DEPARTMENT OF SURFACE ENGINEERING AND OPTOELECTRONICS F-4

The research program is associated with vacuum science, technology and applications. The main activities are focused on plasma science, the modification of advanced biomedical materials and products for improved biocompatibility, the characterization of inorganic, polymer and composite materials with different thin films on the surface, the modification and characterization of fusion-relevant materials, the thermodynamics of trapped gases and methods for sustaining an ultra-high-vacuum environment, vacuum optoelectronics, and basic research in the field of surface and thin-film characterization by electron and ion spectroscopy techniques.

Head:
Prof. Miran Mozetič

The research team has built several plasma reactors in the past decade. The reactors are often made from glass in order to minimize the loss of neutral reactive gaseous species by heterogeneous surface recombination. Namely, the probability of such reactions on a smooth glass surface is low for most reactive particles. Gaseous plasma can be sustained by different discharges, but the team has specialized in electrodeless discharges powered by high-frequency generators. Small reactors are powered with microwaves, but for the sustenance of plasma in large reactors an electromagnetic field in the radiofrequency range performs better. Particularly suitable are both industrial frequencies of 13.56 and 27.12 MHz. A radiofrequency generator is coupled with a metallic coil wrapped on the glass tube. Such a configuration enables very good coupling between plasma electrons and the electromagnetic field in medium-size reactors, but stray effects are observed in large reactors where the plasma is sustained by powerful generators. In such cases stray effects are common and difficult to avoid. The unwanted effects are due to high voltages that appear across the coil at high powers. Such voltages cause stray capacitive coupling of the RF power to grounded metallic components as well as extensive radiation of the electromagnetic waves. Methods for suppressing high voltages, but keeping large powers, have been studied both theoretically and experimentally in the past few years and a patent application has been filed. The patent was granted in 2016 by the German Patent Office in Munich. In it we disclose methods for suppressing stray voltage across the plasma coil by the appropriate coupling of several coils. The invention relates to a device for the excitation of a high-frequency gas plasma, i.e., optimization of the transfer of electromagnetic power from a radio-frequency generator into a gas plasma. The transfer of power is optimized by using two or more parallel overlapping and offset excitation coils that are serially connected into the assembly, consisting of a generator, a high-frequency cable, a matching network and an excitation coil. The measurements on the connections of the excitation coil prove that for equal transfer of power a lower voltage is required on the double excitation coil consisting of overlapping excitation coils connected in parallel than on the ordinary excitation coil. With the same voltage on the connections of the coil, the plasma is also more intensive, if it is generated in two overlapping excitation coils connected in parallel.

The German patent office granted a patent on innovative coupling between an RF generator and gaseous plasma

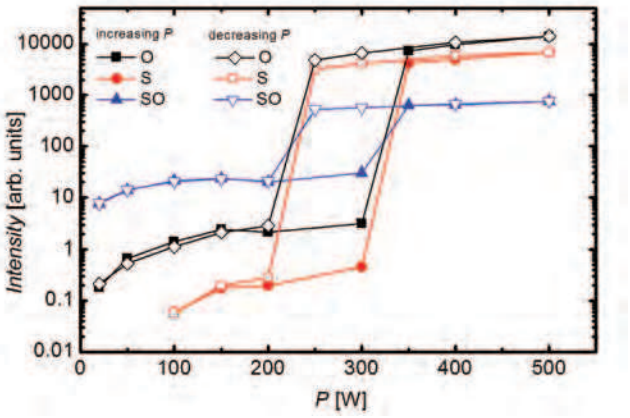


Figure 1: Hysteresis in OES intensities of S, O, and SO versus the forward RF power at a pressure of 30 Pa.

The energy gained by charged gaseous particles oscillating in a high-frequency electric field depends on the mass of the particle. If a RF field is applied, the gaseous ions can hardly follow oscillations in the MHz range, so they gain negligible energy. Electrons are less massive and are accelerating in the field. If they gain enough energy they can multiply during ionization collisions with neutral molecules. The electric field in the coil has at least two components: the capacitive, which develops next to the powered part of the coil; and inductive, which develops inside the coil due to induced electric field. If the predominant component is capacitive, plasma is in the so-called "E-mode". The electric field in this mode is concentrated in a small volume so the density of electrons in gaseous plasma is rather low. In the opposite case the electric field occupies the entire volume inside the coil with a pronounced radial distribution and causes the acceleration of numerous plasma electrons. If the predominant coupling is inductive, the plasma is in "H-mode". The H-mode is characterized by a high electron density and bright luminosity. The appearance of the modes depends on several parameters, with the discharge

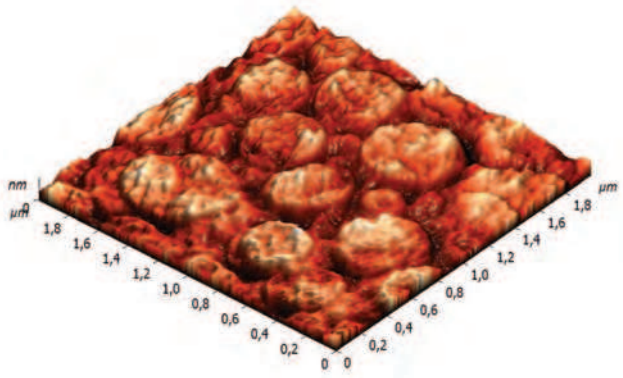


Figure 2: AFM image of originally smooth polymer surface after 80 s of treatment in H_2S plasma in the E-mode.

power and pressure being the most important. The transition between the modes is almost gradual at pressures below about 1 Pa and/or high inductance of the coil, but becomes more abrupt at elevated pressure and lower inductance. The transitions between the modes at a constant pressure and variable power exhibit a pronounced hysteresis. Such effects were studied for the case where plasma was created in sulphur dioxide. SO_2 molecules partially dissociate upon plasma conditions already when the discharge power is low, so that it is in the E-mode. Most intensive radiation arises from the transitions of SO radicals. As the power increases the radiation slightly increases until the transition to the H-mode appears. At this power the plasma luminosity increases abruptly by three orders of magnitude. Simultaneously, the emission from both atomic species (S and O) prevails over the emission of SO radicals, indicating high dissociation of the parent molecules in the H-mode. When decreasing the power, the transition occurs at a lower power, and thus a hysteresis is observed.

