DEPARTMENT OF SOLID STATE PHYSICS F-5

Our research program is focused on the study of the structure and dynamics of disordered and partially ordered condensed matter at the atomic and molecular levels, with a special emphasis on phase transitions. The purpose of these investigations is to discover the basic laws of physics governing the behaviour of these systems, which represent the link between perfectly ordered crystals, on one side, and amorphous matter, soft condensed matter and living systems, on the other. Such knowledge provides the key to our understanding of the macroscopic properties of these systems and is an important condition for the discovery and development of new multifunctional materials, nanomaterials and biomaterials for new applications. An important part of the research program is devoted to the development of new experimental methods and techniques in the field of magnetic resonance, magnetic resonance imaging, fluorescence microspectroscopy, scanning tunnelling, electronic and atomic force microscopy, as well as dielectric relaxation spectroscopy and dynamic specific-heat measurements.

Head:
Prof. Igor Muševič

The experimental techniques used are:

- One (1D) and two (2D) dimensional nuclear magnetic resonance (NMR) and relaxation, as well as quadrupole (NQR) resonance and relaxation,
- Multi-frequency NMR in superconducting magnets of 2T, 6T and 9T, as well as the dispersion of the spin–lattice relaxation time T_1 via field cycling,
- Nuclear double resonance and quadrupole double resonance such as ^{17}O–H and ^{14}N-H,
- Fast field cycling NMR relaxometry,
- Frequency-dependent electron paramagnetic resonance (EPR) and 1D and 2D pulsed EPR and relaxation
- MR imaging and micro-imaging
- Measurement of the electronic transport properties
- Magnetic measurements.
- Fluorescence microscopy and microspectroscopy
- Linear and non-linear dielectric spectroscopy in the range 10^{-2} Hz to 10^{9} Hz,
- Electron microscopy and scanning tunnelling microscopy,
- Atomic force microscopy and force spectroscopy,
- Dynamic specific heat measurements.

The research program of the Department of Solid State Physics at "Jozef Stefan Institute" is performed in close collaboration with the Department of Physics at the Faculty of Mathematics and Physics of the University of Ljubljana, Institute of Mathematics, Physics and Mechanics and the J. Stefan International Postgraduate School. In 2016, the research was performed within three research programs:

- Magnetic resonance and dielectric spectroscopy of smart new materials
- Physics of Soft Matter, Surfaces and Nanostructures
- Experimental Biophysics of Complex Systems

The research group has discovered new quantum phenomena in the magnetism of low-dimensional spin systems. It has studied physical properties of a novel type of nanomaterials suitable for gas sensors and has discovered new materials with a giant electrocaloric effect for applications in cooling devices. The group has developed new polymer-dispersed liquid-crystalline elastomers. The Schottky effect has been demonstrated in quasicrystals, which fundamentally changes the interpretation of their low-temperature electronic and magnetic properties. The research has included pharmaceutical and biological substances.

I. Program group "Magnetic resonance and dielectric spectroscopy of smart new materials"

The research of the program group *Magnetic Resonance and Dielectric Spectroscopy of Smart New Materials* was focused on the study of physical phenomena in condensed matter at the atomic and molecular levels. The purpose of the investigations was to discover the basic laws of physics governing the behaviour of the investigated systems. The attained knowledge provides the key to the understanding of the microscopic and macroscopic properties of various types of solids and is an important condi-

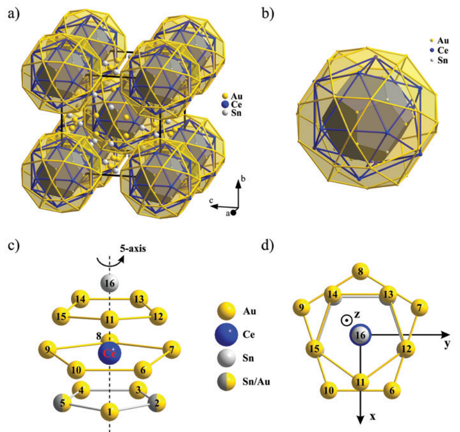

Figure 1: Icosahedral structure and pentagonal distribution of electric charges in Ce-Au-Sn-type quasicrystals for the calculation of the Schottky effect.

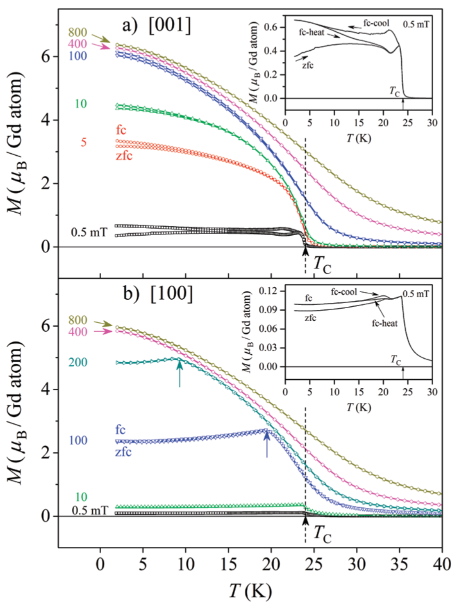

Figure 2: Temperature-dependent magnetization of the Cu-Ca-Gd alloy for a magnetic field directed along the hexagonal axis and in the hexagonal plane.

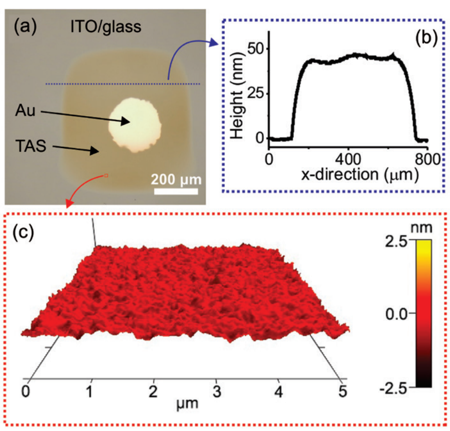

Figure 3: (a) Optical photograph, (b) cross-sectional profile, and (c) 3D AFM topology image of 45-nm-thick printed tantalum-oxide-based (TAS) thin-film capacitor.

tion for the discovery and development of new multifunctional materials and nanomaterials for novel technological applications.

The research program was implemented in close collaboration with the Department of Physics at the Faculty of Mathematics and Physics of the University of Ljubljana, Institute of Mathematics, Physics and Mechanics, and the J. Stefan International Postgraduate School.

In 2016, members of the program group published 47 original scientific papers in international peer-reviewed scientific journals. Among these, one paper was published in Nature Commun. (IF = 11.3), one in Phys. Rev. Lett. (IF = 7.6), one in ACS Applied Mater. & Interfaces (IF = 7.1), two in Sci. Rep. (IF = 5.2), and three in J. Mater. Chem. C (IF = 5.1).

The investigations were focused on the following research fields:

Quasicrystals and complex metallic alloys

In the publication *Schottky effect in the i-Zn-Ag-Sc-Tm icosahedral quasicrystal and its 1/1 Zn-Sc-Tm approximant* (S. Jazbec et al., Phys. Rev. B **93**, 054208 (2016)) we have for the first time experimentally proved the existence of the Schottky effect in quasicrystals. This discovery fundamentally changes the current interpretations of the low-temperature electronic and magnetic effects in quasicrystals and their periodic approximants. We have developed the theory of the Schottky effect for the pentagonal symmetry of the crystal electric fields, applicable to quasicrystals of the structural type Ce-Au-Sn. The icosahedral structure and pentagonal distribution of electric charges in Ce-Au-Sn are shown in Figure 1.

In the publication Random-anisotropy ferromagnetic state in the $Cu_5Gd_{0.54}Ca_{0.42}$ intermetallic compound (M. Krnel et al., Phys. Rev. B **93**, 094202 (2016)) we presented the synthesis of the first ternary compound in the Cu-Ca-Gd system, where the immiscible elements Ca and Gd are chemically bound into a crystal by the third “intervening” element copper, which makes stable binary phases with both elements. We determined physical properties for this new ternary alloy and showed that its magnetic state can be described as a random-anisotropy ferromagnet. Figure 2 shows the temperature-dependent magnetization of the alloy for a magnetic field directed along the hexagonal axis and in the hexagonal plane.

Inkjet printing of uniform dielectric oxide structures

Inkjet printing of high-dielectric-constant metal-oxide layers will enable the low-cost deposition of the essential building blocks in electronics. We have developed an ink formulation suitable for the printing of tantalum-oxide-based dielectric layers. Our goal was to improve the thickness uniformity of dried deposits via optimization of the ink’s solvent composition. We have shown that in addition to designing the solvent mixture according to the viscosity and surface-tension criteria, the volatility of solvents has to be considered, as it strongly influences the thickness uniformity. By rigorously adjusting the solvent composition, we were able to tailor the topology of the deposits and print 45-nm-thick, flat and uniform capacitors with functional properties comparable to spin-coated films. We published our discoveries in *Inkjet printing of uniform dielectric oxide structures from sol-gel inks by adjusting the solvent composition* (A. Matavž, R. C. Frunză, A. Drnovšek, V. Bobnar, B. Malič, Journal of Materials Chemistry C 4, 5634 (2016)).

Development of an eco-friendly material for flexible energy-storage devices

Nanocomposite films were fabricated by incorporating ammonia-functionalized graphene oxide (NGO) into the native (CNF) and TEMPO-oxidized (TCNF) cellulose nanofibrils matrices using a solvent-casting method. The structural and morphological analysis revealed good dispersibility of the NGO sheets in the randomly distributed CNF, and the dense and parallel-oriented TCNF nanofibrils. Such a synergistic effect of both components contributed to ultra-strong and stiff films with good mechanical and thermal stability. Due to the Maxwell-Wagner polarization, the dielectric constant strongly increases already at a low NGO content. Thus, this mechanically strong, flexible, and thermally stable composites are suitable, cost-effective, alternative green materials for flexible energy-storage devices. This research was published in the paper *Mechanically strong, flexible and thermally stable graphene oxide/nanocellulosic films with enhanced dielectric properties* (Y. Beeran P. T. et al., RSC Advances 6, 49138 (2016)).

Stable dielectric response of newly developed low-loss polymer thin films

We have investigated the dielectric properties of aromatic polythiourea (ArPTU, polar polymer containing high dipolar moments with very low defect levels) thin films that were developed on a Pt/SiO_2 substrate. The detected response was compared to the response of commercially available polymers, such as high-density polyethylene (HDPE) and polypropylene (PP), which are at the present both used in foil capacitors. Stable values of the dielectric constant (being two times higher than in HDPE and PP) over broad temperature and frequency ranges and dielectric losses as low as in commercial systems suggest that ArPTU is a promising candidate for future use in a variety of applications. The findings were published in *Stable dielectric response of low-loss aromatic polythiourea thin films on Pt/SiO_2 substrate* (A. Eršte et al., Journal of Advanced Dielectrics 6, 1650003 (2016)).

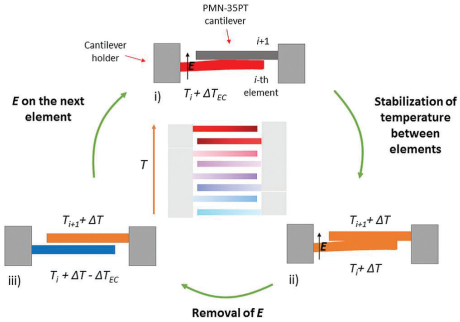

Figure 4: Schematics of the refrigeration cycle of cascade electrocaloric cooling device exploiting in cantilever cooling elements both an electrocaloric and electromechanic response.

