization mechanism from the initial elements to the final colusite at different sintering temperatures. The analyses showed that metallic vanadium particles react with the surrounding copper sulphides to the transient V-rich sulvanite, Cu_3VS_4 (Figure 3b). Further diffusion processes lead to the formation of a V-rich and Sn-deficient colusite phase with a chemical composition around $Cu_{26}V_4Sn_4S_{32}$ with a V:Sn ratio of 1:1, and finally to the V-Sn colusite phase, $Cu_{26}V_2Sn_6S_{32}$ (Figure 3c). Multiscale defects in the final colusite grains have a strong impact over phonon scattering, making it possible to reach ultra-low lattice thermal conductivity. Simultaneously, the electrical transport properties are impacted through variations in charge-carrier concentration and effective mass, leading to a synergistic improvement of both the electrical and thermal properties. The results of this study were performed in the frame of the national research project J1-9177 and are published in Acta Materialia.

Structural inhomogeneities affect the phonon scattering and increase the charge-carrier density, leading to a synergistic improvement of the thermal as well as electrical properties.

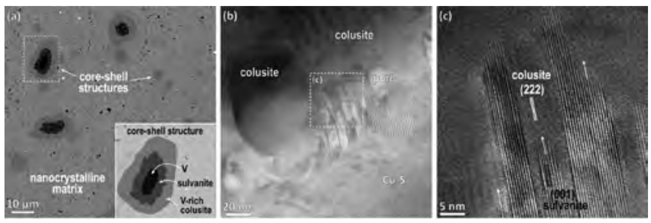

Figure 3: (a) V-rich core-shell structures in the sample after SPS at 600°C. (b) Transition between Cu-sulphide to colusite over transient sulvanite phase. (c) Oriented recrystallization of sulvanite to colusite.

In the scope of an investigation of phase relations in ternary oxide systems where new compounds and solid solutions form and exhibit interesting electric properties, we determined high-temperature phase equilibria in the La_2O_3–TiO_2-Nb_2O_5 system and presented it as a ternary phase diagram. In the system we identified numerous solid solutions based on already known compounds as well as one new solid solution. Extensions of the solid solutions were determined by systematic sample preparation and additional precise analysis. We also identified one new ternary compound and determined its chemical composition. The two-phase ceramics based on one subsystem exhibit very interesting microwave dielectric properties, which can be tailored by changing the relative content of the end components. Thus, the temperature-stable dielectric properties can be achieved at a certain composition.

Our research in the field of functional oxides that exhibit dielectric properties also included "upside-down" ceramic composites based on Li_2MoO_4–$SrTiO_3$ (LMO-ST), prepared by room-temperature fabrication (RTF) as a sustainable alternative to the time- and energy-consuming high-temperature sintering of ceramics (Figure 4). In the scope of our study, various physical parameters that might affect the overall processing and their final dielectric performance, were investigated. LMO-ST composites are based on a high ratio of filler ST, coupled with the corresponding LMO binder. During the room-temperature pressing and subsequent drying at 110°C, the binder proceeds to crystallize on the surface of the filler particles. Consequently, the filler particles become physically bound and the overall porosity decreases (ρ_{rel} = 84%). The experimental results in the low-frequency measurement area (1MHz) exhibit a relative permittivity

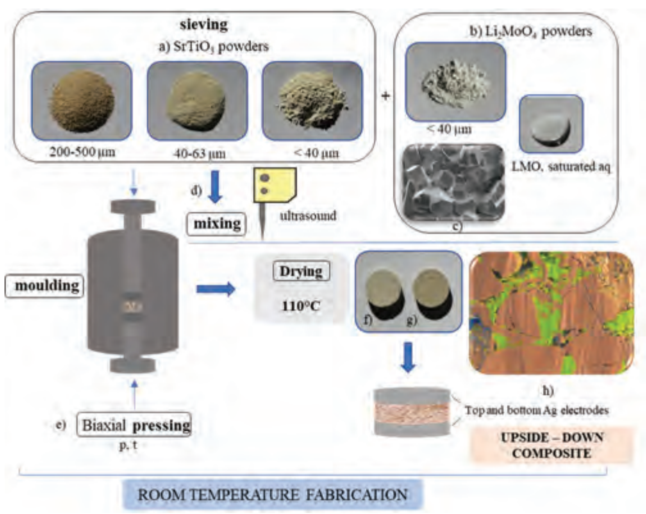

Figure 4: Experimental preparation protocol of upside- down LMO-ST composites is presented on the processing scheme.