Plasma created in sulphur dioxide is used for mimicking sulfurized polymers such as heparin, which is renowned for its anti-thrombogenic properties, and so it is often used as a blood thinner. Heparin binds to the enzyme inhibitor anti-thrombin; therefore, it is a beneficial coating on cardiovascular implants. A brief exposure of polyethylene terephthalate, a polymer commonly used for synthesis of artificial blood vessels, to SO_2 plasma caused mild sulfurization, but atomic oxygen, which abounds in such plasma, causes continuous removal of sulfurized carbon, so the sulphur concentration on the polymer surface was hardly sufficient. Higher concentrations of sulphur on the surface of this polymer were found for the case that the plasma was created in H_2S. Depending on the plasma parameters the sulphur concentration as determined by X-ray photoelectron spectroscopy (XPS) reached almost 40 at.%. A well-pronounced maximum in the sulphur concentration versus the plasma treatment time was observed. A combination of XPS and time-of-flight secondary ion mass spectroscopy (ToF SIMS) techniques revealed the formation of polysulfide on the surface of PET polymer within a limited range of plasma radicals' fluence. The originally smooth polymer surface underwent an interesting change in the surface morphology. Within the limited range of the radicals' fluence, densely distributed circular nanostructures of typical sub-micrometre lateral dimension and a height of several 10 nm were observed by atomic force microscopy (AFM).

The plasma treatment causes changes in both surface morphology and functionality, which in turn influences the adsorption kinetic of proteins upon the incubation of polymeric grafts with human blood. This effect was studied in collaboration with a research team at Soleil synchrotron in France. Thin films of human serum albumin (HSA) were immobilized on polystyrene (PS) substrates previously functionalized either with polar or nonpolar functional groups. The functionalization was performed by treatment with cold gaseous plasma created in pure oxygen and tetrafluoromethane (CF_4) plasmas, respectively. Samples were examined with soft X-rays in the photon energy range of 520 to 710 eV in the ANTARES beam line. Near-edge X-ray absorption fine structure (NEXAFS) was selected for studying the behavior of albumin on the surface of a plasma-treated polymer. NEXAFS spectra of oxygen and fluorine K-edges were collected at different spots on the sample, and measurements at each spot were repeated many times. A strong degradation of the HSA protein upon irradiation with synchrotron light was observed. The weakly irradiated samples exhibited strong absorption at 531.5 eV associated with the O 1s→ϖ^*_{amide} transitions, and a broad non-distinctive peak at 540 eV was attributed to the O 1s→$\sigma^*_{C\text{-}O}$ transitions. Both peaks decreased with increasing irradiation time until they were completely replaced by a broad, non-distinctive peak at around 532 eV, indicating the destruction of the original protein conformation. The shortage of amide groups indicated breakage of the peptide bonds.

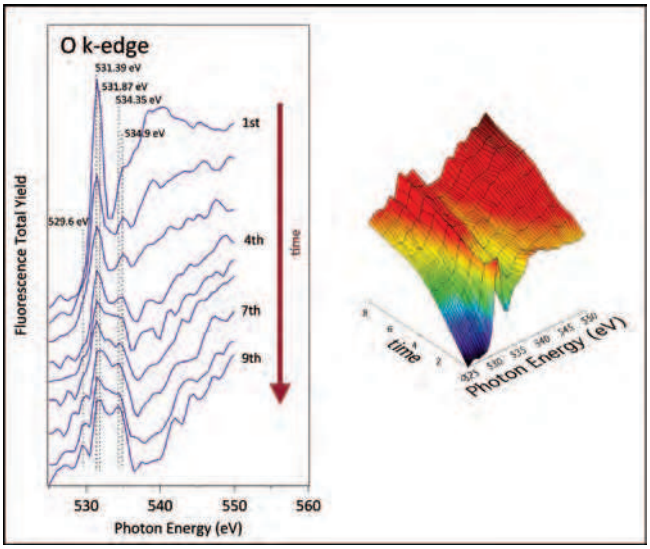


Figure 3: Series of oxygen K-edge NEXAFS spectra of an albumin-incubated sample treated with oxygen plasma and incubated with albumin.

Low-pressure cold plasma is also useful for the treatment of textiles to improve their functional properties. A fruitful collaboration has been established with the Department of Textiles at the Faculty of Natural Sciences and Engineering, University of Ljubljana. Plasma created in various gases was used for both nanostructuring and functionalization of fabrics made from natural fibres. We were following the current trends of using ecologically benign treatments for surface finish as well as dyes extracted

from natural sources. In order to achieve colourful and antibacterial textiles, cotton and bamboo-rayon knitted fabrics were treated using radio-frequency, low-pressure plasma created in water vapour and dyed with the extract of Fallopia japonica (Japanese knotweed) rhizome. Water vapour was used as a natural choice since such fabrics contain a substantial amount of water, which is slowly released upon vacuum conditions. Even a brief plasma treatment induced a weak etching effect on the surface of the cellulose samples, since water molecules in plasma dissociate to produce hydroxyl radicals and oxygen atoms. Both radicals interact chemically with the organic material, thus interacting preferentially with any surface impurities as well as the uppermost layer of cellulose. Plasma-treated samples exhibited a higher dye uptake as well as pronounced antibacterial properties against *S. aureus*.

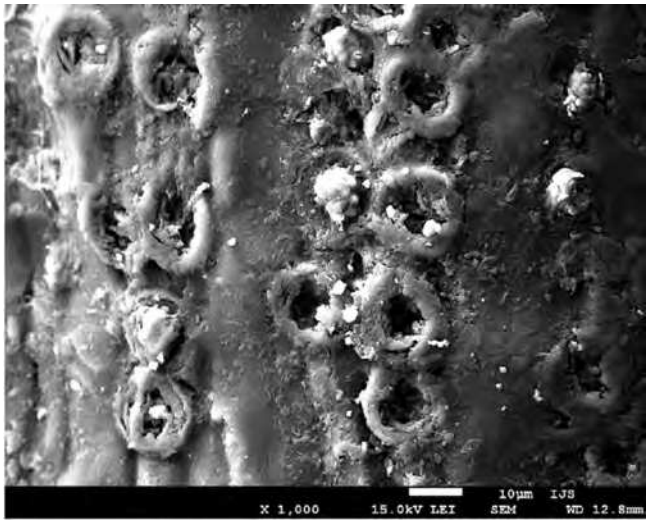


Figure 4: SEM image of a coir fibre after treatment with oxygen plasma reveals an interesting morphology.