Study of nanostructured materials and materials with large electrocaloric effect and its application in a solid-state cooling device:

Using direct measurements, we showed the coexistence of both the electrocaloric and magnetocaloric effect in multiferroic PFN-PMW. We were among the first to demonstrate the existence of a large electrocaloric effect in liquid crystals and of a large elastocaloric effect in liquid-crystal elastomers. In addition, we have analysed the working cycle of a prototype of a cascade electrocaloric device exploiting both the electrocaloric and electromechanic effects. In 2016, the Gorenje d.d. company bought our *Patent application US 2016/0187034 A17700,* 2016, (B. Malič et al.). The above results were published in 11 articles in international scientific journals, among which we must mention *Perovskite ferroelectrics and relaxor-ferroelectric solid solutions with large intrinsic electrocaloric response over broad temperature ranges* (H. Khassaf et al., P. Journal of Materials Chemistry *C,* 4 (2016), 4763), *A multicaloric material as a link between electrocaloric and magnetocaloric refrigeration* (H. Uršič et al., Scientific Reports, 6 (2016), 26629-1-26629-5), *$BaZr_{0.5}Ti_{0.5}O_3$: Lead-free relaxor ferroelectric or dipolar glass* (C. Filipič, Z. Kutnjak, R. Pirc, G. Canu, J. Petzelt, Physical Review B, 93 (2016), 224105-1-224105-8), and *Electrocaloric and elastocaloric effects in soft materials* (M. Trček et al., *Philosophical Transactions A,* 374 (2016), 20150301). Recent publications on electrocalorics and TGB and blue phases have been cited more than 100 times in 2016.

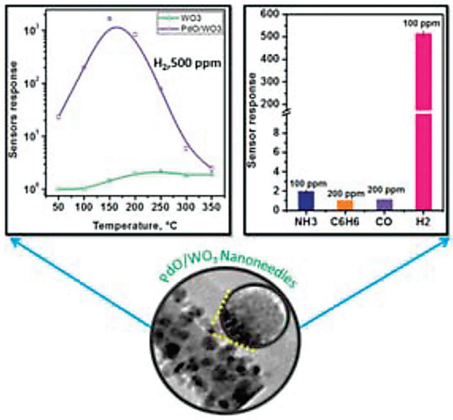

Figure 5: Left: sensor response (WO3 nanoneedles decorated with PdO nanoparticles) on 500 ppm of H_2 between 50 and 350 °C (violet curve) compared with a sensor based on bare WO_3 nanoneedles (green curve). Right: Selectivity diagram of PdO/WO_3 sensor toward NH_3, C_6H_6 and CO interfering gases.

Nanomaterials for gas-sensor applications

Polona Umek collaborated with colleagues from Great Britain, Czech Republic, Belgium, France and Spain in the research of gas sensors based on WO_3 nanoneedles (NN) decorated with PdO nanoparticles (NP). Morphological, structural, and elemental composition analysis revealed that a Pd(acac)$_2$ precursor was very suitable to decorate WO_3 NNs with uniform and well-dispersed PdO NPs. Gas-sensing results revealed that the decoration with PdO NPs led to an ultrasensitive and selective hydrogen (H_2) gas sensor with a low operating temperature (150 °C). The response of the decorated NNs is 755-times higher than that of bare WO_3 NNs. Humidity measurements showed that PdO/WO_3 sensors displayed low-cross-sensitivity towards water vapour, compared to bare WO_3 sensors. The addition of PdO NPs helps to minimize the effect of ambient humidity on the sensor response. The research was published in the article *Aerosol-assisted CVD-grown PdO nanoparticle-decorated tungsten oxide nanoneedles extremely sensitive and selective to hydrogen* (F. E. Annanouch et al., *ACS Applied Materials & Interfaces* 8, 10413 (2016)).

Pharmaceutical substances studied by NQR spectroscopy

^{14}N NQR is a useful tool to characterize pharmaceutical substances and the method of their preparation. In combination with other experimental techniques and quantum chemical calculations, the electronic structure of these molecules and the properties of functional groups can be determined, as shown in the article *Polymorphism and Thermal Stability of Natural Active Ingredients. 3,3'- Diindolylmethane (Chemopreventive and Chemotherapeutic) Studied by a Combined X-Ray, ^{1}H – ^{14}N NMR NQR, DSC and Solid-State DFT/3D HS/QTAIM/RDS Computational Approach* (J. N. Latosinska, M. Latosinska, M. Szafranski, J. Seliger, V. Žagar, Cryst. Growth Des. 16, 4336-4348 (2016)).

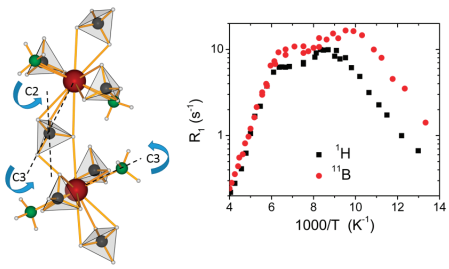

Figure 6: ^{1}H NMR relaxometric study of molecular dynamics in a "de Vries" liquid crystal.

The compound 3,3′-diindolylmethane (DIM) is a major in-vivo product of the digestion of indole-3-carbinol (I3C) and a main mediator of its chemopreventive and chemotherapeutic effects. In this paper, the co-influence of two factors, polymorphism and temperature, on the topology, nature, and strength of the interaction pattern in DIM are in our area of interest. Upon polymorph screening, it has been found that DIM crystallizes in two polymorphic forms, form I (already known) and form II (newly obtained). Differential scanning calorimetry indicated a slightly lower melting point for form I than for

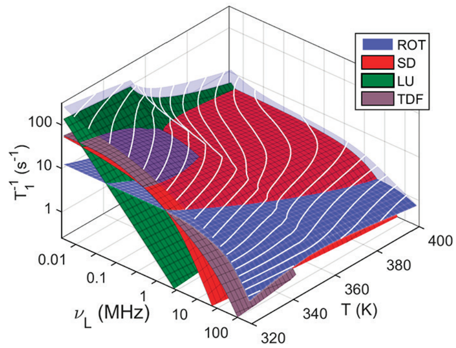

Figure 7: ^{1}H–^{14}N cross-relaxation spectrum analysis in sildenafil and sildenafil citrate.

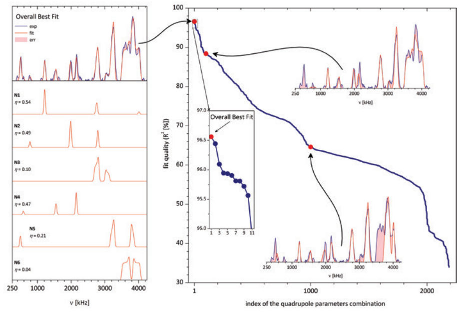

Figure 8. Left: Sildenafil ^{1}H–^{14}N CR spectrum: the experimental data (solid blue line) and the overall best-fit (solid red line). A decomposition of the best fit in contributions from individual nitrogen sites is also shown. Right: The quality of sildenafil CR spectrum fits for all combinations of transition pairing. Here two spectra with poor fits are also shown.

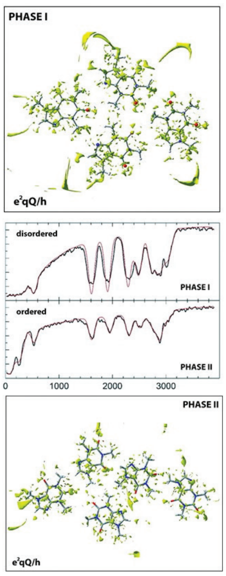

Figure 9: Isosurface plot of EFG asymmetry parameter at each point of the molecular system for phase I (top) and phase II (bottom) of caffeine. Cross-relaxation spectra of caffeine in both phases are shown in the middle.

form II (436 versus 440 K) and the lack of phase transitions in both polymorphs. The crystal and molecular structures of both polymorphs have been determined as a function of temperature from a single-crystal X-ray diffraction. The structure of polymorph I is monoclinic, space group C2/c, while polymorph II is orthorhombic, space group $P2_12_12_1$. The key interaction that determines the crystalline packing in both polymorphs of DIM is the NH···ϖ one. The factor responsible for the locked conformation of DIM in both forms is the electrostatic potential complementarity of the regions of N–H···ϖ, linking neighbouring molecules, which permits easy overcoming of any repulsive interactions that may force the rotation of the molecule. The commercial sample of DIM was found to contain approximately 50% of form I and 50% of form II.

Nuclear magnetic resonance study of molecular dynamics in ammine metal borohydride $Sr(BH_4)_2(NH_3)_2$

Borohydrides are promising hydrogen-storage materials due to their high hydrogen content and relatively low decomposition temperature. In the article *Nuclear magnetic resonance study of molecular dynamics in ammine metal borohydride Sr(BH4)2(NH3)2* (A. Gradišek, L. H. Jepsen, T. R. Jensen, M. S. Conradi, *J. Phys. Chem. C*, 2016, 120, 24646-24654), we investigated $Sr(BH_4)_2(NH_3)_2$, a novel system that contains hydrogen in two molecular groups – BH_4 and NH_3. Molecular dynamics was studied by means of ^{1}H and ^{11}B NMR spectra and spin-lattice relaxation. We identified activation energies for the rotations of BH_4 tetrahedra around two different symmetry axes. Low-temperature measurements unveiled that there are some motions still present around 4 K. In addition, we studied a partially deuterated modification of the compound to further distinguish dynamic processes.

Liquid crystals that exhibit *de Vries* smectic A phases are promising materials for new generations of ferroelectric liquid-crystal displays and other electro-optical devices. We investigated the molecular dynamic properties of a rod-like *de Vries* liquid-crystal compound in the whole mesophasic range by means of fast field-cycling NMR relaxometry. The main molecular motions, i.e., reorientational diffusion, translational self-diffusion, layer undulation, and tilting director fluctuations were fully characterized. The molecular dynamics' behaviour observed across the SmA–SmC* phase transitions of 9HL was consistent with the proposed *cluster diffuse cone* model for the de Vries SmA phase. The findings were published in the article *1H NMR relaxometric study of molecular dynamics in a "de Vries" liquid crystal* (A. Gradišek, V. Domenici, T. Apih, V. Novotná, P. J. Sebastião, *J. Phys. Chem. B*, 2016, 120, 4706-4714).

^{1}H–^{14}N cross-relaxation (CR) spectroscopy is a powerful technique to determine ^{14}N NQR parameters (C_q–), as it requires very small quantities of material. However, the NQR parameters cannot be determined directly from the CR spectrum, but rather through an intermediate step called "peak pairing", that is, finding pairs of ^{14}N transitions belonging to the same nitrogen site. "Peak pairing" is far from straightforward and typically requires good intuition. In order to facilitate CR spectra analysis and make the procedure more robust, we developed an automatic method, which simultaneously fits the lineshapes for all the ^{14}N transitions for all possible combinations of transition pairs, where finally we choose the combination with an overall best fit of the spectrum. For substances with several nitrogen sites, there may be thousands of pairing combinations, but nevertheless, the automatic procedure is still significantly faster than the manual "peak pairing". We have demonstrated the technique on sildenafil (Figure 8) and sildenafil citrate, which both have six nitrogen sites, and published the results in the article *1H-14N cross-relaxation spectrum analysis in sildenafil and sildenafil citrate* (A. Gregorovič, T. Apih, J. Seliger, Solid State Nuc. Mag. 78, 16 (2016)).

Polymorphism of caffeine

The polymorphism of anhydrous caffeine has been studied by ^{1}H–^{14}N NMR–NQR (Nuclear Magnetic Resonance–Nuclear Quadrupole Resonance) double resonance and pure ^{14}N NQR (Nuclear Quadrupole Resonance) and by computational modelling (Density Functional Theory) in the solid state. The assignment of NQR signals detected in stable phase I and in metastable phase II to particular nitrogen sites was verified with the help of DFT. The commercial pharmaceutical sample was found to contain approximately 20–25% of phase I and 75–80% of phase II. The orientational disorder in phase II with a local molecular arrangement mimics that in phase I. Substantial differences in the intermolecular interaction phases I and II of caffeine were analysed using a computational (DFT/QTAIM/RDS) approach and the maps of the principal component of the EFG tensor and its asymmetry parameter at each point of the molecular system were calculated and visualized. The relevant maps calculated for both phases I and II indicate a small variation in electrostatic potential upon phase change. These small differences between packings in phases only slightly disturb the neighbourhood of the N(1) and N(7) nitrogens, and are thus meaningless from the biological point of view. The composition of the two phases in pharmaceutical material should not be an obstacle, which is relevant from the point of view of the pharmaceutical industry.

The study was published in the article *Polymorphism and disorder in natural active ingredients. Low and high-temperature phases of anhydrous caffeine: Spectroscopic (1H–14N NMR–NQR/14N NQR) and solid-state computational modelling (DFT/QTAIM/RDS) study* (J. Seliger et al., European Journal of Pharmaceutical Sciences, 85 (2016), 18).