(ε_r) of 65–78 corresponding with dielectric losses (tan δ) of 0.002–0.05. The properties can attract considerable attention for the utilization of LMO-ST composites in the industry of electroceramics.

Zinc (Zn) is an essential micronutrient in human health and is the reason for the massive annual production of zinc glutonate-based food additives and medicines. Unfortunately, once expired, waste zinc gluconates are generally disposed of with other garbage, causing an excessive influx of zinc ions into the environment, which could deactivate the soil, affect the plant growth and cause the great damage to humans and animals. To reduce environmental pollution and the waste of zinc resources, we investigated the recycling of expired waste zinc gluconate as a source for preparation of photocatalytic ZnO nanostructures. In a typical synthesis, zinc gluconate water solution was placed in a Teflon container, sealed in an autoclave and hydrothermally reacted at 180 °C/12 h. The resulting black suspension was washed, centrifuged and dried. Black powder was fired at 500°C. The XRD analysis has shown that the obtained powder consisted of the ZnO wurzite compound with a 45-nm particle size. However, an SEM investigation has shown ZnO micron spheres that consisted of nanoparticles intertwined with a hollow structure. We have shown that such a structure enables good photocatalytic activity by testing the degradation of the organic methyl blue dye under the UV light, which has shown that 50 % of the dye degrades in 90 min.

Antibacterial and piezoelectric biocompatible materials

With the aim to create novel tools applicable in regenerative medicine and tissue engineering, we are working on designing novel biomaterials with the focus in two areas: designing organic piezoelectrics and developing innovative antimicrobials.

Within the project Mechano-chromic, voltage-sensitive electrostimulators: innovative piezoelectric biomaterials for electro-stimulated cellular growth, in collaboration with partners from ETH, Switzerland, we are developing biocompatible and biodegradable organic piezoelectric films designed to accelerate cellular proliferation. For this purpose, we optimized two processing approaches: drawing and template wetting. Drawing enables thick poly-l-lactide (PLLA) piezoelectric films with a layered structure (Figure 5a). Upon mechanical deformation using ultrasound, films dropped in cell growth media can generate a voltage signal. We observed that biodegration of these films starts as surface erosion due to their hydrophilic surface, which preserves their mechanical and piezoelectric properties for a longer period of time under simulated physiological conditions. The template-wetting method provides nanotextured PLLA films containing aligned nanotubes with approximately 100-nm diameters (Figure 5b). By observing single nanotubes using XRD and polarized Raman, we confirmed that crystallization and molecular orientation are the key properties needed to obtain piezoelectricity. Both types of films, layered and nanostructured, are confirmed to have antibacterial characteristics as a consequence of piezo-stimulation. In the case of nanotubes, piezoelectricity is combined with a nanotexture, which additionally contributes to their antimicrobial performance. In contrast to their effect on bacterial cells and providing antibacterial properties, piezoelectric PLLA films, both layered and nanotextured, do not trigger any haemolysis and damage in animal-sourced red blood cells (RBCs). Staining RBC membrane do not reveal any mechanical damages after piezostimulation and membrane non-permeable FM 646 dye remained on their outer leaflet (Figure 5d).

The optimal functionalization that prevented particle aggregation and further growth in aqueous media was obtained by replacing oleic acid with dopamine ligands.

We also continued our research on developing novel antimicrobial nanomaterials. Within the project Environmentally friendly antimicrobial material for textile with improved properties, together with the Centre for Technology Transfer (CTT) we collaborate with the Hungarian company Innowear-tex, as anti-microbial textile producer, and Portugal industrial textile research institute (CITEVE). Together we are developing and testing a textile prototype containing antimicrobial components based on functionalized gold, initially developed and patented in our lab. In addition, we worked on the preparation of stable aqueous colloidal solutions of monodisperse gallium nanoparticles with different sizes and surface ligands to investigate their antibacterial properties in detail. Starting from a thermal decomposition synthesis that yields monodisperse oleic-acid-capped Ga nanoparticles, we changed the surface properties from hydrophobic to hydrophilic using different ligand-exchange processes. The optimal results were obtained by replacing oleic acid with dopamine ligands (with morphology and water-stability illustrated in Figure 5c). We have explored the influence of near-infrared (NIR) laser irradiation on local heating of doped cobalt ferrite and their composites with functionalized gold nanoparticles to enhance