Another way to improve the performance of medical textiles is the incorporation of nanoparticles into fabrics or embedment into deposited coatings with antibacterial efficiency using atmospheric pressure plasma process. This research has been performed in the frame of the M-ERA. NET programme and strong collaboration with Ghent University. We developed a direct current plasma jet as a plasma-deposition source. The jet was stabilized by fast nitrogen flow. Three different types of the nanoparticles (silver, copper and zinc oxide) were employed as antimicrobial agents. During the deposition most of these nanoparticles were partially oxidized and embedded into the polymer coating generated by admixing hexamethyldisiloxane (HDMSO). The microbiological testing showed that samples loaded with nanoparticles of Ag and Cu and having a barrier layer of 10 nm, exhibit almost 97% bacterial reduction for *Escherichia coli* and *Staphylococcus aureus*, whereas the samples with ZnO nanoparticles provided only 86% reduction of *Staphylococcus aureus*.

Today, synthetic fibre-reinforced plastics have proven to meet the structural and durability requirements of components for various applications. However, glass-reinforced plastics exhibit shortcomings such as their relatively high fibre density, their difficulty to machine and poor recycling properties. With the growing global energy crisis and ecological risks, natural fibre-reinforced polymer composites have attracted more research interest due to their potential for serving as an alternative for artificial fibre composites. Natural fibres offer benefits such as reductions in weight, cost and CO_2 emission; less reliance on oil resources; and recyclability. To use the natural fibre-reinforced polymers, several major technical issues must be solved to facilitate the insertion of natural fibres in polymer composites. A critical factor in reinforced polymers is the strength of the bond between the fibre and polymer matrix, because the load is transmitted through the fibre–matrix interface. In order to improve it, we used the technology of selective plasma etching. An abundant natural source of fibres are coconuts. The raw coir fibres are not suitable for fibre-enforced plastics due to their hydrophobic nature since they contain lots of lignin and pectin. These components must be removed selectively from the fibres' surface to improve the adhesion of any polymer. Such an effect was achieved using rather aggressive oxygen plasma treatment. The impurities were quickly removed, revealing interesting structure of the coir fibres. Furthermore, the cellulose component was nanostructured so the treated fibres assumed excellent wettability – the water absorbency time decreased by two orders of magnitude.

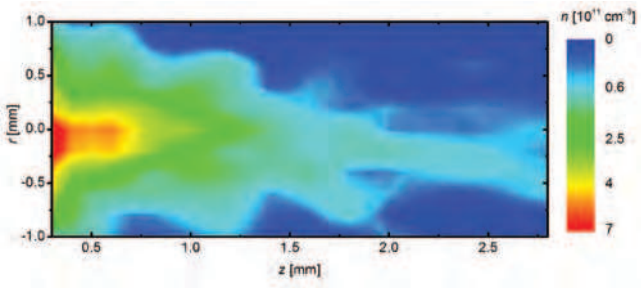


Figure 5: Spatially resolved He metastable density distribution over the effluent of a free atmospheric pressure plasma jet.

Another good example of the selective etching of polymers and polymer-matrix composites is a collaborative work with the industrial partner Kolektor on an improvement of the insulating properties of polyphenolic composites. A composition with suitable fillers is a common strategy to improve the electrical insulation properties of polymeric materials, which is limited by the carbonization of a protruding surface polymer. To resolve this problem, we implemented Ar/O_2 plasma etching of a glass-filled polyphenolic composite to uncover the fillers by selective removal of the surface polymer. The exposure of the glass fillers increased the performance level to 65%, which enabled the material to be used as an insulator for commercial applications. The innovative solution to solving the problem of increasing surface insulation properties without adding expensive fillers to the polymer composite was also protected by a patent application.

Low-pressure, weakly ionized gaseous plasma is also suitable for tailoring the surface properties of inorganic materials. Within a newly granted project we studied the biological response of nanostructured titania that is suitable for the coating of vascular stents. Currently available stents are often made from titanium alloys. Such

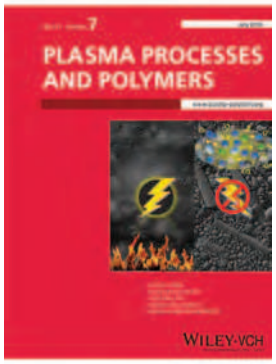


Figure 6: Journal cover page presenting improvement of plasma-etched thermoplastic composites, which become tracking and fire resistant.

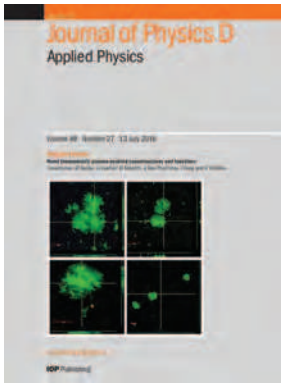
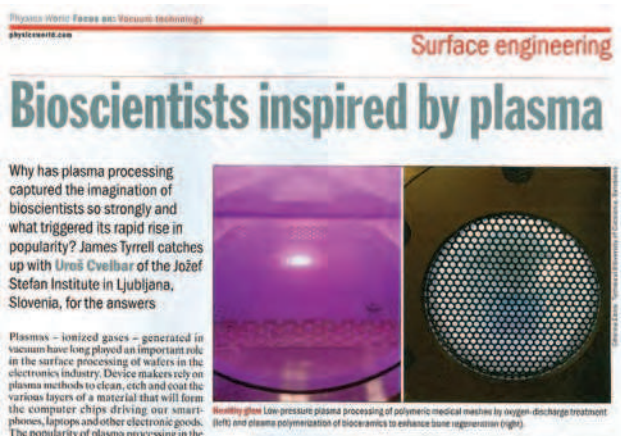