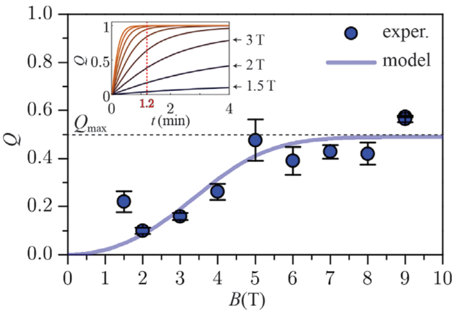

Figure 10: Orientational order parameter Q of liquid-crystal elastomer microparticles dispersed in a PDMS elastomer. Q saturates at $Q_{max} \approx 0.5$ for magnetic fields $B \geq 5$ T. $Q_{max} < 1$ indicates that microparticles are not ideal nematic monodomains. The inset shows theoretically modelled time-dependence of the orientational ordering for different values of magnetic field, corresponding to experimental points Q(B) (blue circles).

Polymer-dispersed liquid-crystal elastomers

We have experimentally investigated the orientational ordering of thermomechanically active liquid-crystal elastomer microparticles dispersed in a PDMS elastomer, using quadrupole-perturbed deuteron NMR. We have also developed a theoretical model of the behaviour of orientational order parameter Q in the external magnetic field B as a function of the microdomain nematic order parameter S and diamagnetic anisotropy $\Delta\mu$, the viscosity of the uncured matrix resin η, and of the curing process kinetic factor k. By comparing theoretical predictions with the experimentally determined values of $Q(B)$, we have demonstrated that the degree of orientational ordering and, consequently, the effective thermomechanical response of the composite material can be tailored by controlling the external magnetic field as well as by properly adjusting the curing time. The research on polymer-dispersed liquid crystal was published in two articles: *Deuteron NMR resolved mesogen vs. crosslinker molecular order and reorientational exchange in liquid single crystal elastomers* (J. Milavec, V. Domenici, B. Zupančič, A. Rešetič, A. Bubnov in B. Zalar, Physical Chemistry Chemical Physics 18, 4071-4077 (2016)) and *Polymer-dispersed liquid crystal elastomers*, (A. Rešetič, J. Milavec, B. Zupančič, V. Domenici in B. Zalar, Nature Communications 7, 13140 (2016)).

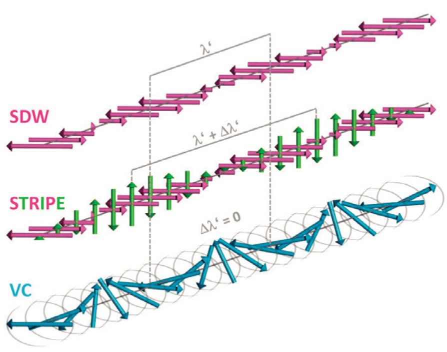

Figure 11: Magnetic order at the V_1 site along the c axis derived for the collinear amplitude-modulated (SDW) phase, for the vector-chiral (VC) phase, and for the spin-stripe (STRIPE) phase. λ' corresponds to the deviation of **k** *from 1/2, i.e., from the antiferromagnetic modulation, while Δλ' corresponds to Δ***k***. Published in M. Pregelj et al., Phys. Rev. B 94, 081114(R) (2016).*

Quantum magnetism

Matej Pregelj, Matjaž Gomilšek, Andrej Zorko, and Denis Arčon, in collaboration with partners from Switzerland, Croatia and France, investigated the mechanism responsible for the occurrence of an unusual spin-stripe phase in the β-$TeVO_4$ compound, which represents a model system of the frustrated ferromagnetic spin-1/2 chain. A combination of magnetic-torque, neutron-diffraction, and spherical-neutron-polarimetry measurements was employed to determine all the magnetic structures that the system develops on cooling in the absence of a magnetic field, i.e., in the vector-chiral phase, in the spin-stripe phase and in the collinear amplitude-modulated phase. Based on these results, they developed a phenomenological model that revealed the anisotropy of the exchange interaction as the key ingredient for the spin-stripe formation in frustrated spin systems. Their discovery was published in the article *Exchange anisotropy as mechanism for spin-stripe formation in frustrated spin chains* (M. Pregelj et al., Phys. Rev. B 94, 081114(R) (2016)).

Matjaž Gomilšek, Martin Klanjšek, Matej Pregelj, and Andrej Zorko collaborated with researchers from China, United Kingdom, and Switzerland in an in-depth investigation of magnetic properties of Zn-brochantite. This is a new realization of the quantum kagome antiferromagnet, a paradigm of geometrical frustration in two dimensions, that was synthesized by the Chinese collaborators in 2014. With the use of various experimental techniques, including nuclear magnetic resonance, muon spin relaxation/rotation, and neutron scattering they established that the ground state of this material is magnetically disordered and dynamical. They observed a quantum-critical behaviour at high temperatures and various spin-liquid instabilities that the system goes through with lowering temperature. Their discovery was published in the paper *Instabilities of spin-liquid states in a quantum kagome antiferromagnet* (M. Gomilšek et al., Phys. Rev. B 93, 060405(R) (2016)).

Additionally, they showed that the low-temperature spin-liquid phase behaves like a spinon metal, which is a novel type of behaviour for the kagome lattice. This observation was published in the paper *μSR insight into the impurity problem in quantum kagome antiferromagnets* (M. Gomilšek et al., Phys. Rev. B 94, 024438 (2016)).

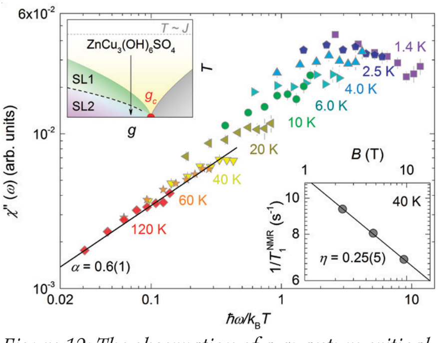

Figure 12: The observation of a quantum-critical scaling of the dynamical susceptibility in Zn-brochantite and the various magnetic states that the system goes through when lowering the temperature (upper inset). Published in M. Gomilšek et al., Phys. Rev. B 93, 060405(R) (2016).

Andrej Zorko, Matjaž Gomilšek, and Matej Pregelj, in collaboration with researchers from Germany, USA, Moldova, and Switzerland investigated new functionality of layered metamagnets, with the use of electron spin resonance in high magnetic fields. The properties of the mixed antiferromagnetic/ferromagnetic phase that is stabilized in a finite range of applied fields around 0.8 T at low temperatures and is characterized by enhanced microwave absorption were thoroughly investigated. They showed that thermal fluctuations play an important role in destabilizing the

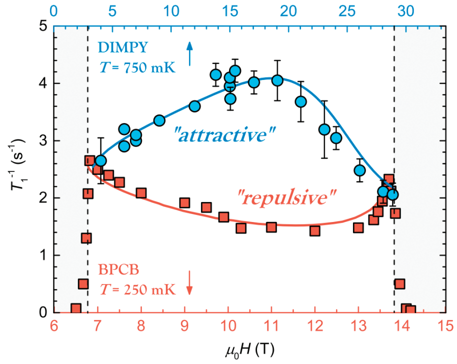

Figure 13: The observed difference of magnetic fluctuations probed by measurements of the spin-lattice relaxation time T_1 in the systems BPCB and DIMPY, containing spin-1/2 ladders with strong rungs and strong legs, respectively.

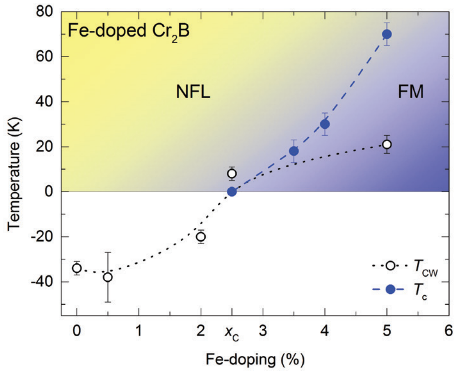

Figure 14: Phase diagram of Fe-doped Cr_2B system obtained from ^{11}B NMR measurements.

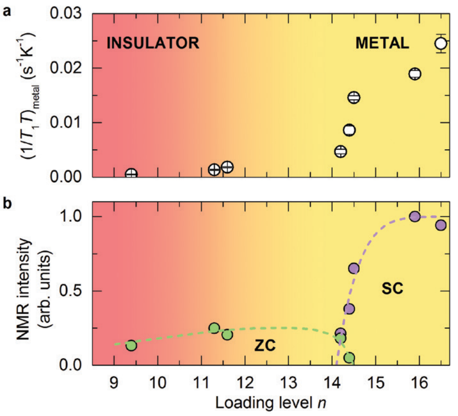

Figure 15: Phase diagram of the sodium-doped LSX zeolite showing the values of (a) metallic contribution to spin-lattice relaxation rate divided by temperature that is proportional to the square of electronic density-of-states, and (b) NMR spectrum intensity for shifted (SC) and unshifted (ZC) components as a function of Na loading level. The colour gradient divides the insulating and metallic regions.

highly absorbing mixed phase. Their discovery was published in the paper *Electron spin resonance insight into broadband absorption of the $Cu_3Bi(SeO_3)_2O_2Br$ metamagnet*, (A. Zorko et al., AIP Advances 6, 056210 (2016)).

Andrej Zorko collaborated with researchers from France, USA and Switzerland in an in-depth neutron scattering investigation of magnetically and structurally chiral Fe langasite, which is a model system of triangle-based frustrated magnets with a strong potential for multiferroicity. They observed bunching of the helical modulation along the *c* axis and the in-plane distortion of the 120° Fe-spin arrangement. These observations enabled a refinement of the spin Hamiltonian, thus providing a link to the magnetically induced electric polarization observed in these systems. The results of this investigation were published in the paper *Helical bunching and symmetry lowering inducing multiferroicity in Fe langasites* (L. Chaix et al., Phys. Rev. B 93, 214419 (2016)).

Martin Klanjšek in collaboration with French and Swiss colleagues studied a difference in the magnetic response of the systems $(C_5H_{12}N)_2CuBr_4$ (BPCB) and $(C_7H_{10}N)_2CuBr_4$ (DIMPY), both containing the spin-1/2 ladders, where the exchange interactions along the rungs are stronger than those along the legs in the first case, and conversely in the second case. They confirmed that the spin ladders in both cases behave as a Tomonaga-Luttinger liquid of spinons. Nevertheless, the systems exhibit markedly different magnetic fluctuations, which can be directly probed by measurements of the spin-lattice relaxation time T_1 in nuclear magnetic resonance. The observed difference emerges from the difference of interactions between the spinons in both cases: these are expectedly repulsive in the first case and surprisingly attractive in the second case. The work is published in *Dichotomy between Attractive and Repulsive Tomonaga-Luttinger Liquids in Spin Ladders* (M. Jeong et al., Phys. Rev. Lett. **117**, 106402 (2016)).

Denis Arčon collaborated with groups from USA (Princeton University, University of Houston) and Israel (The Hebrew University of Jerusalem) on the evolution of magnetic fluctuations in systems, where we induce a transition between the paramagnetic and ferromagnetic metal using some external parameter (e.g., doping or pressure). Theoretical models in such cases predict the closeness of the quantum critical point (QCP) and strong deviations from the Fermi liquid behaviour. The research focused on two model systems, i.e., Fe-doped Cr_2B and $YFe_2(Ge,Si)_2$. In the former case we used ^{11}B nuclear magnetic resonance data to discover the presence of both ferromagnetic and antiferromagnetic fluctuations. The latter are suppressed with Fe doping, before the ferromagnetic ones finally prevail for $x > x_c$. Indications for non-Fermi-liquid behaviour, usually associated with the proximity of a quantum critical point, were found for all samples, including undoped Cr_2B. The sharpness of the ferromagnetic-like transition changes on moving away from x_c, indicating significant changes in the nature of the magnetic transitions in the vicinity of the quantum critical point. Our data provided some important constraints for understanding quantum phase transitions in itinerant ferromagnets in the limit of weak quenched disorder. The results were published in *Evolution of magnetic fluctuations through the Fe-induced paramagnetic to ferromagnetic transition in Cr_2B* (D. Arčon et al., Phys. Rev. B 93, 104413 (2016)). The research of the $YFe_2(Ge,Si)_2$ system had similar goals. The additional importance of these experiments lies in the fact that these structures are isostructural to some iron-based superconductors. We used ^{89}Y NMR to show the presence of ferromagnetic fluctuations, which may have an impact on our understanding of the formation of Cooper pairs in this and other related compounds. The article was submitted to Phys. Rev. Lett. (J. Srpčič et al., arXiv:1608.01130 (2016)).