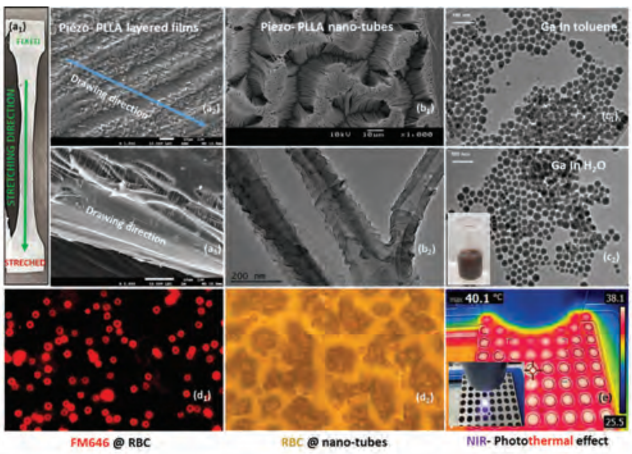

Figure 5: Piezo-PLLA films in the form of layered structure (a_{1-3}) and nanotubes (b_{1-2}). Gallium nanoparticles: from hydrophobic (c_1 in toluene) to hydrophilic (c_2 stable suspension in water). Red blood cells (RBCs) labelled with FM646 (surface impermeable) (d_1) and on top of nanotubes (d_2). NIR laser irradiating nanoparticles and their heating (e).

their antimicrobial activity with the photothermal effect. The heating capacity of the composites obtained upon laser-irradiation is illustrated in Figure 5e. We consider the newly optimized Ga NPs as the most optimal for further antimicrobial studies, particularly as a new platform for photothermal antimicrobial activity.

Materials for heat-insulation applications

Insulation materials have a strong impact on the energy efficiency of buildings, which are one of the main energy-consumers, representing 40 % of all consumed energy in the EU. The use of waste raw materials and less energy-intensive processes are important trends in scientific research, aiming to reduce the industrial impact on the environment.

In accordance with these trends, we investigated the use of waste container glass in foamed-glass production. However, due to the poor glass stability of container glass, i.e., its tendency towards crystallization, it is difficult to obtain a product with a good quality. We investigated crystallization in the container glass by DSC and XRD analyses and observed a complex crystallization with the separation of several crystalline phases. The glass stability improves if the glass is re-melted and becomes similar to the stability of a model soda-lime-silica glass prepared from technical grade chemicals. However, it remains unsuitable for foam-glass production. Therefore, we tested various additives in order to inhibit the crystallization. Finally, we succeeded to inhibit the crystallization process with the selection of the proper fluxing agents (B_2O_3 or borax) in a combination with crystallization inhibitor Al_2O_3. XRD analysis revealed that with the addition of fluxing agents the crystalline content decreased to below 15% and these results are also evidenced by DSC analyses. Measurements of the thermal conductivity on the sintered-glass samples confirmed the important decrease of thermal conductivity by inhibition of the crystallization. Based on the obtained knowledge on the crystallization process, we tested foaming mixtures with the fluxing additives and observed the best results for the addition of B_2O_3. The closed porosity decreased, as expected, due to the smaller crystalline content. However, it was not possible to decrease the density to suitably low values. Therefore, we continued with the development of the foaming recipe by moderately decreasing the content of B_2O_3 and the introduction of phosphates, with the aim to decrease the viscosity and surface tension. The results we obtained are promising and the future focus will be on the preparation of larger foam samples for characterization of the thermal and mechanical properties.

Optimization of the new foaming recipe, containing a combination of fluxing additives and crystallization inhibitor, led us to promising results.

The use of waste materials in combination with water glass can further decrease the environmental impact of foamed-glass production, while maintaining high-quality product characterized by low thermal conductivity. Water glass is a well-known and commonly used additive for foamed-glass production. However, the related foaming mechanisms are scarcely investigated and while a commonly accepted mechanism theory exists, it is not supported by experimental evidence (Figure 6). With the use of waste panel cathode-ray-tube (CRT) glass, which exhibits good glass stability, we focused on revealing the mechanisms of glass foaming with water glass. We analysed the behaviour of the foaming mixture of CRT and water glass during heating via heating stage microscopy (HSM) and thermogravimetry coupled with mass spectroscopy (TG/MS). The atmosphere inside the closed pores of the foamed glass were investigated by gas chromatography (GC/MS), which revealed that, surprisingly, CO_2 is the main component. The results showcase the sensitivity of the foaming mixture on the atmospheric CO_2 which reacts with hydrated layer of glass and forms carbonates. Newly formed carbonates decompose at elevated temperatures, producing CO_2, which is the driving force behind the expansion. Additionally, foaming process can be controlled by controlling the degree to which the reaction between hydrated layer of glass and CO_2 can proceed. We found that this can be achieved by drying the foaming mixture, i.e. freeing it of "low-temperature" water, which inhibits the reaction. Future research will be focused on the exploitation of newly revealed mechanisms to produce sustainable foamed glass.