Figure 7: Journal over page presenting reduction of P. aeruginosa biofilm cells after plasma treatment.

stents lack of desired biological response, mostly due to restenosis, which occurs in more than 33% of cases where stents have been implanted. We developed a method for improving the proliferation of endothelial cells and simultaneously reducing adhesion and the activation of blood platelets on the surface of plasma-modified stents. The innovative method was disclosed in a patent application entitled: "Method for coating a medical device, especially a vascular stent" which has been submitted to the German patent office. We managed to achieve appropriate nanostructuring of the surface (biomimetic surface), which, after a treatment with highly reactive oxygen plasma, prevents platelet adhesion and activation, which in turn significantly reduces the possibilities for thrombotic reactions. Moreover, such a surface treatment also improves the endothelial cell proliferation, which is of primary importance, since such cells represent an ideal natural anti-thrombogenic material. In collaboration with the Faculty of Electrical Engineering, University of Ljubljana, we fabricated uniformly distributed dense and mechanically stable TiO_2 nanotubes on stents' surfaces. The plasma treatment enabled the removal of toxic fluorine, which is otherwise present on the surface due to electrochemical anodization process. *In-vitro* studies with whole human blood clearly showed that the platelets did not interact with surfaces prepared by the methods of invention, especially in the case of the 100-nm nanotube diameter. No platelets were detected on the plasma-treated TiO_2 nanotubes of 100 nm in diameter, and only a few on the nanotubes of 50 nm in diameter. Furthermore, *in-vitro* studies conducted with endothelial cells revealed the superior properties of plasma-treated nanostructured surfaces.

The stocks of fossil fuels are limited and their exploitation causes global warming, so we are looking for alternative energy sources for future generations. The cleanest energy arises from solar radiation, but it is difficult and expensive to transform it into useful energy. An alternative is the application of the same process as powers stars - nuclear fusion. Fusion power has the potential to provide sufficient energy to satisfy mounting demand, and to do so sustainably, with a relatively small impact on the environment. Nuclear fusion has many potential advantages over other energy sources. Firstly, its hydrogen isotope fuels are relatively abundant on earth. Furthermore, a fusion reactor would produce virtually no CO_2 or atmospheric pollutants, and its other radioactive waste products would be very short-lived compared to those produced by conventional nuclear reactors. Therefore, experimental fusion reactors have been built in order to solve numerous technological problems that currently prevent the exploitation of fusion energy. We have been involved in fusion-related research within Eurofusion projects for a decade. In 2016 we performed experiments at ASDEX Upgrade and JET reactors, which are currently the largest operating tokamaks. Our interest was mainly focused on ammonia production in fusion reactors. Because the cooling of the fusion plasma is needed near the plasma-facing components, nitrogen is often seeded into the divertor region. The ammonia is formed mainly in this region by surface processes. We investigated the production of ammonia on different materials currently used for manufacturing plasma-facing components in order to estimate the retention of tritiated ammonia in future reactors. This effect may be detrimental, but we discovered that ammonia also has at least one positive effect; it cleans amorphous hydrogenated carbon from the reactor walls.

The gas dynamics, in particular adsorption/desorption from walls of low-pressure reactors, is often studied by mass spectrometry. The precise quantification of extremely small gas amounts requires the applied quadruple mass spectrometer to be *in-situ* calibrated at very small gas-leak rates. A precise calibration of a mass spectrometer was realized by leaking a specific gas through a fixed opening of the leak valve, connected to the analytical chamber. Exponential pressure decay in the upstream volume means that the molecular gas flow rate is also decaying exponentially. The correlation of the ion current of a specific ion mass versus the gas-leak rate expresses the mass spectrometer's sensitivity over a wide range. During the calibration campaign conducted with hydrogen in an ultra-high vacuum (UHV) chamber, a slight deviation from the exponential decay and a drift of the base background pressure were observed. Both effects were attributed to the hydrogen absorption on surfaces. Its importance was then studied intentionally in detail. An UHV chamber is generally supposed to have a constant base background outgassing rate q_0 over very long periods of time. In experiments with ionized or neutral molecular hydrogen, this level might be increased by the absorption of a small fraction of hydrogen. The absorption of molecular hydrogen was monitored in a small, austenitic stainless-steel UHV chamber during 3 h exposures at initial pressures from 0.01 to 1 mbar at room temperature. An absorbed dose of ~10^{13}–10^{14} atom H cm^{-2} was recorded. After gas removal, the desorption period in the closed vacuum system lasted for 20 h, wherein most of the absorbed hydrogen was released. The initial desorption rate was 10–100 times higher than the previous q_0. Calculations based on well-accepted


Surface engineering

Bioscientists inspired by plasma

Why has plasma processing captured the imagination of bioscientists so strongly and what triggered its rapid rise in popularity? James Tyrrell catches up with Uroš Cvelbar of the Jožef Stefan Institute in Ljubljana, Slovenia, for the answers

Plasmas – ionized gases – generated in vacuum have long played an important role in the surface processing of wafers in the electronics industry. Device makers rely on plasma methods to clean, etch and coat the various layers of a material that will form the computer chips driving our smartphones, laptops and other electronic goods.

Figure 8: Promotion of special issue in J. Phys. D: Appl. Phys. on "Plasma-inspired biomaterials" edited by prof. Cvelbar.

models for hydrogen–metal interactions confirm that the observed absorption–desorption processes are related mainly to the native oxide layer. Its reported thickness is between 1 and 3 nm, and our results express its high solubility, which at 1 nm ranges from $K_{sox}(294\ K) = 2.0\times10^{22}$ to 3.8×10^{22} atom H $cm^{-3}\cdot bar^{-0.5}$. The recombination rate coefficient ranges from $K_{Lox}(294K) = 8.9\times10^{-19}$ to 6.45×10^{-18} $cm^4\ s^{-1}$. The properties of the bulk metal were not affected noticeably in 24 h cycles as the oxide-layer–bulk-metal interactions proceed substantially slower.