Zeolites

Peter Jeglič and Denis Arčon, in collaboration with researchers from Slovenia and Japan, studied Na-type low-silica X (LSX) zeolite loaded with guest Na atoms. They unambiguously confirmed a metallic ground state for higher loading levels. By extracting the density-of-states at the Fermi level as a function of the sodium loading level, they discovered a continuous (crossover-like) evolution across the metal-to-insulator transition. These results reveal a complex loading-level dependence of electronic correlations and disorder due to electron confinement to zeolite cages and were published in the paper, *Metal-to-insulator crossover in alkali doped zeolite* (M. Igarashi et al., Sci. Rep. 6, 18682 (2016)).

II. Research programme "Physics of Soft Matter, Surfaces, and Nanostructures"

The investigations of the research program "Physics of Soft Matter, Surfaces, and Nanostructures" are focused on novel complex soft-matter systems and surfaces with specific functional properties. We investigated in particular liquid-crystalline elastomers and dendrimers as novel multifunctional materials, nematic colloids, molecular motors, soft-matter photonic crystals and novel synthetic or self-assembled micro- and nano-structures. The aim of the program is to understand structural and dynamical properties of these systems, their interactions, their function at the molecular level, and self-assembly mechanisms in soft matter. The underlying idea is that it is possible to understand complex mechanisms, such as self-assembly, on a macroscopic level, using a simplified physical picture and models. In order to provide a comprehensive approach to the problem, the program combines both experimental and theoretical investigations, supported by modelling and simulations. Special emphasis is given to the possible electro-optic and medical applications.

The group explored topological defects in liquid-crystal droplets and shells, the structure of droplets on biofibres and in defect annihilation in liquid crystals. We developed super-resolution microscopy based on microlaser particles and biodegradable optical waveguides for photomedicine. We explored the working mechanism of the motor protein kinesin-14, new low-friction and low-dimensional nanomaterials.

Topology of liquid crystals: Singular points, skyrmions and torons

Chiral nematic liquid crystals exhibit rich topological phenomena, which were predicted and partially observed in chiral nematic droplets and thin liquid-crystal layers on patterned surfaces. It has been predicted that knots and links are stable in chiral nematic droplets, but this was difficult to observe because of the lack of appropriate experimental methods. We have developed a new method for the reconstruction of the director field, which is based on Fluorescent Confocal Polarisation Microscopy (FCPM) imaging in low birefringent liquid crystals with added fluorescent dyes. A new approach was taken in reconstructing the director field in chiral nematic droplets based on a simulated annealing algorithm. This combined method proved to be very efficient in reconstructing experimental 3D FCMP images. We observed that in chiral nematic droplets, topological singularities always appear in a form of point defects or simple rings, which are never knotted or linked. The complexity of the topological structures in chiral nematic droplets depends on the ratio of the helical pitch of the liquid crystal and the diameter of the droplet. In the case of low chirality, the number of point defects is small and they tend to be expelled to the surface of the droplet. The number of defects is always odd, which is due to the conservation of the total topological charge. We successfully reconstructed droplet structure with three point defects, which showed a cross-section of the Bloch skyrmion, which is similar to skyrmion structures in chiral magnets. When the number of point defects is increased to five for higher chirality, we observed another topological structure, which is akin to the toron structure observed in thin chiral nematic layers. Both skyrmion and toron structures are smoothly embedded in spherical confinement. This work presents the first exact reconstruction of the topology of 3D director in chiral nematic droplets and was published in Scientific Reports (G. Posnjak, S. Čopar and I. Muševič, *Scientific Reports* 6: 26361 (2016)).

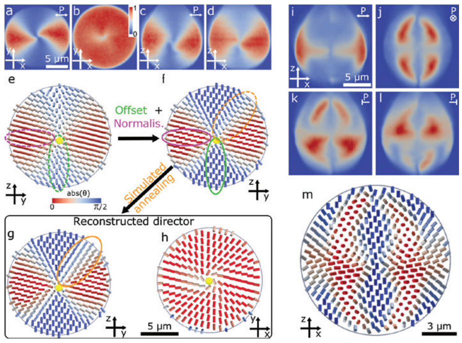

Figure 16: (a-d, i-l) Examples of fluorescent images taken at different polarisations of the fluorescent excitation beam. The panels (e-m) show the reconstructed director structure in a chiral nematic droplet.

Skyrmion structures were also observed in thin nematic LC films on chemically patterned patchy surfaces. When the sample was quenched from the fully aligned state using a strong external electric field, the director on the patterned patches spontaneously relaxed into a vortex-like structure, centred on the patch, as shown in the crossed-polarised image in Figure 17. This work was published in Cattaneo et al., *Soft Matter* **12**, 853 (2016).

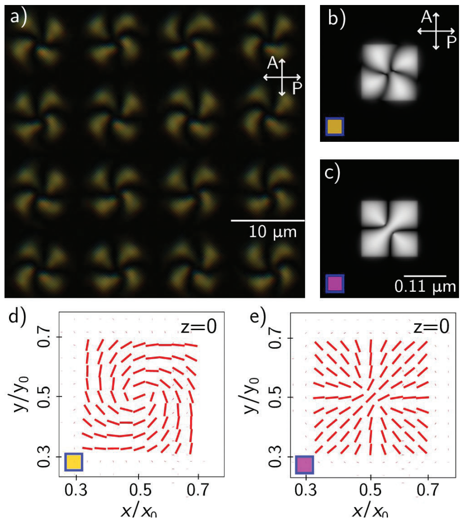

Figure 17: Skyrmions are vortex-like structures, which are clearly observed between crossed polarisers. (a) Experimental optical microscopy image viewed in white light transmission between crossed polarizers after the application of a potential of 30 V. (b and c) Are simulated optical microscopy images for two defect states with the lowest free energy; (d and e) are the corresponding director fields at the patterned surface (z = 0).

Sensing surface morphology of biofibers by decorating spider silk and cellulosic filaments with nematic microdroplets

Liquid-crystal droplets deposited on microthin biofibres – including spider silk and cellulosic fibres – were shown to reveal characteristics of the fibres' surface, performing as simple but sensitive surface sensors. By combining experiments and numerical modelling, different types of fibres are identified through the fibre-to-nematic droplet interactions, including perpendicular and axial or helicoidal planar molecular alignment. The nematic droplets as sensors also directly reveal the chirality of the cellulosic fibres. Different fibre entanglements can be identified by depositing droplets exactly at the fibres' crossings. More generally, the presented method can be used as a simple but powerful approach for probing the surface properties of small-size bio-objects, opening a route to their precise characterization. This work is a collaboration between the soft matter

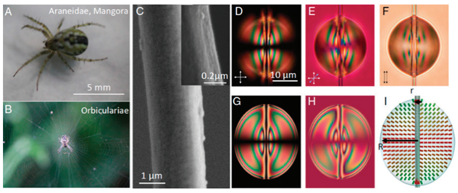

Figure 18: Droplets of a complex nematic fluid were shown to perform as robust sensors for detecting the surface morphology of bio-fibres, such as spider silk and cellulose (PNAS 113, 1174 (2016)).

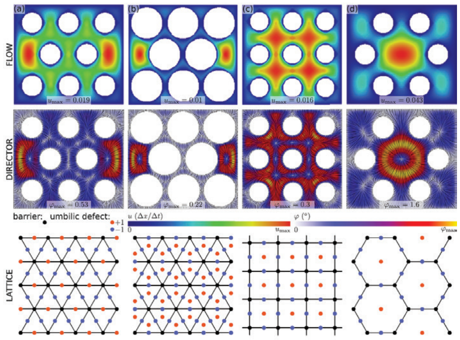

Figure 19: Porous nematic microchannels as generators of umbilic defect lattices (PRF 1, 023303 (2016)).

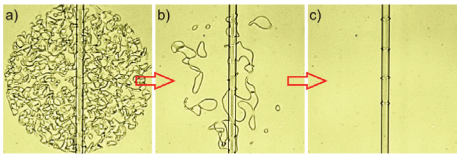

Figure 20: During the fast quenching of a liquid crystal from isotropic to nematic phase tangle of defect lines appear (a) and two pairs of Saturn rings and anti-rings are formed around the glass fibre (c).

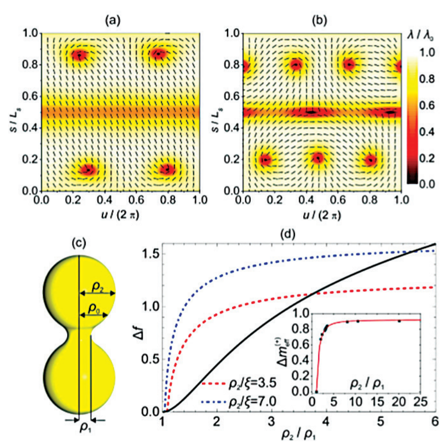

Figure 21: Depinning threshold in dumb-bell configurations. Panels (a,b) show nematic ordering in the (u, s) plane just below and above the threshold. The shape, calculated at the threshold, is presented in panel (c). In panel (d) the free-energy penalties to form a pair defect-antidefect and the effective topological charge are plotted as a function of geometrical parameters.

group in Ljubljana (modelling) and Lisbon (experiments) and was published in L. E. Aguirre et al., *Sensing surface morphology of biofibers by decorating spider silk and cellulosic filaments with nematic microdroplets*, Proc. Natl. Acad. Sci. USA 113, 1174 (2016).

Porous nematic microfluidics for the generation of defect lattices as photonic crystals

Porous nematic microfluidics was demonstrated as a novel route for controlling the microstructure of the nematic order. Specifically, we showed the emergence of regular networks of topological defects, ranging in symmetry from triangular, square, to even kagome. This approach shows interesting possibilities as flow-tunable photonic crystal. The work was published in *Porous nematic microfluidics for generation of umbilic defects and umbilic defect lattices* (J. Aplinc, S. Morris and M. Ravnik, Phys. Rev. Fluids 1, 023303 (2016)).

Annihilation dynamics of topological monopoles on a fibre in a nematic liquid crystal

We studied the dynamics of topological defects on a glass fibre immersed in a nematic liquid crystal. We have used the laser tweezers to create isolated pairs of topological monopoles with the opposite topogical charge and we have observed their annihilation process. When the fibre was set perpendicular to the nematic director, the monopoles were point defects in a form of radial and hyperbolic hedgehog and they attracted at small separations with an elastic force, which is proportional to the inverse square of the separation, following the Coulomb law for electric monopoles. The work was published in M. Nikkhou et al., Phys. Rev. E 93, 062703 (2016). In the case of a parallel fibre to nematic director the monopoles are in the form of Saturn ring and Saturn anti-ring. Here in thick cells we again observe a Coulomb-like attraction, while in thin cells there is an additional string-like force attributed to the formation of defect lines, connecting both monopoles. This force is independent of the separation between monopoles and prevails Coulomb-like attraction at large separations. These findings were published in M. Nikkhou et al., Phys. Rev. E 93, 062703 (2016).

We found that the dynamics of topological monopole annihilation on a fibre is very different for thick and thin nematic layers in thick cells, the two defects show a Coulomb-like pair attraction with no background force, which decays as an inverse square of the defect separation. However, for cell thickness comparable to the glass fibre diameter, there is another dominant type of force which is string-like and independent of the defect separation. It turns out that this constant force of attraction in thin cells is due to the interconnection of topological defects by additional defect lines which are running along the fibre surface. This work was published in M. Nikkhou et al., Eur. Phys. J. E 39: 100 (2016).