Figure 6: Higher addition of water glass allows the same expansions to be achieved at lower temperatures, which has a favourable effect on the energy complexity of production.

Projects

As part of the **M-ERA-NET project: SunToChem**, researchers from the Jožef Stefan Institute (JSI), the Institute of Solid State Physics, the University of Latvia (ISSP-UL) and the Department of Chemical Engineering of the National University of Taiwan (CHe-NTU) are pooling the latest knowledge in the field of particle morphology design (JSI), theoretical calculations (FP) and photocatalytic measurements (ChE-NTU) to prepare efficient perovskite photocatalysts for the formation of H_2 by water cleavage. The main purpose of the project is to precisely control particle characteristics such as exposed surface types, finishes, crystal defects (oxygen gaps), mesocrystallinity, hetero-structuredness, and ferroelectricity to increase photocatalytic efficiency based on better charge-carrier separation and light absorption. Funded by: M-ERA.NET European transnational agency. Coordinator: dr. Marjeta Maček Kržmanc

Applied project **Mineral wool composites with improved insulation properties** is focused on the development of a new, innovative preparation procedure for mineral wool composites with decreased thermal conductivity. Theoretical calculations on the thermal conductivity of the composites were experimentally validated, confirming the great potential of the new composites. Testing of mechanical properties of the composites revealed that modifications to the surface properties is necessary to obtain suitable stability of the composite. Surface properties of the composite's components properties were modified by thermal and chemical routes. The results showed that any excessive amount of water used in the processing is detrimental for mechanical as well as insulation properties. Thereafter, investigation focused on the development of a dry composite processing route, which gave the best results in terms of mechanical and insulation properties. The dry processing route also has the highest industrial feasibility. Funding agency: Slovenian Research Agency. Coordinator: Jakob König.

Project **SIOX** aims to exploit the rich functionalities of oxides and their heterostructures, which show great promise within the emerging field of oxide electronics. For their implementation, the epitaxial integration of oxides with silicon platforms using industrially appropriate technology is urgently needed, and its development represents the main goal of SIOX. Funding agency: M-ERA.NET European Transnational Agency. Coordinator and principal investigator: Asst. Prof. Matjaž Spreitzer.

Awards and appointments

1. Heli Jantunen: Yushan Scholar Award, Yushan, Taiwan, Ministry of Education (MOE), ROC Taiwan, Ultra-low temperature co-firing ceramics.
2. Matjaž Spreitzer, Srečo Škapin: Silver award of the CCIS for the innovation TCG Autoskimm, Maribor, Chamber of Commerce and Industry of Slovenia, Development of automatic slag skimming process to reduce aluminum losses and ensure reproducible melt quality.
3. Matjaž Spreitzer, Srečo Škapin: Silver award of the CCIS for the innovation New super-light and super hard engineering materials, Maribor, Chamber of Commerce and Industry of Slovenia, Development of a laboratory-verified synthetic pathway for the production of lightweight, super-solid advanced materials based on Al-Mg-B-Ti.
4. Matjaž Spreitzer: Success Story - ENPIEZO, Austria, M-era.Net Network, Innovative Surfaces, Coatings and Interfaces: Enabling technology for high-quality piezoMEMS.
5. Danilo Suvorov, Srečo Škapin, Marija Vukomanović: Special prize for innovations for economy, Ljubljana, Center for technology transfer and innovation JSI, Contact-based, leaching-free antimicrobial textile Silver-free, wearable germ protection.
6. Marija Vukomanović: Success Story within KETGate project, Interreg Central Europe, Ljubljana, Center for technology transfer and innovation JSI, Development of products based on nanofibers with potential antimicrobial effect for various applications.

Organization of conferences, congresses and meetings

1. Workshop on international project M.ERA-NET "SunToChem: Engineering of perovskite photocatalysts for sunlight-driven hydrogen evolution from water splitting", 11. 6. 2020 & 9. 12. 2020 (virtual).
2. Kick-off meeting of international project "Mechano-chromic, voltage-sensitive electrostimulators: innovative piezoelectric biomaterials for electro-stimulated cellular growth", 15. 9. 2020 (virtual).
3. Kick-off meeting of international project KET4Clean Production: "Environmentally friendly antimicrobial material for textile with improved properties", 21. 9. 2020 (virtual).
4. Workshop on international project M.ERA-NET "SIOX: Engineering of silicon-oxide interface using the pulsed-laser deposition technique", 20.7. 2020 (virtual).