Apart from low-pressure plasma we are also involved in research on non-equilibrium gaseous plasma created at atmospheric pressure. Although such plasma has several advantages over low-pressure plasma, the inadequate knowledge of its characteristics still prevents mass application on an industrial scale. An investigation of excited species, metastable states, reactive species, etc. is one of the highly desirable goals. Due to its important role in plasma generation and plasma chemistry processes, metastable helium (He) atoms are a great candidate for this kind of an investigation. We studied the properties of atmospheric pressure plasma jet (APPJ) in collaboration with our colleagues from the Institute of Physics in Zagreb, Croatia. Using cavity ring down spectroscopy (CRDS) we measured the density of He atoms in the metastable state (2^3S_1), across the single electrode APPJ during the treatment of various samples. For the first time we managed to obtain the spatially resolved He metastable density distribution over the effluent of the APPJ. We found a correlation between sample conductivities and metastable He densities above the sample surface. The metastable He density can be increased with decreasing sample distance, increasing conductive sample surface area and by increasing He flow,which what is important for the application of such plasma for tailoring the surface properties of materials on a small scale.

Figure 9: An atmospheric pressure plasma reactor was integrated to the production line at Tosama company for the deposition of antimicrobial thin films on wound care products in the frame of the European project IP4Plasma

Atmospheric pressure gaseous plasma is not suitable for the uniform treatment of three-dimensional objects due to strong gradients in reactive particles densities, but performs well for the treatment of planar objects. The best results are obtained with porous two-dimensional products such as textiles. A technology for the treatment of infinite textiles used for wound healing has been developed in the frame of the EU project "IP4Plasma": Industrial Innovations Based on EU Intellectual Property Assets in the Field of Atmospheric Pressure Plasma Technology. The project was completed successfully in the autumn of 2016. The IP4Plasma project was funded by the European Union under the 7th Framework Programme for Research and Innovation. It lasted three years and involved some leading experts in surface engineering by gaseous plasma, equipment manufacturers and users of plasma technologies. Nine European partners from research organizations and industry were involved: Spinverse Ltd (Finland), Fraunhofer Institute for Surface Engineering and Thin Films IST (Germany), IMA (Belgium), Jozef Stefan Institute (Slovenia), LIONEX GmbH (Germany), SOFTAL Corona & Plasma GmbH (Germany), Tosama (Slovenia), VITO - Flemish Institute for Technological Research (Belgium) and 2B (Italy). The result of this project is a new technology for the plasma deposition of coatings on wound dressings, improving the wound-draining behaviour and add anti-inflammatory properties of products made by Tosama company. Our group performed a precise surface characterization of plasma-deposited coatings using the XPS and ToF-SIMS methods. In the frame of the project we also developed a new method for the fast and in-line monitoring of the efficiency of the air plasma surface activation at very high speed of textiles, which has a great potential for global industrial applications.

The European project IP4Plasma involving nine European partners, among them the Jožef Stefan Institute and the Tosama company from Slovenia, was completed successfully

Similarly, the control and regulated release of antibiotic drugs from plasma-treated medical implant surfaces could be achieved using atmospheric plasma sources. Calcium phosphate ceramics are promising bone substitutes, since they have good biocompatibility and bioresorbability. Currently, such ceramics loaded with antibiotics in order to prevent infections are already on the market, but the control of release patterns has to be further improved. Cold plasmas can provide useful means of modifying the surface interactions with drugs through surface modification. For this reason, we explored the possibilities of using atmospheric pressure plasmas as a tool for modifications of calcium phosphate materials with newly

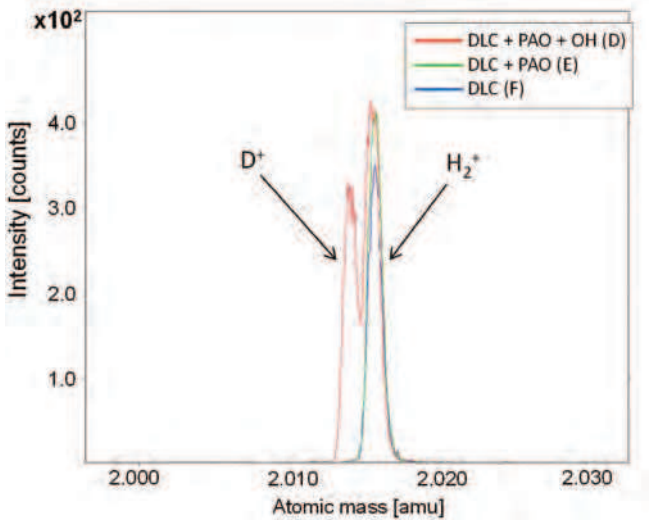


Figure 10: High-resolution mass spectra obtained by the ToF-SIMS method from diamond-like carbon after the desorption of a lubricant containing deuterated hexadecanol molecules.

populated bonds and charges, with the aim of enabling higher loading and controlled drug release. For surface modifications of β-tricalcium phosphate ceramics we implemented APPJ sustained in helium as a tool for tuning the controlled release of the antibiotic doxycycline hyclate, employed as a drug model. The surface chemistry was tailored upon interaction with the APPJ. We managed to obtain an increased oxygen-to-carbon ratio without changes in the topography as well as a build-up of surface charges. This led to slower and steady release kinetics after bonding drugs to the surface. Moreover, we demonstrated that atmospheric pressure plasma might prove to be a promising new tool that will lead to the design of a better controlled drug release from bio-ceramic matrices.

Diamond-like carbon (DLC) films are one of the fastest developing coatings ensuring low friction and protecting the sliding surfaces of various mechanical components. Because of their superior sliding properties, DLC coatings are now being widely used in many applications such as IC engines, slider bearings and hard discs. Despite the good sliding properties, even in the absence of any lubricant, the use of a lubricant seems inevitable for better heat dissipation and thus extended service life. The interaction between lubricants and DLC coatings is still not well understood, despite many studies over the past few years. We used ToF-SIMS and XPS methods to examine the adsorption ability and mechanisms with respect to two oiliness additives, i.e., hexadecanol and hexadecanoic acid, on the surface of weakly oxidized DLC coatings. Additionally, we analysed the resistance of the adsorbed additive films against external influences. Neither of these surface-sensitive techniques is capable of distinguishing between hydrogen from the substrate and the additives. In order to obtain impeccable results, the additives were deuterated. The high resolution of the ToF SIMS instrument allowed for a distinction between deuterium atoms from the additive and hydrogen molecules from the substrate in secondary-ion spectra. Our results show that both molecules adsorb on the surface oxides and hydroxides and shield these structures with their hydrocarbon tails. This makes the surfaces less polar, which was manifested in a smaller polar component of the surface energy. Of the two examined molecules, the hexadecanoic acid showed a greater adsorption ability than the alcohol, which explains the better tribological properties when the acid was used as an additive in a lubrication oil.