Topological defects in thin nematic shells

We studied numerically topological defects (TDs) in effectively two-dimensional closed soft films exhibiting in-plane orientational ordering. We introduced the Effective Topological Charge Cancellation mechanism controlling the localized positional assembling tendency of TDs and the formation of pairs defect-antidefect on curved surfaces and/or the presence of relevant "impurities" (e.g., nanoparticles). For this purpose an effective topological charge m_{eff} is defined consisting of real, virtual and smeared curvature topological charges within a surface patch identified by the characteristic spatially averaged local Gaussian curvature *K*. We demonstrate a strong tendency enforcing $m_{eff} \rightarrow 0$ on surfaces composed of surface patches exhibiting significantly different values of *K*. For non-zero m_{eff} we estimate a critical depinning threshold to form pairs of defect-antidefect using the electrostatic analogy. The work was presented in two invited lectures and in the publication L. Mesarec et al., Scientific Reports 6, no. 27117, 1-9 (2016).

Biodegradable optical waveguides for use in photomedicine

A new class of optical waveguides for use in deep-tissue photomedicine were demonstrated (S. Nizamoglu, et al., *Nature Communications* 7, 10374, 2016). These waveguides were made out of biocompatible and biodegradable polymer materials, which can be implanted into the body and are naturally degraded over time. The waveguides enable the use of a number of medical laser treatments and diagnostics deep into the body, which were till now only limited to the surface due to limited penetration of light into the tissues. As an example of a possible application, laser wound closure is demonstrated, which could lead to faster healing and less scarring. Biocompatible and biodegradable waveguides can also be directly applied to other light-based diagnostics, surgery and therapeutics.

Optical super-resolution microscopy based on microlaser particles

A novel imaging technique was developed which instead of standard fluorescent molecules, uses small lasers embedded in the sample as probes [S. Cho et al., Phys. Rev. Lett. 117, 193902 (2016)]. The main characteristics of the microlasers are their very nonlinear response to the incoming pump beam intensity. The pump beam is scanned across the sample to form a 2D or 3D image. If the pump beam is set just above the laser threshold, only microlasers exactly in the canter of the beam will emit laser light. This makes it possible to achieve super-resolution as well as to get confocal images with low background without the need for pinholes. Images at a resolution six times higher than that of fluorescence-based microscopes were demonstrated by using a nanowire laser. The new technique was termed *laser particle-based stimulated emission microscopy* (LASE).

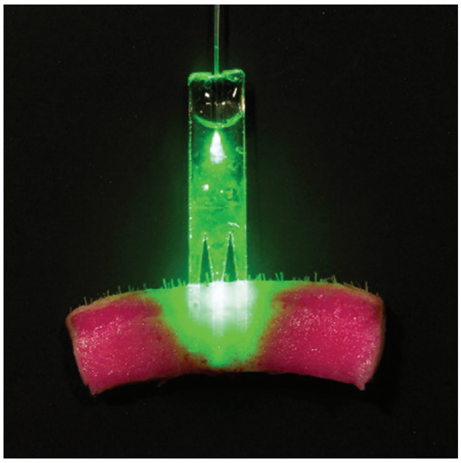

Figure 22: A biodegradable optical waveguide through which green laser light is sent into a piece of skin tissue.

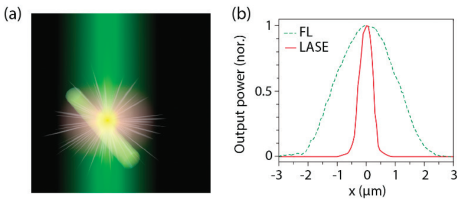

Figure 23: (a) Artistic view of a nanowire microlaser illuminated by an external beam of light. (b) Comparison of resolution between regular fluorescence imaging and the new LASE microscopy.

Liquid-crystal microphotonics

We continued our studies of the possible application of liquid crystals and their structures such as droplets and fibres in photonics. We numerically demonstrated wave guiding of laser beams by birefringent profiles of the escaped topological defect lines. The radially escaped nematic director profiles of a liquid crystal with negative birefringence are able to focus and guide light with radio polarisation, whereas the opposite-azimuthal polarisation passes through unaffected. Lensing by liquid-crystal structure was also demonstrated, which could be controlled by an external electric field. The light attenuation is low and these escaped defect lines have the potential for application in photonic waveguiding. We have also studied the lasing properties of chiral nematic 3D microlasers which were polymerised, as shown in Figure X3. The lasing shows two distinct mechanisms, namely the photonic band edge lasing and lasing from the whispering gallery modes. It was demonstrated that the polarisation of the liquid crystal greatly increases the lasing stability.

We also published an extended review paper on liquid-crystal microphotonics (I. Muševič, Liquid Crystal Reviews 4, 1 (2016)). This work summarises the main aspects of liquid-crystal microphotonics including nematic colloids and liquid-crystal dispersions.

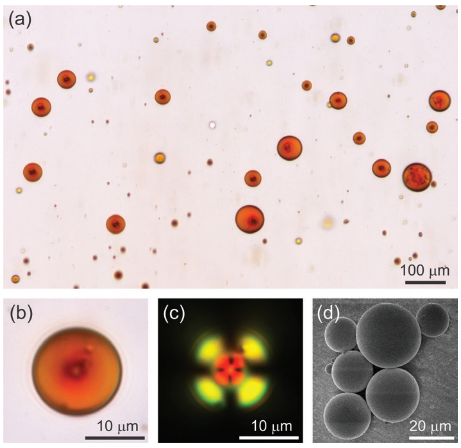

Figure 24: Dispersion of polymerised chiral nematic droplets in glycerol. They are red because the DCM fluorescent dye was added to a liquid crystal. The lower panels show examples of droplets and SEM image of a cluster of polymerised and dried microlasers.

Molecular motors

In collaboration with researchers from Dresden and Warsaw we investigated the working mechanism of the motor protein kinesin-14. Even though the main task of most cytoskeletal motors is longitudinal motion, many of them also exert a torque on their filaments, leading to helical motion. The significance of this torque is still unknown, but it might be involved in the establishment of body chirality in certain organisms. In our motility assay the motors are attached to the surface and move microtubules, whose longitudinal and angular motion is simultaneously observed through attached quantum dots and FLIC microscopy. Unexpectedly, the period of the helical motion strongly depends on the ATP concentration. We developed a minimal mechanochemical model for kinesin-14, which allows us to explain this dependence and also to reconstruct the motor's working cycle. Our results demonstrate how measurements on large ensembles can be used to infer the properties of individual molecules. The work was published in *Proc. Natl. Acad. Sci. USA* 113, E6582–E6589 (2016).

Low-friction nanomaterials

Hard coatings have been used as wear-protection coatings for decades but without optimization of conventional lubrication systems. In the paper "Tribological performance of TiN, TiAlN and CrN hard coatings lubricated by MoS_2 nanotubes in Polyalphaolefin oil". Wear, vol. 352-353, p. 72, by S. Paskvale, M. Remskar, M. Čekada, we reported that the addition of MoS_2 nanotubes in polyalphaolefin (PAO) oils leads to a significant reduction in friction and to a decrease in the wear behaviour of tool steel AISI D2 coated with TiN, TiAlN and CrN hard coatings. Comparative tests using conventional MoS_2 platelets in PAO oil was performed on these hard coatings. In all cases, the MoS_2 nanotubes substantially decreased friction (on CrN for 55%, on TiN for 65%, and on TiAlN for 25%), while the MoS_2 platelets were less efficient or even increased friction.

In the paper *Transitioning to sustainable production – Part III: developments and possibilities for integration of nanotechnology into material processing technologies* (P. Krajnik et al., J. of Cleaner Production 112, 1156 (2016)) we reported on the superior tribological properties of cooling-lubricating fluids based on biodegradable vegetable oils with added functionalized MoS_2 nanotubes, to those of conventional metalworking fluids.

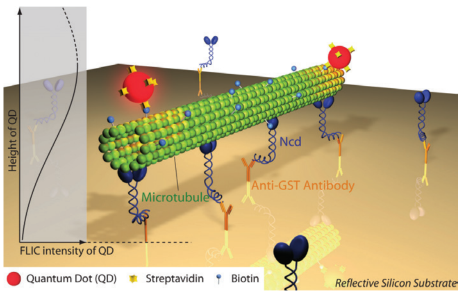

Figure 25: Measurement of longitudinal and rotational motion of microtubules using quantum dots and FLIC microscopy.

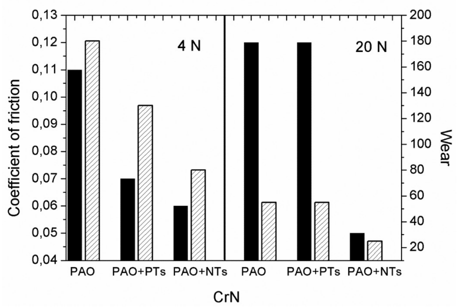

Figure 26: Coefficients of friction and wear at the 4N and 20N loads at the contact between CrN hard coating and steel (100Cr6) ball. We used the following lubricants: pure PAO oil, PAO oil with 2 wt.% of MoS_2 nanotubes (PAO+NTs) or. standard MoS_2 platelets (MoS2+PTs).

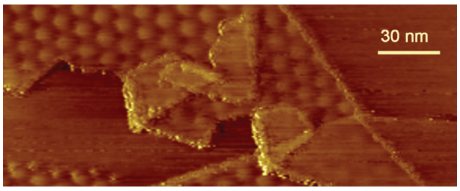

Figure 27: STM picture of a superstructure in graphene lying on graphite substrate.

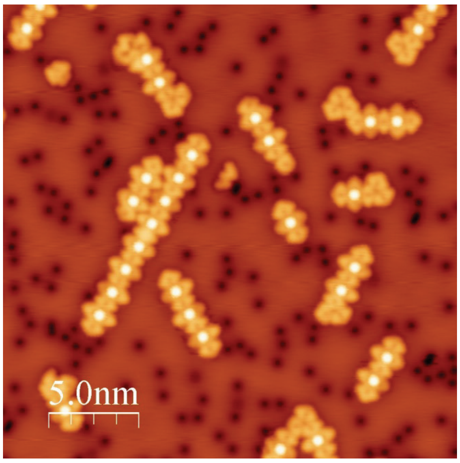

Figure 28: High-resolution STM image showing molecular chains of organic BETS and $GaCl_4$ molecules on Ag(111) surface (25 × 25 nm², T=4.2K)

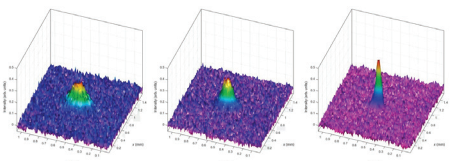

Figure 29: Velocity-distribution images showing about 50,000 caesium atoms being evaporative cooled to temperatures around 1 nK, where the transition to a Bose-Einstein condensate occurs.

Low-dimensional materials

Molybdenum trioxide, MoO_3, belongs to semiconductors with a wide energy band gap. It is used in photovoltaics, as sensors and for energy storage. In the article "Oxygen deficiency in MoO_3 polycrystalline nanowires and nanotubes", Materials Chemistry and Physics 170 (2016) 154, by A. Varlec, D. Arčon, S.D. Škapin and M. Remškar, we reported on the first synthesis route of the orthorhombic MoO_3 nanotubes by oxidation of molybdenum-sulphur-iodine nanowires. Oxygen deficiency was determined by electron-paramagnetic resonance observing paramagnetic defects (Mo_5+) and explained using Raman spectroscopy by appearance of a new resonant band (1004 cm-1).

Superstructures observed by scanning tunnelling microscopy on graphite have been reported several decades ago, but the interest in these superstructures recently intensified due to their occurrence in graphene grown on different substrates. In the article *Influence of surface defects on superlattice patterns in graphene on graphite* (M. Remškar and J. Jelenc, Surface Science 651, 51 (2016)) we reported experimental findings that the orientation of the superstructure is influenced by surface defects and edges of graphene. Superstructures in graphene put on graphite exist even if the graphene is not supported by graphite over its entire area. The modulation of the density of states influences the strength of intra-layer carbon bonds in such a way that the graphene breaks along the superstructure minima.