INTERNATIONAL PROJECTS

1. Investigation of NdDyCoCuFe Rare Earth Alloys Alloys and Related Compounds
   Asst. Prof. Matjaž Spreitzer
   Urban Mining Company
2. Investigation of NdDyCoCuFe Rare Earth Alloys Alloys and Related Compounds
   Asst. Prof. Matjaž Spreitzer
   Urban Mining Company
3. COST CA 17140; Cancer Nanomedicine - From the Bench to the Bedside (NANO2CL)
   Asst. Prof. Marija Vukomanović
   Cost Association Aisbl
4. Stoichiometry Engineering of Epitaxial PMN-PT Thin Films
   Asst. Prof. Matjaž Spreitzer
   Slovenian Research Agency

RESEARCH PROGRAMME

1. Contemporary Inorganic Materials and Nanotechnologies
   Asst. Prof. Matjaž Spreitzer

R & D GRANTS AND CONTRACTS

1. Non-traditional isotopes as identifiers of authigenic carbonates
   Prof. Srečo Davor Škapin
2. Synthesis and characterization of alkali activated foams based on different waste
   Prof. Srečo Davor Škapin
3. Piezoelectric Biomaterials for Electro-stimulated Regeneration
   Asst. Prof. Marija Vukomanović
4. Nanoscale investigations of diffusion controlled topotaxial phase transformations in rutile-corundum host systems
   Asst. Prof. Nina Daneu
5. Engineering of oxides on silicon for future electronics
   Asst. Prof. Matjaž Spreitzer
6. Mineral inclusions in garnet from macroscopic to atomic scale: Opening the petrogenetic archive
   Asst. Prof. Nina Daneu
7. Strain and domain structure engineering in epitaxial relaxor ferroelectric thin films
   Asst. Prof. Matjaž Spreitzer
8. Mechano-chromic, voltage-sensitive electrostimulators: innovative piezoelectric biomaterials for electro-stimulated cellular growth
   Asst. Prof. Marija Vukomanović
9. Engineering of relaxor ferroelectric thin films for piezoelectric and energy storage applications
   Asst. Prof. Matjaž Spreitzer
10. Mineral wool composite with improved insulation properties
    Dr. Jakob König
11. Central European SME Gateway zo Key-enabling Technology Infrastructures - Sparking new Transnational KET Innovation Ecosystem
    Asst. Prof. Matjaž Spreitzer
    Bay Zoltan Alkalmazott Kutatasi Kozhasznu
12. Innovative ECO plasma seed treatment (for sowing and for human and animal diet/nutrition
    Asst. Prof. Marija Vukomanović
    Ministry of Education, Science and Sport
13. Strategic Research & Innovation Partnership Factories of the Future (SRIP FoF)
    Asst. Prof. Matjaž Spreitzer
    Ministry of Economic Development and Technology
14. Control of crystallization in glass materials for thermal insulation
    Dr. Sonja Smiljanić
    Ministry of Education, Science and Sport
15. HarvEnPiez: Innovative nano-materials and architectures for integratedpiezoelectric energy harvesting applications
    Dr. Marjeta Maček Kržmanc
    Ministry of Education, Science and Sport
16. SIOX: Engineering of silicon-oxide interface using the pulsed-laser deposition technique
    Asst. Prof. Matjaž Spreitzer
    Ministry of Education, Science and Sport
17. SunToChem: Engineering of perovskite photocatalysts for sunlight-driven hydrogen evolution from water splitting
    Dr. Marjeta Maček Kržmanc
    Ministry of Education, Science and Sport
18. Reimbursement of costs of scientific publications in golden open access for 2019, 2020
    Asst. Prof. Matjaž Spreitzer
    Slovenian Research Agency
19. XRD Analysis
    Asst. Prof. Matjaž Spreitzer
20. Stay of Nina Kuzmić iin Oulu, Finland - Low Temperature Densification of Strontium Titanate Ceramics, May - June 2020
    Nina Kuzmić
    Jecs Trust
21. KET4CLEAN-INNOWEAR-TEX; Costs of Work of K9 on the Case KET4CLEAN PRODUCTION-INNOWEAR-TEX
    Asst. Prof. Matjaž Spreitzer
    Innowear-tex Kft.