Figure 11: The JVC-16 & EVC- 14 conference attracted 181 participants from 25 countries.

The research team organized several international scientific meetings including the 16th Joint Vacuum Conference (JVC-16) and the 14th European Vacuum Conference (EVC-14). The conference took place in Portorož between June 6th and 10th.

Some outstanding publications in the past three years

1. Vesel, A.; Mozetic, M.; Zaplotnik, R., Device for high-frequency gas plasma excitation: DE 112012000015 (B4), 2016-04-21. *Munchen: Deutches Patent Office* 2016.
2. Zaplotnik, R.; Vesel, A.; Mozetič, M., Investigation of reactive plasma species created in SO_2 by an inductively coupled RF discharge in E- and H-mode. *Journal of applied physics,* 2016, *120*, 163302-1-163302-9.
3. Recek, N.; Primc, G.; Vesel, A.; Mozetič, M.; Avila, J.; Razado-Colambo, I.; Asensio, M. C., Degradation of albumin on plasma-treated polystyrene by soft X-ray exposure. *Polymers*, 2016, *8*, 244-1-244-7.
4. Gorjanc, M.; Savić, A.; Topalić-Trivunović, L.; Mozetič, M.; Zaplotnik, R.; Vesel, A.; Grujić, D., Dyeing of plasma treated cotton and bamboo rayon with Fallopia japonica extract. *Cellulose* 2016, *23*, 2221-2228.
5. Drenik, A.; Mourkas, A.; Zaplotnik, R.; Primc, G.; Mozetič, M.; Panjan, P.; Alegre, D.; Tabarés, F.L., Erosion of a-C:H in the afterglow of ammonia plasma. *Journal of Nuclear Materials* 2016, *475*, 237-242.
6. Zaplotnik, R.; Bišćan, M.; Popović, D.; Mozetič, M.; Milošević, S., Metastable helium atom density in a single electrode atmospheric plasma jet during sample treatment. *Plasma Sources Science and Technology* 2016, *25*, 035023.
7. Simič, R.; Kalin, M.; Kovač, J.; Jakša, G., Adsorption of alcohols and fatty acids onto hydrogenated (a-C:H) DLC coatings. *Applied Surface Science* 2016, 363, 466-476.
8. Canal, C.; Modic, M.; Cvelbar, U.; Ginebra, M.P., Regulating th eantibiotic drug release from β-ricalcium phosphate ceramics by atmospheric pressure surface engineering. *Biomaterials science* 2016, 5, 1454-1461.
9. Puliyalil, H.; Slobodian, P.; Sedlacik, M.; Benlikaya, R.; Riha, P.; Ostrikov, K.; Cvelbar, U., Plasma-enabled sensing of urea and related amides on polyaniline. *Frontiers of Chemical Science and Engineering* 2016, 10, 265-272.
10. Nemanič, V.; Žumer, M., Quantification of small gas amounts with an ion trap mass spectrometer, *International Journal of Mass Spectrometry* 2016, 401, 17-21

Patents granted

1. Alenka Vesel, Miran Mozetič, Rok Zaplotnik, Device for high-frequency gas plasma excitation, DE112012000015 (B4), Deutsches Patent- unt Markenamt, 21. 04. 2016
2. Alenka Vesel, Rok Zaplotnik, Miran Mozetič, Method for cleaning of with body fluid-contaminatedmedical implantants and devices with the use of atomic oxygen, SI24840 (A), Slovenian Intellectual Property Office, 29. 04. 2016
3. Gregor Filipič, Kristina Eleršič, Darij Kreuh, Janez Kovač, Uroš Cvelbar, Miran Mozetič, A method of colouring titanium and titanium alloys, SI24851 (A), Slovenian Intellectual Property Office, 29. 04. 2016

INTERNATIONAL PROJECTS

1. 7FP - IP4Plasma; Industrial Innovations Based on EU Intellectual Property Assets in the Field of Atmospheric Plasma Technology
   Asst. Prof. Janez Kovač
   European Commission
2. COST TD1208; Electrical Discharges with Liquids for Future Applications; COST Training School on Liquid Discharges
   Prof. Uroš Cvelbar
   Cost Office
3. NATO Grant; SPS 984555; Atmospheric Pressure Plasma Jet for Neutralisation of CBW
   Prof. Uroš Cvelbar
   Nato - North Atlantic Treaty Organisation
4. COST CA15114; Anti-Microbal Coating Innovations to prevent Infectious Diseases (AMICI)
   Prof. Uroš Cvelbar
   Cost Office
5. Education-ED-FU, EUROFUSION
   Prof. Miran Mozetič
   European Commission
6. Sniffing for Carcinogenic Substances - Research for Toxic Gas Molecule Sensing with Networks of Carbon Nanowalls
   Prof. Uroš Cvelbar
   Slovenian Research Agency
7. Advanced Photo-electrochemical Cells with Nanostructured Iron Oxide Electrodes
   Prof. Miran Mozetič
   Slovenian Research Agency
8. Irradiation of Metal Oxide Nanowires
   Prof. Uroš Cvelbar
   Slovenian Research Agency
9. Biocompatible Nanostructured Tetragonal Zirconium Oxide Thin Films with Alternative Stabilization Dopants
   Prof. Miran Mozetič
   Slovenian Research Agency
10. Innovative Method for Synthesis of Thin Absorption Films for Photovoltaics
    Asst. Prof. Alenka Vesel
    Slovenian Research Agency
11. Sterilization of Heat-sensitive Materials with Innovative Plasma Source of UV Radiation
    Prof. Miran Mozetič
    Slovenian Research Agency
12. Dust in Plasmas (DIP)
    Prof. Miran Mozetič
    Slovenian Research Agency
13. MS-MZDR/16-1-B2-071; ECS Electrochemical Society
    Prof. Uroš Cvelbar
    Slovenian Research Agency
14. Presentations and Invited Talk at the Conference at the University of Liverpool: Plasma Technology as a Tool for the Inactivation of Food-related Microorganisms
    Prof. Miran Mozetič
    Slovenian Research Agency
15. Small Services
    Prof. Uroš Cvelbar