Nanosafety

In the telecast *When science explodes*, aired on the national television (Slo1) on 17 Dec, 2016 as a part of education program *Bite into science*, and in the telecast *Black market flourishes, fireworks also have a dark side* aired by a commercial TV (POP TV) in broadcast *Inspector* on Dec. 22, 2016, M. Remskar reported on air pollution by nanoparticles released during use of fireworks and sparklers.

Small structures and 1D chains of organic molecules

By carefully controlling the growth conditions, we can fabricate different nanostructures and 1D chains of organic BETS molecules (Fig.) on silver (111) surfaces. We are studying the structure and properties of such formations using low-temperature scanning tunnelling microscopy and spectroscopy. We measured a narrow gap in the density of states, which indicates the chains to be semiconductiing. As previously observed on monolayer islands, grown from same material (single crystals of $(BETS)_2GaCl_4$), the $GaCl_4$ molecules can fill the gaps between pairs of BETS molecules and greatly influence the electronic properties of molecular chains.

Ultra-cold atoms

For the first time in the Laboratory for Cold Atoms at Jožef Stefan Institute caesium atoms were evaporative cooled to temperatures of about 1 nK. Simultaneously, their density was increased, which leads to formation of Bose-Einstein condensate (Figure 29). Currently, we are trying to increase the number of atoms in the condensate and to achieve the condensation at even higher temperatures.

III. Research program "Experimental biophysics of complex systems and imaging in biomedicine«

The program "**Experimental biophysics of complex systems and imaging in biomedicine**" combines the research of the processes and structure of the biological systems with the development of advanced experimental techniques, especially microspectroscopies, super-resolution microscopies, and imaging techniques. Our group is mainly focused on understanding the response of the molecular and supra-molecular structures to the interaction between materials and living cells, and to the interaction between light and living cells. We are interested in mechanisms of this response, time scales and conditions as well as its application in medicine, especially in the field of medical materials and devices, and in healthcare in general. With the development of spectroscopic, microscopic and microspectroscopic techniques, we aim to provide a new understanding of biological systems, which will open up new possibilities in the design of novel medical devices for therapy, diagnostics and regeneration – one of the main health issues among the aging population of the developed world. Our group mastered various spectroscopic techniques, such as the EPR and FTIR, microscopic and microspectroscopic fluorescence techniques such as FMS and many special MRI techniques and we have introduced super-resolution microscopic techniques such as the STED, FCS and STED

FCS, together with the novel two-photon STED and spectral sensitive STED. Among the methods of magnetic resonance imaging, a new method, which enables the monitoring of the electric field in tumours during their treatment by electroporation high-voltage electric pulses, has been developed. In addition, we have developed a method of multiparametric magnetic resonance imaging, which has been found to be very efficient in the characterization of food, drugs and various processes. By using high spatial resolution magnetic resonance imaging, we can monitor the efficiency of the surface treatment, formation and dissolution of gel layers as well as diffusion measurements in samples with restricted geometry.

FMS detection of the lipid wraps around the metal-oxide nanotubes has been confirmed for the first time using STED microscopy, which directly identified the entry of the particles into the cells. FMS has been used to detect the edges of a new blood clot after the laser-induced blood photocoagulation. New methods were developed to monitor food processing and food-quality control based on the multiparametric MR imaging.

Cell-material interaction studies

The cell-material interaction studies, especially from the viewpoint of bioactivity and biocompatibility, are undoubtedly one of the hottest biophysics research topics. We have previously shown that titanium dioxide nanoparticles strongly interact with lipid membranes from either model vesicles or even live cells – they can adsorb to the membrane and wrap themselves by a lipid corona. We have recently indisputably corroborated this idea with additional experiments using original approaches, such as fluorescence (micro)spectroscopy with in-house-designed and synthesized environment sensitive molecular probes, and state-of-the-art biophysical methods, such as fluorescence cross-correlation spectroscopy (FCCS) and super-resolution fluorescence imaging (STED). For the latter two, we teamed with the renowned prof. Christian Eggeling from the University of Oxford (UK) to foster the transfer of knowledge on these advanced techniques, which will also be available in our laboratory.

Many studies on the safety of engineered nanomaterials focused only on finding correlations between nanomaterial properties and adverse health outcomes, without taking into account underlying molecular events. A consortium of research institutions (including our group) and companies teamed up for the SmartNanoTox project with a common goal of identifying molecular initiating events and key events on a cellular level and connecting them to adverse health outcomes after inhalation of the nanomaterial. This approach should therefore yield a mechanistic picture of nanomaterial toxicity, which will lead to the discovery of causal links between molecular initiating events from the in-vitro models and the adverse health outcomes determined with animal models. Using the existing literature, we have identified the most suitable cell-based and cell-free *in-vitro* models of the lung. Some of the molecular initiating events identified are: nanomaterial – lipid interaction including corona formation after exposure of a nanoparticle to lung surfactant, cellular uptake of nanoparticles, and lysosomal destabilization. We have successfully labelled TiO_2 nanotubes with different fluorophores, which are also suitable for high-resolution STED imaging. Our preliminary data show that the nanotubes enter the cells as single nanotubes – an event that cannot be resolved from confocal microscopy (see Figure 30).

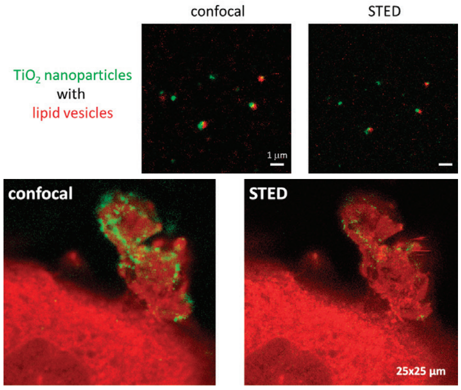

Figure 30: Co-localization of the lipid wraps (red) and nanotubes with STED microscopy (top) of the fluorescently labelled TiO2 nanotubes (green). High resolution STED microscopy of fluorescently labelled TiO_2 nanotubes (green) and a cell (red) enables direct imaging of nanoparticles entering the cell.

Fluorescence microspectroscopy (FMS)

Fluorescence microspectroscopy (FMS) reveals physical properties of molecular environment of fluorescent probes. For example, we have developed probes that are sensitive to the local pH value. They only activate at low pH. In addition, their spectral properties change, if they aggregate. There are a number of mechanisms being exploited with these probes to study molecular vicinity. Widely used is fluorescence resonance energy transfer (FRET). Lately, contact- or aggregation-based mechanisms are also being utilized. In the case of rhodamine probes, aggregate formation leads to non-fluorescent ground-state complexes or spectral shifts. With calibration of concentration and pH dependence, the developed probes will be useful for a quantitative determination of the level of aggregation, i.e., as sensors for the detection of molecular contact.

Multiparametric detection of the impact of the high-intensity light source on biological systems

A new experimental system for multiparametric detection of the impact of the high intensity light source on biological systems was developed. Common fluorescence detection of individual structures of the retina before and after the injury with a strongly focused high-intensity light source was changed and improved with fluorescence micro-spectral detection. The system was developed on an existing fluorescence microspectroscopy (FMS) machine with a newly installed near-IR laser source with a well-defined spatiotemporal resolution. Using this system, we were able to successfully characterize the interaction of the light source with biological matter. In addition, a new method for the localization and dynamics monitoring of blood clotting following the blood vessel injury was introduced, based on the optical tweezers and their mechanical manipulation of individual or multiple erythrocytes.

To mimic the *in vivo* coagulation processes during vessel disruption, we used retinal tissue samples from *ex vivo* porcine eyes. The detection of blood coagulation was performed by the fluorescence microspectroscopy (FMS) system developed in our laboratory. In order to identify the extent of the clot formation after the accurately localized vessel rupture in the intact retina, we measured the auto-fluorescence contrast inside the blood vessel indicating a blood flow. A significant decrease in the negative contrast as detected after one minute is the result of the decreased number of erythrocytes in the volume. The observed blood flow showed the inability of the formed clot to completely seal/close the vessel. Using the negative contrast fluorescence technique, it is difficult to distinguish between the non-coagulated and coagulated region inside the ruptured vessel, but with the FMS blood-clot characterization technique, the differences between the non-coagulated blood (blue colour) and coagulated blood (green colour) in the initial clot localization could be easily observed. The measured red spectral shift of $\Delta\lambda$ = 1-2 nm in the damaged region directly indicates the changed absorption properties of hemoglobin and thus the local physio-chemical changes, which means the onset of the clot formation. We can see that part of the targeted region just below the ruptured vessel wall remains non-coagulated (blue colour).

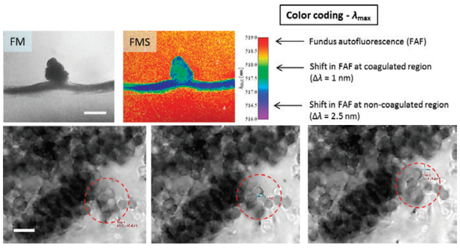

Figure 31: FMS approach to localize a blood clot 5 minutes after laser induced vessel rupture (top, scale bar is 200 μm) and blood clot boundary identification by optical tweezers mechanical manipulation of individual erythrocytes (bottom, scale bar is 10 μm). The concurrent movement of closely packed erythrocytes induced by a laser tweezers (see cross locator) is denoted within the red circle.

In order to confirm the initial clot formation, we used optical tweezers. Strong binding between individual erythrocytes a few tens of μm outside of the ruptured vessel formed on a minute timescale after a vessel injury. Optical tweezers manipulation in a vertical direction (see cross-locator in Figure 31), with trapping force of $F \approx 10$ pN (P = 50 mW), used the concurrent movement of a group of more than 10 closely packed erythrocytes. The optical force was unable to detach single erythrocytes from the bulk, which indicates strong adhesion, i.e., the initial state of the clot formation. For comparison, erythrocytes inside the vessel, a few tens of microns away from the ruptured site, did not aggregate. Our results show that the initial clot formation is in agreement with our hypothesis that the initial clot formation is localized to the site where the plasma calcium concentration is decreased in the region where blood plasma is diluted with released cytoplasm of injured tissue surrounding the blood vessel.

Based on our collaboration with the Smithies' lab from the University of North Carolina and our work published in the Langmuir journal, we were invited to describe and film all the details of our method for the Size Controlled Synthesis of Stable Oligomeric Clusters of Gold Nanoparticles under Ambient Conditions (J. Vis. Exp. 2016 (108):e53388). In this work, we described how reducing dilute aqueous $HAuCl_4$ with sodium thiocyanate (NaSCN) under alkaline conditions produces 2–3-nm-diameter nanoparticles and stable grape-like oligomeric clusters of yellow nanoparticles. The produced yellow oligoclusters range in size from ~3 to ~25 nm. This size range can be further extended by an add-on method utilizing hydroxylated gold chloride ($Na^+[Au(OH_{4-x})Cl_x]^-$) to autocatalytically increase the number of subunits in the as-synthesized oligocluster nanoparticles, providing a total range of 3 nm to 70 nm. We were able to concentrate the oligoclusters more than 300 fold without aggregation and the crude reaction mixtures remained stable for months without further processing.

Diffusion measurement by modulated gradient

We improved our method for diffusion measurement by modulated gradients. In some of our experiments, especially those on bulk liquids, we found that the method gives overestimated results for the diffusion constant with higher frequencies of modulated gradients. In the study, we showed that the origin of the error is in neglecting the off-resonance contributions to the signal of multiple spin echoes in a high magnetic field gradient. Because of these contributions, the total signal was decaying faster than was predicted by our theory, which led to the overestimated calculated diffusion constant. We found a solution to the problem in zero frequency filtering of the spin echo signals, which removed most of the off-resonance signals and therefore made our theoretical model valid again. The results of the study were published in the Journal of Magnetic Resonance, 2016, 270: 77-86.