VISITORS FROM ABROAD

1. Dr. Manal Benyoussef, Laboratoire de Physique de la Matière Condensée (LPMC), Amiens, France, 27. 1. to 13. 3. 2020 and 1. 6. to 30. 9. 2020.
2. Dr. Taisia Alifirova, Department of Lithospheric Research, University of Vienna, Austria, 19. 7. to 24. 7. 2020.

Visiting Researchers

1. Dr. Saswati Santra, Indian Institute of Science, Bangalore, India, 15. 2. to 31.8. 2020.
2. Dr. Jamal Belhadi, Laboratoire de Physique de la Matière Condensée (LPMC), Amiens, France, 1. 3. 2019 to 29. 2. 2020.
3. Dr. Sonja Smiljanić, University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia, 1. 6. 2019 to 31.3. 2022.

STAFF

Researchers

1. Asst. Prof. Nina Daneu
2. Heli Maarit Jantunen, B. Sc.
3. *Zoran Jovanović, left 05.01.20*
4. Dr. Jakob König
5. Dr. Gertjan Koster
6. Dr. Špela Kunej
7. Dr. Marjeta Maček Kržmanc
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9. Prof. Srečo Davor Škapin
10. Dr. Marija Vukomanović

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11. Jamal Belhadi, B. Sc.
12. *Dr. Sonja Jovanović, left 05.01.20*
13. Dr. Mario Kurtjak
14. Sonja Smiljanić, B. Sc.
15. Dr. Urška Trstenjak

Postgraduates

16. Petruša Borštnar, B. Sc.
17. Alja Čontala, B. Sc.
18. Uroš Hribar, B. Sc.
19. Nina Kuzmić, B. Sc.
20. Tjaša Parkelj Potočnik, B. Sc.
21. Lea Udovč, B. Sc.

Technical officers

22. David Fabijan, B. Sc.
23. Tina Radošević, B. Sc.
24. Damjan Vengust, B. Sc.

Technical and administrative staff

25. Vesna Butinar, B. Sc.
26. Silvo Zupančič

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ORIGINAL ARTICLE

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2. Phu T. P. Le, Johan E. ten Elshof, Gertjan Koster, "Shape control of $Ca_2Nb_3O_{10}$ nanosheets: paving the way for monolithic integration of functional oxides with CMOS", *ACS applied nano materials*, 2020, **3**, 9, 9487-9493.
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5. Martin B. Østergaard, Manlin Zhang, Xiaomei Shen, Rasmus R. Petersen, Jakob Koenig, Peter D. Lee, Yuanzheng Yue, Biao Cai, "High-speed synchrotron X-ray imaging of glass foaming and thermal conductivity simulation", *Acta materialia*, 2020, **189**, 85-92.
6. Gabin Guélou, Christophe Couder, Abdelhamid Bourhim, Oleg I. Lebedev, Nina Daneu, Florian Appert, Jean Juraszek, Pierre Lemoine, Lorraine Segreto, Emmanuel Guilmeau, "A scalable synthesis route for multiscale defect engineering in the sustainable thermoelectric quaternary sulfide $Cu_{26}V_2Sn_6SB_{32}$", *Acta materialia*, 2020, **195**, 229-239.
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Published Conference Contribution

1. Katja Traven, Mark Češnovar, Srečo D. Škapin, Vilma Ducman, "Evaluation of fly ash-based alkali activated foams at room and elevated temperatures", In: *2nd International Conference on Technologies & Business Models for Circular Economy*, Proceedings, Maribor Faculty of Chemistry and Chemical Engineering, 2020, 23-34.
2. Tina Radošević, Anja Černoša, Manca Kovač Viršek, Martina Kocijan, Damjan Vengust, Cene Gostinčar, Aleš Mihelič, Nina Gunde-Cimerman, Sašo Šturm, Matejka Podlogar, "Razgradnja tekstilnih mikroplastičnih vlaken s fotokatalizo in glivami", In: *Vodni dnevi 2020, 17.-18. september 2020, Rimske Toplice, Kongresni center Rimske terme*, zbornik referatov, Slovensko društvo za zaščito voda, 2020, 203-213.

Theses and Mentoring

1. Janvit Teržan, *Propene partial oxidation with molecular oxygen over alkali modified CuO_x/SiO_2 catalysts:* doctoral dissertation, Ljubljana, 2020 (mentor Matjaž Spreitzer; co-mentor Petar Djinović).