RESEARCH PROGRAMS

1. Vacuum technique and materials for electronics
   Dr. Vincenc Nemanič
2. Thin film structures and plasma surface engineering
   Prof. Miran Mozetič

R & D GRANTS AND CONTRACTS

1. Understanding plasma processes and thin film growth in High Power Impulse Magnetron Sputtering
   Prof. Uroš Cvelbar
2. Nanoscale engineering of the contract interfaces for green lubrication technology
   Asst. Prof. Janez Kovač
3. Multifunctional electrospunned nanofibers development and dynamic interaction studies with pathogen bacteria
   Prof. Miran Mozetič
4. Development of the functional textiles used fot the treatment of diabetic foot (malum perforans)
   Prof. Miran Mozetič
5. New materials for printed sensors and indicators and their integration in smart printed matter
   Asst. Prof. Alenka Vesel
6. Interaction between fully dissociated moderately ionized ammonia plasma and glass-fiber reinforced polymers
   Prof. Miran Mozetič
7. Nanostructures and related composites for detection of hazardous gaseous molecules
   Prof. Uroš Cvelbar
8. Functionalization of polymer cardiovascular implants for optimal hemocompatibility
   Asst. Prof. Alenka Vesel
9. New generation of superior creep resistant steels with nanoparticles modified microstructure
   Prof. Uroš Cvelbar
10. Advanced hydrodesulphurisation with catalyst nanomaterials
    Prof. Uroš Cvelbar
11. Advanced hemocompatible surfaces of vascular stents
    Dr. Ita Junkar
12. Self-lubricating and wear resistant PVD hard coatings based on (V,Cr,Al,Ti)N for hot-working processes
    Asst. Prof. Janez Kovač
13. Building blocks, tools and systems for the Factories of the Future – GOSTOP
    Prof. Miran Mozetič
14. Food for future - F4F
    Asst. Prof. Alenka Vesel
15. Potential of biomass for development of advanced materials and bio-based products
    Dr. Ita Junkar
16. Novel type of antibacterial coatings on textile materials and plastics with controllable release of antibacterial agent
    Prof. Uroš Cvelbar
    Hydrogen Permeation Measurements on PVD-Coated Eurofer
    Dr. Vincenc Nemanič
    Ústav Fyziky Plazmatu Av Čr, V. V. I.

VISITORS FROM ABROAD

1. Prof. Dr Xiao Xia Zhong, Shanghai University, Shanghai, China, 31 January–1 February 2016
2. Prof. Dr Xiao Xia Zhong, Shanghai University, Shanghai, China, 10–12 February 2016
3. Prof. Dr Davide Mariotti, Ulster University, Jordanstown, UK, 2–5 April 2016
4. Prof. Dr Joanna Pawlat, Lublin University of Technology, Lublin, Poland, 16–17 April 2016
5. Prof. Dr Joanna Pawlat, University of Technology, Lublin, Poland, 21–22 April 2016
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7. Prof. Lin Dai, The University of Hong Kong, Hong Kong, China, 15–17 May 2016
8. Prof. Rosa Chan, The University of Hong Kong, Hong Kong, China, 15–17 May 2016
9. Christian Nöbauer, Vienna University of Technology, Vienna, Austria, 22–26 May 2016
10. Yishan Han, Shanghai University, Shanghai, China, 5–14 June 2016
11. Prof. Jiang Yong Wang, Shanghai University, Shanghai, China, 9–14 July 2016
12. Doc. Ing. Petr Slobodian, Ph.D., Tomas Bata University in Zlín, Zlín, Czech Republic, 20–23 September 2016
13. Jiri Matyas, Tomas Bata University in Zlín, Zlín, Czech Republic, 20–23 September 2016
14. Ondra Grulicha, Tomas Bata University in Zlín, Zlín, Czech Republic, 1 August–30 September 2016

15. Martina Minařík, Tomas Bata University in Zlín, Zlín, Czech Republic, 1 August–30 September 2016
16. Prof. Dr Hyung Jun Cho, Nagoya University, Nagoya, Japan, 12–15 November 2016
17. Christian Nöbauer, Vienna University of Technology, Vienna, Austria, 20–22 October 2016
18. Prof. Dr Christoph Eisenmengger – Sittner, Vienna University of Technology, Vienna, Austria, 20–22 October 2016
19. Masakazu Tomatsu, Nagoya University, Nagoya, Japan, 12–15 November 2016
20. Prof. Dr Makota Sekine, Nagoya University, Nagoya, Japan, 12–15 November 2016
21. Prof. Dr Petr Špatenka, Czech Technical University in Prague, Prague, Czech Republic, 22–24 November 2016

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19. Tinkara Bezovšek, B. Sc.
20. Urška Kisovec, B. Sc.
21. Janez Trtnik

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Original Article

1. Somayeh Akbari, Janez Kovač, Mitjan Kalin, "Effect of ZDDP concentration on the thermal film formation on steel, hydrogenated non-doped and Si-doped DLC", *Appl. surf. sci.*, vol. 383, pp. 191-199, Oct. 2016.
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3. Mojca Božič, Vera Vivod, Robert Vogrinčič, Irena Ban, Gregor Jakša, Silvo Hribernik, Darinka Fakin, Vanja Kokol, "Enhanced catalytic activity of the surface modified TiO_2 −MWCNT nanocomposites under visible light", *J. colloid interface sci.*, vol. 465, pp. 93-105, 2016.
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11. Ita Junkar, Mukta Vishwanath Kulkarni, Barbara Drašler, Neža Rugelj, Anca Mazare, Ajda Flašker, Damjana Drobne, Petr Humpolíček, Matic Resnik, Patrik Schmuki, Miran Mozetič, Aleš Iglič, "Influence of various sterilization procedures on TiO_2 nanotubes used for biomedical devices", *Bioelectrochemistry*, vol. 109, pp. 79-86, Jun. 2016.
12. Ita Junkar, Mukta Vishwanath Kulkarni, Barbara Drašler, Neža Rugelj, Nina Recek, Damjana Drobne, Janez Kovač, Petr Humpolíček, Aleš Iglič, Miran Mozetič, "Enhanced biocompatibility of TiO_2 surfaces by highly reactive plasma", *J. phys., D, Appl. phys.*, vol. 49, no. 24, pp. 244002-1-244002-10, 2016.
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Review Article