Dry-curing of different meat products

By using multiparametric magnetic resonance imaging, we studied dry-curing of different meat products. Relaxation time T_1 and T_2 mapping, and the apparent diffusion constant (ADC) mapping were used to find the differences between two different ham muscles (biceps femoris and semimembranosus) at two different stages of salting (low and high). We showed that the maps can be converted into one-dimensional distributions of the parameters T1, T2 and ADC, and in two-dimensional correlations between the parameters ADC-T2, ADC-T1, T1-T2, which show characteristic peaks in the distribution. The location and distribution of these peaks are very sensitive to both the tissue type and the influence of the salting. The characterization was better with the two-dimensional correlation than with one-dimensional distributions. To these three mapping methods, we also added quantitative magnetization transfer imaging, which was found to be efficient for determining the protein content. We concluded that these methods, having greater accessibility to NMR / MRI systems, could serve as an effective tool for monitoring the processing of dry-cured meat products, as well as to control their quality. This research, which was published in the journal Meat Science, 2016, 122: 109, was achieved in cooperation with the researchers from the Agricultural Institute of Slovenia. We also studied the effects of the electroporation on the properties of a potato tuber. We found that with the electric field of more than 400 V/cm, cells start to release substances, which result in an increase of T2 relaxation time. The effect was found to be larger with a higher electric field and was also larger immediately after the electroporation than several hours after it. We found no significant changes associated with electroporation in maps of the apparent diffusion constant or on the maps of T1 relaxation time. During the delivery of the electroporation pulses, we were able to monitor the electric field in the sample using the MREIT method. This enabled us to find relations between the electric field in the sample and its effect on the change of NMR relaxation parameters as well as on the diffusion constant. The findings of this study were published in the Innovative Food Science and Emerging Technologies, 2016, 37: 384.

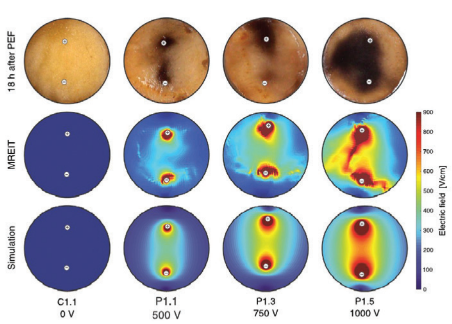

Figure 32: Electric field in the potato tuber sample established during electroporation as measured by the MRTEIT technique (middle row) is in a good agreement with the results of simulation (bottom row) as well as with the release of phenolic compounds that darkened due to an oxidation reaction (optical photographs in the top row). In the study voltages of electroporation pulses were 500, 750 and 1000 V.

Influence of the highly soluble pentoxifylline drug on the dynamics of medium penetration into the tablet and the formation of the gel layer in xanthan tablets

We also investigated the influence of the highly soluble pentoxifylline drug on the dynamics of medium penetration into the tablet and the formation of the gel layer in xanthan tablets. Xanthan is an anionic polymer that exhibits pH- and ionic-strength-dependent swelling. For this reason, the impact of the medium properties on xanthan swelling has also been studied. For hydrophilic polymers, it is generally accepted that, once in contact with a body fluids, they hydrate and swell, forming a gel layer that regulates the penetration of body fluids into the tablet and the dissolution of the incorporated drug. Therefore, the knowledge of the gel layer characteristics is of crucial importance for the use of controlled drug-delivery systems. A combination of different MRI methods enables an accurate determination of the medium penetration into the tablet, as well as hydrogel formation *in situ*. The results of xanthan swelling and pentoxifylline release kinetics were compared to the mathematical model, which combines the polymer swelling kinetics and drug diffusion and solubility to obtain the release mechanism. In water and diluted acid medium (pH >3) with low ionic strength, the main release mechanism is erosion, whereas in acid medium (pH 1.2) and in media with high ionic strength ($\mu \geq 0.2$), the diffusion mechanism dominates, owing to the changes in the polymer structure in media with different pH and ionic strength. The results were published in a paper entitled *The Influence of other high loading and xanthan tablets and media with Different physiological pH and ionic strength on swelling and release* in the Journal of Molecular Pharmaceutics, 2016, 13: 1147. This study was performed in collaboration with our colleagues from the Faculty of Pharmacy, University of Ljubljana.

Penetration of tung oil into various wood species

Furthermore, we studied the penetration of tung oil into various wood species. Tung oil is used as environmentally friendly wood preservatives. However, tung oil does not penetrate deeply into the wood due to its high viscosity. Magnetic resonance imaging was applied to elucidate the influence of the applied impregnation method (immersion in oil or vacuum impregnation with oil) and on the wood species used. It has been shown that the oil penetrated deeply in the wood after the impregnation process than after the immersion process, where the oil remained only on the sample surface. In addition, the depth of penetration of the oil into the wood also depends on the wood species and on the orientation of the sample. Since wood is an anisotropic material, the penetration of the oil is the largest in the axial direction. The results of the research were combined in an article accepted for publication in the Journal Industrial Crops and Products, 2017, 96: 149. The study was performed in collaboration with our colleagues from the Department of Biotechnical Faculty.

Our research has been supported by a number of international projects financed by the European Union. It was also supported within the bilateral Slovenian – USA, Slovenian – German and Slovenian – Greek and other scientific cooperations. In 2016, the Department had cooperation with 108 partners from Slovenia and abroad. Among them:

- The high magnetic field centres in Grenoble, France, and Nijmegen, The Netherlands
- The high magnetic field centre at the University Florida, Tallahassee, Florida, USA
- The ETH, Zürich, Switzerland
- The Ioffe Institute in St. Petersburg, Russia
- The University of Duisburg, the University of Mainz and the University of Saarbrucken in Germany
- The University of California, the University of Utah and the Liquid Crystal Institute, Kent, Ohio, USA,
- National Institute for Research in Inorganic Materials, Tsukuba, Japan
- NCSR Demokritos, Athens, Greece
- Institut für Biophysik und Nanosystemforschung OAW, Graz, Austria

- Bioénergétique et Ingénierie des Protéines, CNRS Marseille, France
- Architecture et Fonction des Macromolécules Biologiques, CNRS Marseille, France
- The Max Delbruck Center for Molecular medicine in Berlin
- The Dartmouth Medical School, Hanover, NH, USA
- The Mayo Clinic, Rochester, USA
- Kyung Hee University, Suwon, Korea
- Technische Universität Ilmenau, Ilmenau, Germany
- Elettra Sincrotrone Trieste, Trieste, Italy
- University if North Carolina at Chapel Hill
- Max-Delbrück-Centrum für Molekulare Medizin (MDC)

made the above studies possible.

Some outstanding publications in 2016

1. A. Rešetič, J. Milavec, B. Zupančič, V. Domenici, B. Zalar. Polymer-dispersed liquid crystal elastomers. *Nature Communications* 7, 13140 (2016).
2. M. Jeong, M. Klanjšek et al. Dichotomy between attractive and repulsive tomonaga-luttinger liquids in spin ladders. *Physical Review Letters* 117, 106402 (2016).
3. F. E. Annanouch, P. Umek et al. Aerosol-assisted CVD-grown PdO nanoparticle-decorated tungsten oxide nanoneedles extremely sensitive and selective to hydrogen. *ACS Applied Materials & Interfaces* 8, 10413 (2016).
4. H. Uršič, V. Bobnar, B. Malič, C. Filipič, M. Vrabelj, S. Drnovšek, Jo Younghun, M. Wencka, Z. Kutnjak. A multicaloric material as a link between electrocaloric and magnetocaloric refrigeration. *Scientific Reports* 6, 26629 (2016).
5. M. Igarashi, P. Jeglič, A. Kranjc, R. Žitko, T. Nakano, Y. Nozue, and D. Arčon. Metal-to-insulator crossover in alkali doped zeolite. *Scientific Reports* 6, 18682 (2016).
6. G. Posnjak, S. Čopar and I. Muševič. Points, skyrmions and torons in chiral nematic droplets. *Scientific Reports* 6, 26361 (2016).
7. L. E. Aguirre, A. de Oliveira, D. Seč, S. Čopar, P. L. Almeida, M. Ravnik, M. H. Godinho, S. Žumer. Sensing surface morphology of biofibers by decorating spider silk and cellulosic filaments with nematic microdroplets. *Proc. Natl. Acad. Sci. USA* 113, 1174 (2016).
8. S. Nizamoglu, M. Humar et al. Bioabsorbable polymer optical waveguides for deep-tissue photomedicine. *Nature Communications* 7, 10374, 2016).
9. S. Cho, M. Humar, N. Martino, S. H. Yun. Laser Particle Stimulated Emission Microscopy. *Phys. Rev. Lett.* 117, 193902 (2016).
10. B. Nitzsche, E. Dudek, L. Hajdo, A. A. Kasprzak, A. Vilfan, S. Diez. Working stroke of the kinesin-14, ncd, comprises two substeps of different direction. *Proc. Natl. Acad. Sci. USA* 113, E6582 (2016).

Some outstanding publications in 2015

1. M. Sluban, P. Umek, Z. Jagličić, J. Buh, P. Šmitek, C. Bittencourt, P. Guttmann, M.-H. Delville, D. Mihailović, D. Arčon. Controlling disorder and superconductivity in titanium oxynitride nanoribbons with anion exchange. *ACS Nano* 9 (2015), 10133.
2. M. Pregelj, A. Zorko, O. Zaharko, H. Nojiri, H. Berger, L. Chapon, D. Arčon. Spin-stripe phase in a frustrated zigzag spin-1/2 chain. *Nature Communications* 6, 7255(2015).
3. M. Klanjšek, D. Arčon, A. Sans, P. Adler, M. Jansen, C. Felser. Phonon-modulated magnetic interactions and spin Tomonaga-Luttinger liquid in the p-orbital antiferromagnet CsO_2. *Physical Review Letters* **115**, 057205(2015).
4. R. H. Zadik, A. Potočnik, P. Jeglič, D. Arčon, et al. Optimized unconventional superconductivity in a molecular Jahn-Teller metal. *Science Advances* **1**, e1500059(2015).
5. M. Pregelj, A. Zorko, M. Gomilšek, et al. Controllable broadband absorption in the mixed phase of metamagnets. *Advanced Functional Materials* **25**, 3634 (2015).
6. M. Nikkhou, M. Škarabot, S. Čopar, M. Ravnik, S. Žumer, I. Muševič. Light-controlled topological charge in a nematic liquid crystal. *Nature Physics* **11**, 183 (2015).
7. S. Čopar, U. Tkalec, I. Muševič, S. Žumer. Knot theory realizations in nematic colloids. *Proc. Natl. Acad. Sci.* **112**, 1675 (2015)).

8. R. Podlipec, J. Štrancar. Cell-scaffold adhesion dynamics measured in first seconds predicts cell growth on days scale - optical tweezers study. *ACS Applied Materials & Interfaces* 7, 6782(2015).
9. T. Koklič, R. Chattopadhyay, R. Majumder, B. R. Lenz. Factor Xa dimerization competes with prothrombinase complex formation on platelet-like membrane surfaces. *Biochemical Journal* 467, 37(2015).
10. Z. Arsov, U. Švajger, J. Mravljak, S. Pajk, A. Kotar, I. Urbančič, J. Štrancar, M. Anderluh. Internalization and accumulation in dendritic cells of a small pH-activatable glycomimetic fluorescent probe as revealed by spectral detection. *ChemBioChem* 16, 2660(2015).

Some outstanding publications in 2014

1. A. Zorko, O. Adamopoulos, M. Komelj, D. Arčon, A. Lappas. Frustration-induced nanometre-scale inhomogeneity in a triangular antiferromagnet. Nature Comms 5, 3222 (2014).
2. P. Koželj, S. Vrtnik, A. Jelen, S. Jazbec, Z. Jagličić, S. Maiti, M. Feuerbacher, W. Steurer, J. Dolinšek, Phys. Rev. Lett. 113, 107001 (2014).
3. R. Pirc, B. Rožič, J. Koruza, B. Malič, Z. Kutnjak, Negative electrocaloric effect in antiferroelectric $PbZrO_3$. Europhysics Letters 107, 17002-1-5(2014).
4. A. Martinez, M. Ravnik, B. Lucero, R. Visvanathan, S. Žumer, and I.I. Smalyukh Mutually tangled colloidal knots and induced defect loops in nematic fields, Nature Mater. 13, 258-263 (2014).
5. D. Seč, S. Čopar and S. Žumer, Topological zoo of free-standing knots in confined chiral nematic fluids, Nature Comms. 5, 3057 (2014).
6. J. Dontabhaktuni, M. Ravnik and S. Žumer, Quasicrystalline tilings with nematic colloidal platelets, Proceedings of the National Academy of Sciences of the United States of America 111, 2464 (2014).
7. S. Čopar, Topology and geometry of nematic braids, Phys. Rep. 538, 1-37 (2014).
8. A. Vilfan, Myosin directionality results from coupling between ATP hydrolysis, lever motion, and actin binding. Proceedings of the National Academy of Sciences of the United States of America 111, E2076 (2014).
9. Urbančič, I., Ljubetič, A. & Štrancar, J. Resolving Internal Motional Correlations to Complete the Conformational Entropy Meter. J. Phys. Chem. Lett. 5, 3593–3600 (2014).
10. Podlipec, R. et al. Molecular Mobility of Scaffolds' Biopolymers Influences Cell Growth. ACS Appl. Mater. Interfaces 6, 15980–15990 (2014).
11. Mikhaylov, G. et al. Selective targeting of tumor and stromal cells by a nanocarrier system displaying lipidated cathepsin B inhibitor. Angew. Chem. Int. Ed Engl. 53, 10077–10081 (2014).

Awards and appointments

1. Dr. Matjaž Humar: 1st Place Poster Prize at prestigious Nobel Laureate Meeting 2016, Lindau, Germany. Matjaž presented a poster about lasers embedded into single live cells for the first time. He has also demonstrated that fat cells already present in the human body already contain tiny lasers, which only need to be activated.
2. Dr. Matjaž Humar: Bronze Award from community Šempeter-Vrtojba for 2016, Šempeter-Vrtojba. The prize for the high successes in the world scale in recent years and as a stimulation for further scientific work.
3. dr. Janez Pirš, Hononrary distinction of "Jožef Stefan" Institute, Ljubljana, Slovenia, Honorary distinction for his successful contribution for developing new high-tech products based on scientific and technological achievements of the 'Jožef stefan' Institute.

Organization of conferences, congresses and meetings

1. 6th Workshop on Liquid Crystals for Photonics, 14. 9. – 16. 9. 2016, Ljubljana, Slovenia
2. 10. Conference of physicists in basic research, 16. 11. 2016, Otočec, Slovenia

Patent granted

1. Igor Muševič, Matjaž Humar, Spherical liquid-crystal laser, US9263843 (B2), US Patent Office, 16. 02. 2016

INTERNATIONAL PROJECTS

1. 7FP - ESNSTM; Electron Spin Noise Scanning Tunneling Microscopy
Prof. Janez Dolinšek
European Commission
2. 7FP - NanoMag; Magnetic Nanoparticles and Thin Films for Spintronic Applications and High Performance Permanent Magnets
Prof. Janez Dolinšek
European Commission
3. 7FP - SIMDALEE2; Sources, Interaction with Matter Detection and Analysis of Low Energy Electrons 2
Prof. Maja Remškar
European Commission
4. 7FP - LIVINGLASER; A Laser made Entirely of Living Cells and Materials derived from Living Organisms
Prof. Igor Muševič
European Commission
5. 7 FP; ERA CHAIR ISO-FOOD - Era Chairs for Isotope Techniques in Food Quality, Safety and Traceability
Prof. Maja Remškar
European Commission
6. COST MP1201; Rational Design of Hybrid Organic-Inorganic Interfaces: The Next Step Towards Advanced Functional Materials
Dr. Polona Umek
Cost Office
7. COST CA15107; Multi-Functional Nano-Carbon Composite Materials Network
Dr. Polona Umek
Cost Office
8. COST CA15209; European Network on NMR Relaxometry
Prof. Tomaž Apih
Cost Office
9. COST CA16109;Chemical On-Line cOmpoSition and Source Apportionment of fine aerosoL
Dr. Griša Močnik
Cost Office
10. H2020 - SmartNanoTox; Smart Tools for Gauging Nano Hazards
Prof. Janez Štrancar
European Commission
11. Solar Cell Application of Rf Rotating Plasma Modified Inorganic Nanotubes
Prof. Maja Remškar
Slovenian Research Agency
12. Spin-liquid Ground State of Quantum Kagome Antiferromagnets from a Local-probe Perspective
Asst. Prof. Andrej Zorko
Slovenian Research Agency
13. Controlled Nanoparticle Assemblies in Complex Soft Matrices
Prof. Samo Kralj
Slovenian Research Agency
14. Investigating Catalytic and Physical Properties of CuGdCa Alloys
Prof. Tomaž Apih
Slovenian Research Agency
15. Aromatic Polymers with Ultrahigh Breakdown Field Strength, Low Dielectric Loss, and High Electric Energy Density
Prof. Zdravko Kutnjak
Slovenian Research Agency
16. Investigation of Complex Materials for Hydrogen Storage
Prof. Janez Dolinšek
Slovenian Research Agency
17. Lipid Wrapped Gold Nanoparticles and Activity of Factor Xa
Prof. Janez Štrancar
Slovenian Research Agency
18. Crystal and Electronic Structure of NbS3 Phases
Dr. Erik Zupanič
Slovenian Research Agency
19. Radiative forcing of desert mineral dust and PM10 concentrations over Southern Europe
Prof. Maja Remškar
Slovenian Research Agency
20. Lead-free (Ba0.8Ca0.2)1-xLa2x/3TiO3 based electrocaloric materials for new dielectric cooling technologies
Prof. Zdravko Kutnjak
Slovenian Research Agency
21. Stabilisation of lattices of topological defects
Prof. Samo Kralj
Slovenian Research Agency

RESEARCH PROGRAMS

1. Physics of Soft Matter, Surfaces and Nanostructures
Prof. Slobodan Žumer
2. Experimental Biophysics of Complex Systems
Prof. Janez Štrancar
3. Magnetic resonance and dielectric spectroscopy of „smart" new materials
Prof. Janez Dolinšek

R & D GRANTS AND CONTRACTS

1. Topology and Photonics of Liquid Crystal Colloids and Dispersions
Prof. Igor Muševič
2. Thermophoretic guidance, accumulation and sorting of biomolecules in microfluidic devices
Asst. Prof. Andrej Vilfan
3. Intra-pocket-targeted nanomedicines for treatment of periodontal disease
Prof. Maja Remškar
4. New advanced electrocaloric materials for novel environmentally-friendly dielectric refrigeration technology
Prof. Zdravko Kutnjak
5. The textural analysis of spatiotemporal changes for breast lesions diagnosis on ultrafastbreast MRIs
Prof. Igor Serša
6. Role of Calcium and lipid membranes in survival of critically ill patients
Dr. Tilen Koklič
7. Multifunctional materials for actuator and cooling devices
Prof. Zdravko Kutnjak
8. High-Entropy Alloys
Dr. Stanislav Vrtnik
9. Metamaterials from liquid crystal colloids
Asst. Prof. Miha Ravnik
10. Optimization strategies in biological and artificial microfluidic systems
Asst. Prof. Andrej Vilfan
11. Selective and hipersensitive microcapacitive sensor system for targetted molecular detection in the atmosphere
Prof. Igor Muševič
12. Correlated electrons in cnofined molecular systems
Prof. Denis Arčon
13. Water exclusion efficacy, measure for prediction of wood performance against wood decay fungi
Prof. Igor Serša
14. Micro-electromechanical and electrocaloric layer elements
Prof. Zdravko Kutnjak
15. Performance of wood and lignocelolosic composites in outdoor applications
Prof. Igor Serša
16. Advanced electrocaloric energij conversion
Prof. Zdravko Kutnjak
17. Microspectroscopy-based optimization of the effects of laser pulses on the retina
Prof. Janez Štrancar
18. SCOPES; Spin-liquid and Spin-ice States in Frustrated Rare-earth and Transition Metal Spinels
Dr. Matej Pregelj
Snf- Swiss National Science Foundation
19. Irradiation and Analysis of Nano SiC Samples
Prof. Vid Bobnar
National Nuclear Research Center
20. Building blocks, tools and systems for the Factories of the Future – GOSTOP
Prof. Janez Štrancar

NEW CONTRACTS

1. MRI scanning of samples
Prof. Igor Serša
KRKA, TOVARNA ZDRAVIL, D.D.
2. Analyzes with nuclear quadrupole resonance (NQR
Prof. Tomaž Apih
LEK d.d.
3. Measurement of optical transmissivity
Prof. Igor Muševič
RLS Merilna tehnika d.o.o.
4. Microspectroscopy-based optimization of the effects of laser pulses on the retina
Prof. Janez Štrancar
OPTOTEK d.o.o.

VISITORS FROM ABROAD

1. dr. Mutsuo Igarashi, Gunma National College of Technology, Maebashi, Japan, 16. 1. 2016 – 24. 1. 2016, 21. 8. 2016 – 2. 9. 2016
2. mag. Kushtrim Podrimqaku, University of Pristina, Pristina, Kosovo, 21. 1. 2016 – 27. 1. 2016
3. mag. Valon Veliu, University of Pristina, Pristina, Kosovo, 21. 1. 2016 – 27. 1. 2016
4. dr. Uliana Ognysta, Institute of Physics, National Academy of Science of Ukraine, Kiev, Ukraine, 31. 1. 2016 – 10. 3. 2016
5. dr. Vaida Lunkuviene, Faculty of Natural Sciences of Vilnius University, Vilnius, Litva, 1. 2. 2016 – 31. 3. 2016
6. dr. Alicja Filipek, Institute of Physics, Polish Academy of Sciences, Warsaw, Poland, 20. 2. 2016 – 5. 3. 2016
7. dr. Alan Soper, ISIS Facility STFC Rutherford Appleton Laboratory, Harwell, Oxford, Great Britain, 1. 3. 2016 – 5. 3. 2016
8. dr. Randall Kamien, University of Pennsylvania, Philadelphia, USA, 6. 3. 2016 – 9. 3. 2016
9. dr. Tina Pavlin, University of Bergen, Bergen, Norway, 4. 4. 2016 – 10. 4. 2016
10. dr. Surajit Dhara, School of Physics University of Hyderabad, Talangana, India, 7. 5. 2016 – 11. 6. 2016
11. doc. dr. Michael Grbic, Faculty of Science, University of Zagreb, Zagreb, Croatia, 16. 5. 2016
12. dr. Katarina Butalović, Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia, 1. 6. 2016 – 3. 6. 2016
13. dr. Milijana Savić, Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia, 1. 6. 2016 – 3. 6. 2016
14. dr. Manel Rodriguez Ripoll, AC2T research GmbH, Wiener Neustadt, Austria, 7. 6. 2016
15. dr. Bouchra Asbani, Universite de Picardie Jules Verne, Laboratoire de la Mateiere Condense (LPMC), Amiens, France, 11. 7. 2016 – 8. 8. 2016
16. dr. Mutsuo Igarashi, Gunma National College of Technology, Maebashi, Japan, 21. 8. 2016 – 2. 9. 2016, 27. 10. 2016 – 8. 11. 2016
17. prof. dr. Christian Eggeling, Weatherall Institute of Molecular Medicine, Radcliffe Department of Medicine – Investinative Medicine, University of Oxford, Great Britain, 24. 8. 2016 – 27. 8. 2016
18. dr. Carla Bittencourt, University of Mons, Mons, Belgium, 7. 9. 2016 – 31. 10. 2016
19. dr. Jun-ichi Fukuda, Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan, 11. 9. 2016 – 6. 10. 2016
20. dr. Sergey Lushnikov, AF Ioffe Physicotechnical Institute, RAS, St. Petersburg, Russia, 3. 10. 2016 – 31. 10. 2016
21. dr. Magdalena Wencka, Institute of Molecular Physics, Polish Academy of Sciences, Poznan, Poland, 19. 10. 2016 – 28. 10. 2016
22. prof. dr. Francesco Sagues, University of Barcelona, Barcelona, Spain, 26. 10. 2016 – 28. 10. 2016
23. prof. Eung Je Woo, Kyung Hee University, Seoul, Korea, 13. 11. 2016 – 19. 11. 2016
24. dr. Ana Varlec, APE Research, Area Science Park, Basovizza, Italy, 20. 11. 2016 – 2. 12. 2016

STAFF

Researchers
1. Prof. Tomaž Apih
2. Prof. Denis Arčon*
3. Asst. Prof. Zoran Arsov
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