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Short Article

1. Mukta Vishwanath Kulkarni, Ita Junkar, Harinarayanan Puliyalil, Aleš Iglič, "Wettability switch of anodic titanium dioxide nanotubes with various diameters", *Biophys. j.*, vol. 110, iss. 3, sup. 1, pp. 339a, Feb. 2016.

Published Conference Contribution

1. Somayeh Akbari, Janez Kovač, Mitjan Kalin, "Study the chemical structure of the ZDDP thermal film on steel and dlc surfaces at different times and ZDDP concentrations using ATR-FTIR and XPS", In: *Zbornik predavanj posvetovanja o tribologiji, mazivih in tehnični diagnostiki*, SLOTRIB 2016, f. 91-105.
2. Mojca Božič, Vera Vivod, Robert Vogrinčič, Silvo Hribernik, Irena Ban, Gregor Jakša, Darinka Fakin, Vanja Kokol, "New photocatalysts based on the surface modified TiO2-MWCNTs for decolourization of methylene blue dye", In: *Proceedings*, 16th World Textile Conference AUTEX 2016, 8-10 June 2016, Ljubljana, Slovenia, pp. 1-7.
3. Svjetlana Janjić, Ivana Dojčinović, Aleksandar Savić, Miran Mozetič, Gregor Primc, Lidija Černe Hočevar, Marija Gorjanc, "Antibacterial lyocell fibres obtained using plasma treatment and chitosan", In: *Proceedings*, 16th World Textile Conference AUTEX 2016, 8-10 June 2016, Ljubljana, Slovenia, 7 pp.
4. Boštjan Jenčič, Luka Jeromel, Nina Ogrinc Potočnik, Katarina Vogel-Mikuš, Eva Kovačec, Marjana Regvar, Zdravko Siketić, Primož Vavpetič, Zdravko Rupnik, Klemen Bučar, Mitja Kelemen, Janez Kovač, Primož Pelicon, "Molecular imaging of cannabis leaf tissue with MeV-SIMS method", In: *The 22nd International Conference on Ion Beam Analysis (IBA 2015), June 14 - 19, 2015, Opatija, Croatia*, (Nuclear instruments & methods in physics research, Section B, vol. 371, 2016), pp. 205-210.
5. A. G. Nikiforov, Xiaolong Deng, Iulia Onyshchenko, Danijela Vujošević, Vineta Vuksanović, Uroš Cvelbar, Nathalie De Geyter, Rino Morent, Christophe Leys, "Atmospheric pressure plasma deposition of antimicrobial coatings on non-woven textiles", In: *Proceedings of the 6th Central European Symposium on Plasma Chemistry, CESPC-6, September 6-10, 2015, Bressanone, Italy*, (EPJ, Applied physics, Vol. 75, no. 2, 2016), pp. 24710-1- 24710-6.
6. Jelena Vasiljević, Brigita Tomšič, Milena Zorko, Miran Mozetič, Ivan Jerman, Jože Medved, Boris Orel, Barbara Simončič, "Towards the fabrication of "green" flame retardant cotton by the sol-gel processing of hybrid precursors", In: *Proceedings*, 16th World Textile Conference AUTEX 2016, 8-10 June 2016, Ljubljana, Slovenia, 8 pp.
7. Stojana Veskovič Bukudur, Janez Kovač, Peter Panjan, Damjan Klobčar, Milan Bizjak, Blaž Karpe, "Deposition of Al thin film on FeCrAl alloy and continuous electrical resistance measurement", In: *Zbornik radova*, 11th Scientific - Research Symposium with international participation, Metallic and nonmetallic materials, production, properties, application, Zenica, 21.-22. april 2016, pp. 109-117.

Independent Component Part or a Chapter in a Monograph

1. Ita Junkar, "Interaction of cells and platelets with biomaterial surface treated with gaseous plasma", In: *Advances in biomembranes and lipid self-assembly. Volume 23*, Aleš Iglič, ed., Chandrashekhar Kulkarni, ed., Michael Rappolt, ed., Amsterdam [etc.], Elsevier, 2016, pp. 25-59.
2. Alenka Vesel, Miran Mozetič, "Low-pressure plasma-assisted polymer surface modifications", In: *Printing on polymers: fundamentals and applications*, Joanna Izdebska, ed., Sabu Thomas, ed., Amsterdam [etc.], Elsevier, 2016, pp. 101-121.
3. Runcy Wilson, Anil Kumar, Miran Mozetič, Uroš Cvelbar, Sabu Thomas, "Diffusion, transport, and barrier properties of IPNs", In: *Micro- and nano-structured interpenetrating polymer networks: from design to applications*, Sabu Thomas, ed., Uroš Cvelbar, ed., Hoboken, Wiley, 2016, pp. 319-339.

Patent

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2. Alenka Vesel, Rok Zaplotnik, Miran Mozetič, *Method for cleaning of with body fluid-contaminated medical implantants and devices with the use of atomic oxygen,* SI24840 (A), Urad RS za intelektualno lastnino, 29. 04. 2016.
3. Gregor Filipič, Kristina Eleršič, Darij Kreuh, Janez Kovač, Uroš Cvelbar, Miran Mozetič, *A method of colouring titanium and titanium alloys,* SI24851 (A), Urad RS za intelektualno lastnino, 29. 04. 2016.

Mentoring

1. Harinarayanan Puliyalil, *Selective plasma etching of polymer matrix composites for improvement of their surface properties:* doctoral dissertation, Ljubljana, 2016 (mentor Uroš Cvelbar; co-mentor Miran Mozetič).